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The discharge of the waste weir, when water is going over its crest at a depth of 5 feet, is therefore as follows :—

For the first portion,

Discharge $= 990 \times 5 \times 12\frac{1}{2}$* $= 61{,}875$ cubic feet per second.

For the second portion,

Discharge $= 668 \times 5 \times 10\frac{11}{12}$* $= 36{,}461$ cubic feet per second.

Total discharge $= 98{,}336$ cubic feet per second.

The discharge of the river during the greatest known flood being 82,079 cubic feet per second, the waste weir is capable of carrying off, $98{,}336 - 82{,}079 = 16{,}257$ cubic feet per second in excess of what is likely to be required of it.

* *Vide* Neville's Hydraulic Tables.

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No. CLVII.

IRRIGATION OF SINDH.

Memo. by COLONEL R. STRACHEY, R.E., *Inspector General of Irrigation, on the extension of Irrigation in Sindh.*—31*st January*, 1867.

THE rain-fall in Sindh is so small, that cultivation may be said to be almost impossible without the aid of irrigation in some form. The ordinary means of obtaining water for this purpose is to draw canals from the Indus. But it has been beyond the power of the people to maintain a supply of water in their canals, excepting during the season of the inundation, which corresponds to the rainy months of other parts of India, and to the agricultural khureef season. It follows that, as a rule, the cultivation of Sindh is limited to a khureef crop; and the rubbee, or cold season crop, is less than one-tenth of the whole. Further, the produce of the khureef crops is in a great measure consumed in the country, supplying the food of the population and their cattle. The more valuable cereal grains and oil seeds are the produce of the rubbee crops, and from the causes that have been mentioned, the quantity of these is very small, and under existing circumstances is not likely to be increased to any sensible extent.

The cultivation dependent on the canals may be divided into two great classes:—*First*, that which can be carried on with water naturally flowing over the surface of the land, in Sindh termed *Moke*, and equivalent to *Tor* of the North-West Provinces; and *second*, that which requires the water to be artificially raised to lands, the surface of which is above the water-level of the canals, in Sindh called *Churkee*, and in the North-West *Dál*.

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The moke cultivation is far less certain and less valuable than might at first sight appear likely, consequent on the almost entire absence of control over the level of the water in the canals. This level simply depends on the rise and fall of the river, and excepting in some few specially favorable cases, the risk of the cultivators in moke cultivation is very considerable, and the relative value as compared to churkee, greatly reduced.

The churkee cultivation is so called from being dependent on the use of the "churka," or Persian wheel, by which the water is lifted to the necessary level. It is probable that considerably more than one-half of the whole cultivated area is churkee land, and it is not likely that the average height to which the water has to be raised is less than 5 or 6 feet. It will be obvious that a very great expenditure of labor is requisite to lift water in this manner. Major Lambert, the Collector of Kurrachee, has got together a great number of estimates of the cost of this operation, and he reckons that it amounts, on the average of the whole Province, to about Rs. 15 an acre. It is wonderful how the country can support such a burden on its agriculture. The charge on the Sindhee peasant, over half of the Province, to place him in the position in which nature places the agricultural community of most countries without any cost, by means of the regular rain-fall, is not less than is paid in England as the whole amount of rent.

But besides these difficulties, others of hardly less importance arise from the rude manner in which the irrigation channels have been formed in the first instance. Want of stability in the heads of the main canals; obstruction of the channels by the deposit of silt, due to irregularities of inclination, or other causes; injuries to water-courses and adjacent lands from the breaching of embanked channels, ill-designed or constructed; submergence of lands by reason of the escape of water from canals, the supply in which has been in excess of the requirements for irrigation; injuries of various descriptions, arising from the Indus floods breaking into the water-courses and the irrigated lands: these are some of the more important defects to which the present system of irrigation is liable.

Till the present time, there has been hardly any application of engineering science to the improvement of this state of things, and the existing Canal Engineers are little more than superior Overseers of the annual canal clearances, under the direction of the Revenue District Officers. Some improvements, not without value, have been made from time to time in the

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rude system of canals which existed when Sindh first became a British Province, and in the Shikarpoor Collectorate, the supply of water has been sensibly increased with a corresponding distinct increase of cultivation and revenue. But, as a whole, the condition of the country and the people must be regarded as almost stationary; and that this should be the case seems quite sufficiently explained by the adverse combination of circumstances which have been mentioned.

The irregularity of the flow of the canals, and their rude character, often leads to a wasteful use of the water in moke lands. The limitation of the quantity of water supplied by the canals, combined with the absence of rain, prevents the land recovering itself after cropping, and induces a practice of long fallows of two or three years; this leads to very slovenly husbandry, the ground being seldom properly cleared of weeds and jungle. The heavy labor attendant on the raising of the water, restricts greatly the extent of land which might, under more favorable conditions, be tilled by the existing population. The almost complete absence of a rubbee crop, although the climate and the greater part of the soil is believed to be as favorable for its production in Sindh as in the North-West Provinces, deprives the cultivator of what, under a happier arrangement of water-supply, should be to him a source of great comparative wealth and absolute prosperity. The poverty and the stationary material position of the population, and the small amount of exportable produce which comes into the markets prevent the expansion of trade, opposes the growth of Kurrachee, the port of export, and starves the Railway which leads from the agricultural districts to this port.

The obvious remedy for all these evils is to be found in the substitution of perennial, for the existing intermittent, irrigation canals, and of water delivered at the level of the surface, instead of at a level which requires that it should be lifted by animal power. If water could thus be given to the whole Province (excluding, of course, those parts which are sandy desert, and naturally incapable of culture), it would be but little, if at all, inferior in productive capacity to the best Districts of India; and making allowance for all the barren regions, Sindh would yet remain one of the most important Provinces of the British territories.

And there is much reason to hope that such a remedy may be practically possible of application in the chief part of the culturable country. It will, of course, require very careful consideration before the needful works for

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carrying out such a change of system in the irrigation of the Province are put in hand; and at the present moment the only essential thing is to arrive at a conclusion whether the objects to be gained by success, and the prospect of such success are of that nature which should induce the Government to take the necessary steps to order further investigation, and to determine that the requisite works should be carried out if these investigations are satisfactory.

It may be assumed that there is no further need for discussing the character of the objects to be gained; their paramount importance is self-evident.

As to the prospects of success in accomplishing the ends in view, there are two principal lights in which the matter must be considered: *first*, the Engineering; and *second*, the Financial. It cannot be properly said in this case that such works as are suggested are strictly necessary to protect the country from famine. There is already sufficient safeguard against this extreme evil. What is sought is to improve the position of the population by greatly increasing the facilities for agriculture. The obligation on the State to do this, unless at all events there be no attendant increase of charge put on the general finances, can, perhaps, be hardly pressed with justice to the interest of the community as a whole; and it may fairly be accepted as a criterion by which to guide our action, that the works shall be distinctly profitable to the State. This point, therefore, will call for careful examination.

On the engineering question much need not be said beyond what will suffice, as *primâ facie* evidence, that the scheme as a whole is practicable. The Indus supplies what is virtually an unlimited quantity of water, and the levels of the country are known to be such as will admit of the easy formation of canals having the needful requisites. Nature has happily provided many spots which appear quite suitable for permanent heads for perennial canals, without involving the construction of very difficult or expensive works. Such are Rohree and the opposite bank of the Indus at Sukkur, Sehwun, Kotree, and Jurruck. At all these places solid rock formations occur on the river's bank, and the channel has, for a very long period, remained constant at these localities. Above Sukkur no rock occurs in the river bed, but there is no reason to doubt that a permanent canal head could be kept open where there is no rock, though at what cost, and with what general financial results, must depend on circumstances now

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unknown. On the whole, the facilities for canal construction in Sindh are singularly great.

The question has long been discussed, whether the large quantity of silt carried in suspension by the Indus would not be a cause of such obstruction to any perennial canal as would virtually make it useless. I regard such fears as quite chimerical, but it may be desirable to state briefly my reasons for saying this. First, it is a fact that many of the existing large inundation canals remain open permanently without sensible silt deposit. Next, where silt is deposited, it may unhesitatingly be attributed to the direct operation of causes which should not come into play in properly designed canals. In the existing canals, these deposits most frequently occur either near the mouth or at the extremity. In the first of these cases, the deposit is commonly the result of the erosive action of the river on its bank near the canal mouth. The water under these circumstances becomes abnormally charged with earthy and sandy matter as it enters the canal, and, as a matter of course, much of this is dropped shortly afterwards. When the canal mouths are free from such erosive river action, and the general slope of their beds is sufficient, they remain unobstructed. The obstruction of the lower extremity of the canals is the immediate result of deficient fall, and in many cases almost total stoppage of the current of water. These defects could not exist in properly designed channels. On the whole, the deposit of silt, wherever it occurs, is the result of irregular river action, or of irregular velocity within the canals. The result of the improved system would be to arrest the river action on its banks at the mouth of the canal, and to preserve the velocity of the water within the channels at a suitable uniform rate which should prevent the silt in suspension being deposited until it is carried out into the fields, or the very smallest of the water-courses. The increased height, at which the water-surface would be maintained in the canals, would materially assist in obtaining an improved velocity in the distributing channels; and the same result would be caused by the concentration of the supply into fewer and larger canals which would follow the suppression of some of the far too numerous cuts which have been formed in a state of society where there was no authority to exercise a proper control over the economical distribution of the water. It is the common belief that silt held in suspension is an absolute advantage to the cultivator if it can be distributed with the water over the surface of the land. If any deposit of silt should take place in the minor

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channels, in which the velocities are likely to be least, and the levels less under engineering control, it can be removed without sensible practical inconvenience, and with the least amount of labor.

I may here conveniently refer to a point which seems to call for special consideration in the formation of any project for improved irrigation works in Sindh. Where irrigation is introduced into a country for the first time, the arrangement of the minor distributing channels may be controlled by the Engineers almost as completely as that of the chief feeding lines of canal. But in Sindh, where all cultivation at present depends on irrigation, it seems almost obligatory to make use of the existing minor channels, if not exclusively, at least to the very utmost extent that is possible. The necessity for this will be apparent when it is remembered that the whole fabric of property in land is, so to speak, built up upon the net-work of water-courses which supply the great essential for all cultivation. The inhabited and cultivated lands follow the lines of canal. Where the revenue settlement has been completed, it has been based on the supply of water by the existing channels. To do otherwise than continue to supply the water by these channels would not only call for a very great additional amount of labor for the excavation of new water-courses, but would tend most seriously to disturb the tenures of land and everything connected with the agriculture of the country. The aim of the Engineers, therefore, should be to introduce water as early as possible, and with the least possible disturbance of the existing net-work of channels, on the improved system. It would be their business, at a later period, to weed out by degrees all the really objectionable features of the distributing channels first forced upon them. It will, of course, be possible that, in some cases, important modifications in supply channels may be unavoidable from the first, but so far as I am able to judge, these should be exceptions to the general rule as before stated. It is my belief that the adoption of this system will in all respects be the most desirable, whether regard be had to the interests of the cultivator; of the State as superior landlord; of the Exchequer in the matter of first cost and eventual speedy return; of the Engineers in obtaining a proper practical knowledge of the requirements of the country for its irrigation, and a gradual but complete power of control over the supply of the water in the most thrifty manner. It is necessary to bear in mind clearly that from the very conditions of the problem, our Engineers will come to the task imposed on them without a detailed practical knowledge of the exact require-

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ments of the country in respect to water, and that their position, in the face of a population which has practised irrigation from time immemorial, is very different from what it might have been in a country into which canals were to be introduced for the first time.

The condition which for these reasons I regard as obligatory, of working the new system of irrigation through the existing distributing channels, it is almost needless to say cannot be productive of anything but saving of expense, time and labor; and under such an arrangement, the full benefit of the improved system will be obtained by the people and the State in a far shorter time than could be reasonably expected in a country new to irrigation, and requiring to be provided with distributing channels. One of the chief causes of the slow progress of irrigation from the Ganges Canal is understood to have been the want of minor distributing channels.

Of course it is impossible to offer an opinion of any value as to the probable cost of works such as have been spoken of, without first obtaining detailed designs and estimates. But without any precise knowledge of the exact cost, some useful light may be thrown on the financial part of the discussion by considering the probable return from an improved system of irrigation, and calculating the amount of capital which it would cover.

The total area of land under crops watered by the canals maintained by the Government in Sindh, is at present about 1,200,000 acres. The average combined charge for land revenue and water is about Rs 2-4 per acre. It will certainly be a very moderate estimate if we reckon that, under a system of high level water-supply, permanently kept up, and completely under control, an additional charge of Rs. 1 per acre might be made on land actually cropped under irrigation, raising the total charge to Rs. 3-4 per acre. In the North Western Provinces I believe that the average charge would be as much as Rs. 4-8, and in Madras it would be never less than Rs. 5, and often more. Next, it may be reckoned that for the khureef crop in Sindh, a constant flow of water of one cubic foot per second will water about 50 acres of land. This is considerably less than the corresponding area in Madras or the North-West, but allowance must be made for the larger quantity of water required in a country without rain. From actual observation in Sindh on one of the canals in the Hydrabad Collectorate, one cubic foot has been found to water 68 acres. On other canals a much smaller result was found.

If we then assume that, out of the existing area, one million acres could

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be brought under the improved system at 50 acres per foot, this would require a total water-supply for the whole Province of 20,000 cubic feet per second, which may be considered as equivalent to three canals, each as large as the Ganges Canal.

It will be remembered that the existing cultivation is exclusively khureef. With the perennial supply of water, a rubbee crop may be reckoned upon. Now the consumption of water for rubbee irrigation is much less than for khureef, and making a reasonable allowance as before for the want of rain in Sindh, one cubic foot of rubbee supply may be reckoned to irrigate 100 acres. Therefore the new rubbee crop will amount to two million acres.

The increased revenue will then be 1 Re. per acre on the old acreage, and Rs. 3-4 on the new acreage, that is—

				Rs.
1 million acres, at Re. 1,	...	...	...	10,00,000
2 „ „ 3-4,	...	...	...	65,00,000
Total,			...	75,00,000

showing a total increase of revenue of 75 lakhs gross, or £750,000 yearly.

At the rates for land and water combined in force in the North Western Provinces, the total gross increase would be approximately—

				Rs.
1 million acres, at Rs. 2-4,	...	...	...	22,50,000
2 „ „ 4-8,	...	...	...	90,00,000
Total,			...	1,12,50,000

showing a total of 112½ lakhs, or £1,125,000 yearly.

It will next be necessary to estimate the probable charges against this increase. For the canal maintenance and establishments, 12 annas per acre irrigated is not likely to be exceeded, judging by the results of the North Western canals; and even as small a charge as 8 annas an acre is likely to suffice. This charge, at the 12 annas rate, would amount on three million acres to 22½ lakhs yearly. Against this has to be set off the present charge for the same purposes, which may be taken at 3½ lakhs, leaving a net increase of charge of 19 lakhs. To this must be added, however, a sum to cover the additional charges connected with the realization of the increased land revenue. Taking the approximate rate of charge on this account as 10 per cent. on the revenue realized, the addition would be 7½ lakhs, or 11½ lakhs, according to the total rate realized from the land.

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Under the first hypothesis of a total maximum charge of Rs. 8-4 per acre, the net increase of revenue would be 48½ lakhs, and at the maximum rate of Rs. 4-8 per acre, it would be 86 lakhs. The former amount would be equivalent to 5 per cent. on about 9½ millions sterling; and the latter to 5 per cent. on 17 millions.

The inference that may be drawn from these calculations is, that if such an increase of cultivation as is spoken of can fairly be anticipated to follow the improved system of irrigation, it would, on the lower estimate, not be unprofitable to the State to spend 9½ millions on the requisite works, and on the higher 17 millions might be spent. Of course it is not for a moment implied that this gives any key to the actual outlay really likely to be necessary, and all that is desired is to show that, on a very moderate estimate of areas and rates of profit, there is *primâ facie* evidence that a large outlay of capital would be covered. It may be added that the Ganges Canal, which is acknowledged to be a very expensive work, is likely to cost when complete, rather more than 3 millions sterling. It was before remarked that, to give such an extent of irrigation, as has been reckoned upon, a supply about three times that of the Ganges Canal would be required. On the standard of the Ganges Canal, therefore, the cost of the works might be taken at 9 millions, so that even at this very high rate of cost, the works would probably be remunerative. If an opinion on such a subject is to be hazarded in the present position of the question, it might, perhaps not be unreasonable to consider the Ganges Canal standard fully one-third too high for the much more favorable circumstances of Sindh; and at such a rate, six milions sterling would be the whole sum needed, on which, at the lowest rate of income, a return of £485,000 yearly would be realized, being above 8 per cent. At the higher rate, the return would be £860,000, or 14 per cent.

I would repeat that it is to be understood that the above figures are only intended to show, on such data as can be got, the probably eventual operation of the improved system of irrigation. Time would be required both for the outlay of such large sums, and for the full realization of the entire profits; on the other hand there is every reason to suppose that considerably larger areas of cultivation, and considerably higher rates of charge, could eventually be attained. I conclude therefore that, on the whole, it is fair to anticipate that the interest on any amount of capital really required for such works would be covered by the returns at an early period, and

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that the prosecution of the proposed further investigations, and the preparation of suitable projects and estimates, is entirely justified.

I have reckoned on a total cultivated area of 8 million acres, and it will be as well to show how far such an extent of land is likely to be available. I estimate that the entire area of the land that could be watered on the right bank of the Indus, between Sukkur and Sehwun, is 3½ million acres. On the left bank of the Indus, between Rohree and Hyderabad, the total area of British territory is about 2½ million acres. Together, this supplies 6 million acres, and rejecting one-fourth as an allowance to cover barren or unirrigable land, there would remain 4½ million acres irrigable. In the North West Provinces, it is understood that about one-third of the culturable land is irrigated yearly in the best cultivated districts. But in Sindh, where the whole cultivation requires irrigation, a larger proportion must be taken, and it seems fair to assume that one-half may be irrigated at one time. This would allow of alternate years for fallow for all land, one crop only being taken in each year, which seems amply sufficient. In the area designated we should, on this basis, have 2¼ million acres irrigated yearly, leaving three-fourths of a million to be provided in the lower part of the Delta, and on both sides of the Indus above Sukker, or by a larger amount of land under crop at one time. This additional quantity might very fairly be expected to be obtained from these sources.

As to the power of the existing population to extend the area of cultivation from one to three million acres, it may be said that the relief obtained by the cessation of the lifting the water, will release a very large amount of labor which will be immediately available for extending the area under crop at one time. The money value of this labor may be taken at about Rs. 15 per acre on 500,000 acres, or Rs. 75,00,000. The saving of such an amount in labor, whether it is sufficient to meet the full demand for so large an increase of cultivation, as has been reckoned upon or not, must have a very great influence on the progress of the Province; and even if there be some exaggeration in the cost of this labor, it is almost certain that the real relief will be so great as to give an entirely different character to the agriculture of Sindh.

Although my visit to Sindh has been limited to a short period, and my means of forming sound opinions on matters of detail have, therefore, been restricted, it may be useful if I indicate generally the direction in which it has appeared to me that such investigations should be carried out. In

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doing this, however, it is fitting that I should disclaim any intention of doing more than offering suggestions for the consideration of the Officers who may be charged with such a duty, and placing in a somewhat more definite light the character of the operations which I regard as so desirable.

A project was prepared some years ago by Lieut.-Colonel Fife, R.E., for a perennial high level canal to be drawn from the Indus at Rohree. For reasons which need not be referred to, no action has yet been taken on this scheme, though it was strongly supported by the present Governor of Bombay, who at that time was Commissioner in Sindh, much on the grounds which have been adduced in the earlier part of this Memorandum. This project, however, provided for a small supply of water only, 1,400 cubic feet per second, and was intended to be worked altogether apart from, and in addition to, the existing system of inundation canals. This indeed was a natural course to suggest at that time. Now, that opinion has so greatly changed as to the proper system of dealing with works of irrigation, and that more comprehensive views can be put forward with reasonable expectations of their receiving attention, such a project must be regarded as insufficient. I have discussed with Lieut.-Colonel Fife the extension which might properly be given to this project so as to bring it into relation with such a general scheme of irrigation as that which I advocate. The conclusion to which I have come is, that this canal should carry about 7,000 cubic feet of water per second, and should supply the whole of the Hyderabad Collectorate as far as the Foolailee Channel. It should be so arranged as to throw water into all the canals now fed from the Indus between Rohree and the mouth of the Foolailee.

The Foolailee is so large a channel, and carries so large a body of water in the inundation season, and is in such good general condition, that it seems desirable to maintain it at all events for the present. The channels which now flow from its left or northerly bank will all be supplied from the new canal, and the water saved will go to increase the quantity available on the south. If needful, an additional head might be opened opposite to Kotree near Hyderabad, for the supply of the lower portion of the Delta, and a similar work could be constructed opposite Jarruck. It is probable that the canal from Rohree will give a sufficient supply of water for the rubbee cultivation throughout the Hyderabad Collectorate. It is questionable how far rubbee can be profitably raised in the lower part of

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the Delta, and it must be left for further investigation to show the precise form which should be given to the works for this portion of the Province. Both at Jurrack and Kotree, facilities exist for the formation of dams such as the Madras Anicuts, and, on the whole, there is nothing to prevent a very ample water-supply being given to the eastern half of the Delta.

On the left bank of the Indus, above Rohree, there is less apparent facility for improving the irrigation. There is no permanent bank and the country is liable to heavy inundation. But there is no reason to question the practicability of maintaining a permanent canal head at some suitable point, or of protecting the country which is now flooded.

On the right bank of the Indus, above Sukkur, the conditions are more favorable than on the left bank, but there may be difficulty or expense in maintaining a permanent head. At Sukkur there is a very favorable locality for a canal head to supply the region between Sukkur and Sehwun, at which place the alluvial plain of Sindh is cut off by the hills which there abut directly on the Indus. It seems probable that a single large canal, of about the same size as that proposed for the left bank, viz., to discharge 7,000 cubic feet per second, would supply the whole area of the Shikarpoor and Kurrachee Districts between Sukkur and Sehwun. The water-supply in this part of the Province is at present much more ample than in Hyderabad; but from the absence of a proper engineering control over the supply, considerable danger is incurred of serious floods, and as a fact, injury from this cause is too frequent. From the strong slope of the surface towards the west, the extremities of the distributing channels in many places require to be embanked, and this having been carried out without a proper system of levels, and without due attention to the precautions required under such circumstances, much waste of water and injurious flooding of land takes place.

On the east, or left bank of the Indus, the land is generally so high as to require the natural fall of the surface to be economized to secure a satisfactory slope for the distributing channels. Here the first object of the Engineers will doubtless be to bring in the main supply at an improved level as early as possible. This being done, the existing channels will be capable of doing greatly increased irrigating duty, and their thorough rearrangement may be carried out by degrees afterwards.

On the right, or west bank, I am inclined to think that attention is at once required to the main distributing channels; and that by placing these

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in a position of proper efficiency as regards their levels, having due regard to their eventual character as channels to carry a high level supply, great immediate improvement could be secured. The fall from the Indus to the south-west is so great, moreover, that real danger of a serious nature is incurred by leaving the main channels open from the river without engineering control. The success which is claimed for some of the canals made by the District Revenue Officers, and particularly that called the Fordwah, is undoubted; but it would be a great misfortune if, from the want of efficient power of control over the water entering such cuts, a calamitous flood were to happen, and there is every appearance of such an event being at least possible. The head sluice of the Forwah is in a very critical condition, and if it were carried away, it would not be easy to save Larkhana from a damaging flood, if the result was not something of a much graver sort, such as a large portion of the Indus breaking out over the country in that direction.

The country between Sehwun and Jurruck is hardly susceptible of perennial irrigation from the Indus, and calls for no further comment.

The western Delta, so far as it may be found to require improved irrigation, can readily be supplied from Kotree or Jurruck. It is from this quarter also that it is probable that Kurrachee must look for a fresh water-supply, of the abundance which seems requisite for a town and port of the importance which it is likely to assume. I see no engineering difficulty in the way of sending down a copious supply of fresh water into the Garra Creek from Jurruck or Kotree, and thence carrying it, by help of a weir, across the Mulleer River to Kurrachee. By avoiding all expenditure that was not essential for such an object, it could, I think, be attained for an outlay not incommensurate with its importance, but of course exact surveys and estimates alone can test speculations of this nature.

It only remains for me to refer briefly to the extreme eastern Districts of Sindh, Thurr and Parker. These now receive a limited supply of water during the inundation by an old channel called the Narra, fed by a new head constructed by our Engineers, drawn from the Indus at Rohree. A new Canal has also been excavated from the end of this old channel, and is known as the Mitrow Canal. From various causes, this canal has not been so successful as could have been desired, or was anticipated. The efficient source of these causes of want of success will, I think, be suffici-

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ently found in the absence of a proper professional administration for irrigation operations in Sindh; and the removal of this defect will, I have no doubt, be very soon followed by the application of all needful remedies to the shortcomings of the Mitrow Canal. There are some other minor channels leading from the Narra, lately dug, which have already done much good in extending cultivation; and there should be no great difficulty or expense in considerably adding to the supply of water thrown into these districts, either by the Narra Channel, or from the surplus of the new main Hyderabad Canal, or from the Foolailee, or some new channel taken from the Indus near Hyderabad.

I shall now proceed to make some observations as to the fiscal system which seems likely to be best suited to the condition of things which would exist were the proposed irrigation works carried out. The question at once arises, whether the whole of the State demand should be levied in one sum as at present, or whether a separate water-rate should be levied: and if so, under what sort of system and with what objects? At first sight there is an appearance of simplicity in the present system which recommends it as preferable to the confessedly artificial plan of levying a separate water-rate where, as a fact, cultivation is not possible without irrigation. But further reflection seems to me to show that, in truth, the land revenue is fixed on a perfectly artificial system, and that when a settlement of the revenue has been made, the charge on this account no longer, so to speak, represents agricultural facts, but is a deduction from them. So long as the land revenue is directly based on the actual produce of any field under cultivation, such cultivation being impossible without water, to separate the charge for the water must of course be quite an arbitrary proceeding. But as soon as the land revenue becomes an average or estimated sum, which will satisfy the Government as a composition for a term of years, it is just as easy and simple to separate this into two parts, as to take it in one sum, if there be any sufficient cause for doing it. The question therefore is, whether there is such a cause; and I think it will readily be shown that the system of making the separate charge for water, which has been adopted in other parts of India, should eventually be followed in Sindh also.

If the supply of water were unlimited, there would be no reason for controlling or checking its use. But this not being the case, and the value of the water being so great, it becomes very important that no

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waste should be allowed; that the available supply should be distributed equitably, having regard to the area of land under cultivation and prescriptive rights of priority of enjoyment; and that the State which supplies the water at the general expense of the country, should receive in payment for it a fair sum to cover the actual cost of maintenance and the interest on capital, and to provide a reasonable profit in aid of the general resources of the State. Now, the introduction of systematic irrigation is essentially a tentative process. It is only by experience that it can be ascertained how much water is required for the several qualities of land and crop, and what is its value; and the first duty of the irrigation Engineer is to endeavor to ascertain these points. For the former purpose, he measures the irrigated area and finds out what extent can be watered by a given volume of water. In like manner, in fixing and apportioning the charge for the use of water, it is almost essential to begin by a calculation based on the area of land irrigated. In a more advanced stage it becomes possible to make compositions at fixed sums, or to regulate, the charge according to the volume of water actually supplied; but, practically, neither of these courses can be adopted with advantage until sufficient experience has been gained, under a system of crop measurement, of the actual wants of the lands to be watered, and of the value of the water as supplied for irrigation.

On the introduction of improved irrigation in Sindh, it will thus be necessary to ascertain the actual areas irrigated: *first*, to get data for calculating the proper irrigating duty of the water; and *second*, to apportion the increased charge fairly. Even if the increased charge were levied simply as an increased lump-sum of land revenue, it must in detail be arrived at by a consideration of the actual area cultivated with the improved water-supply. And this will hold good whether the Revenue Settlement has been made or not.

Moreover, where the settlement has been made on the basis of the old condition of irrigation, and an improvement in this takes place, it will not be possible with equity to make a *pro ratâ* addition to the whole revenue, because it will not follow that all the land will be benefitted, for every year of the residue of the term, or for any one year. It is only after experience shall have shown what is a fair average estimate for one year, with another of the benefits of the new system, that the water-rate could be brought under settlement with the land revenue.

It seems, therefore, almost an obligatory measure that, in all settled

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villages, during the period of transition at least, a separate water-rate shall be taken, on the reckoned actual irrigated area. Now, before the new canals are completed, the whole of Sindh will almost certainly have come under revenue settlement, and therefore the separate water-rate will practically everywhere become necessary.

It further appears desirable that, following the practice of the North-West Provinces, the increased charge for the improved water-supply shall be borne by the cultivator as distinguished from the zemindar. The existing land revenue being in fact that proportion of the rental received by the zemindar from the cultivator, which custom assigns to the State, it appears proper to leave this unchanged until the cultivator's rental is raised. It is probable that in Sindh, as in the North-West, the improvement of the irrigation will not at all of necessity lead to the direct increase of the cultivator's rental. Where, for instance, the customary rental is a certain share of the produce, the profits of the cultivator might be greatly increased by reduction of the cost of irrigation without any important change taking place in the produce which alone regulates the zemindar's interest in the process. Here the cultivator would receive the whole benefit, and should bear the whole charge. Where rents and zemindar's profits practically become increased as a secondary result of these improvements, it will be just that the Government should participate in the increased profits according to the customary rule of the country, and under the terms of any revenue settlement from time to time existing.

In connexion with the matters last discussed, it may be convenient to say a few words on the subject of the Sindh *Huccaba*, or rate to cover the cost of canal clearance. As a fact, no such rate is levied, excepting from Jagheerdars, and the *huccaba* for revenue-paying lands is only distinguished from the land revenue proper by being arbitrarily separated in the Collector's accounts. Before the British occupation of Sindh, the usual custom was, that the Zemindars cleared the canals by their own cultivators, the Government making a small allowance of grain to the work-people, and paying for the supervision, but at the same time taking a corresponding small portion of the produce, under the same of *huccaba*, in addition to the regular land revenue. When Sindh became British, the revenue in kind was commuted into a money payment, and the practice of clearing the canals by unpaid labor was also discontinued, the Government in lieu fixing the money land revenue rate at such an amount as covered the esti-

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mated cost of clearance by paid work-people. Of course this was done in a rough and approximate way. Subsequently, when it was pointed out that, under this system, the Jagheerdars got their canals cleared at the expense of Government, it was ruled that they should be required to pay 3 annas per beegah (about half an acre) to make good this charge for all land irrigated by them from canals cleared by Government; and at the same rate, a separation was made in the Collector's accounts of the nominal *huccaba* from the land revenue.

Under a later arrangement, this nominal *huccaba* rate has been ordered to be transferred from the Imperial to the Local Fund income, the charge for the canal clearances at the same time being made a local charge. Obviously, the sole financial effect of this measure is to make a permanent contract with the Sindh Local Funds for canal clearances at the rate of 3 annas per Sindh beegah irrigated. It will suffice if I here briefly state my opinion that such a system is even now needless and objectionable, and that it would be quite inapplicable to the condition of things that would exist, were a proper irrigation administration established in the Province. That the apparent necessity for such a measure should have been conceived to exist, seems to me the result of misconceptions and defects of administrative system, which I may take another opportunity to explain.

It remains for me to refer to one other consideration which should receive serious attention when adopting a policy of providing Sindh with permanent irrigation at a high level. I refer to the grave responsibility which will rest on the State to maintain the works in proper efficiency. Any want of attention to the water-supply of a country so completely without rain, and so thoroughly dependent as it would become on a highly artificial system of irrigation, will be calamitous. A country thus placed is in a position as critical as one in which the entire surface is preserved from the irruption of the sea by dykes.

The conclusion to be adopted in the face of this responsibility should certainly not be that on this account such works should not be undertaken, but that every possible precaution should be adopted to guard against accidents. And having regard to the character of the risk, and to the present comparatively small amount of the population of Sindh, it seems unsafe to trust to the ordinary supply of labor that could be obtained in the open market, to meet all possible emergencies that might arise after such a canal system as I have contemplated had come into operation. Whether for effect-

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ing clearances of the channels, or repairing breaches in the embankments, or carrying out any other really essential work, the administration should have the power, under suitable check, of commanding the labor of the entire community to effect what was necessary in behalf of the general interests. If a conscription or an enrolment of the whole number of able-bodied citizens is legitimate for the defence of a country against an armed enemy of the State, how much more legitimate is the exercise of a similar power for the protection of the whole community from the most frightful calamity that can befall it—a general drought and famine. If the tremendous character of such visitations had been estimated at their proper value, some of the blackest pages in the history of the British administration in India would have had no place there; and it would be inexcusable indeed, if, in the face of the lesson which has been lately read to us in Cuttack, any proper precaution was omitted when attempting to deal with the irrigation of a whole Province. A law having such an intention as is here contemplated, exists, I think, in Madras; and something of this nature should be introduced in Sindh simultaneously with the resolution to prosecute the new system of works.

R. S.

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No. CLVIII.

BERAR SPECIFICATIONS.

Extracts from Specifications for Ordinary Work and Repairs, as drawn out for the Province of Berar. By Capt. H. H. Foord, A.I.C.E., *Exec. Engineer.*

Road Metal Work.

The roads in Berar are of four descriptions, viz., sand, moorum, sand and moorum, and broken stone.

Moorum Roads.—Moorum roads will generally be metalled with moorum to a width of 18 feet and a thickness of 1 foot. A coating of 4 inches of the moorum is first to be spread on the road bed, and vehicles allowed to pass over it till it becomes tolerably firm, and is *nearly* but *not* entirely consolidated; men are to be stationed to continually rake in the ruts, as fast as they appear. The second coating of 4 inches is then to be added, and treated like the first; when this is nearly consolidated the remaining 4 inches is to be spread and well rolled with a heavy roller until it is well consolidated. The second and third coats of moorum are to be added during the wet weather. The Contractor will be required to give the road over, with the full thickness of 1 foot of consolidated moorum.

Sand Roads.—The sand is to be clean and sharp, and the thickness will be 9 inches unless otherwise specified. A coating of 3 inches is first to be spread on the prepared earth road, and well rolled until the sand and black soil are prefectly amalgamated; the second coat is then to be given, and the rolling continued with heavy cast-iron rollers, until it is consolidated; the remaining 3 inches are then to be spread and well rolled; the rolling is to

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be continued until the surface of the road becomes perfectly smooth, hard, and compact. The sand should be spread during the monsoon, and every opportunity must be availed of, during a cessation of the rain, for rolling the road.

In certain cases, where sand is not procurable of the above description, gravel from the bed of rivers may be used. In this case, the Contractor will be required to sift the pebbles, two sieves being provided for this purpose, one with wires 1½ inches apart, so that all pebbles above that size may be rejected; the other should have spaces of ¾ of an inch, and the material which passes through it should be thrown away; it is strictly forbidden to place large pebbles at the bottom of the road and cover it over with gravel of the proper description. The gravel is to be spread in the same way and subjected to the same treatment as specified above for sand roads.

Sand and Moorum Roads.—Roads made of sand and moorum combined are to be made in strict accordance with the directions given above; the thickness of moorum will be 9 inches, laid in three courses of 3 inches each, and one coat of sand 3 inches thick. The whole to be well rolled until consolidated.

Broken Stone Roads.—The stone used shall be black basalt broken into pieces as nearly cubical as possible (all slices and splinters to be rejected), the largest of which, in its longest dimensions not to exceed 2 inches, and none smaller than 1 inch to be used. The Contractor will have to give over the specified thickness of metal after consolidation; unless otherwise specified, the roads will have 9 inches thickness of broken stone metal. The road bed having been thoroughly drained, is to be properly shaped and sloped each way from the centre, so as to discharge what water may penetrate to it; care must be taken not to give this crowning by an extra thickness of metal on the centre of the road, but by properly forming the road bed; upon this bed, a coating of 3 inches of clean broken stones, free from any earthy mixture, is to be spread on a dry day. The traffic is then to be admitted on it, men being stationed to rake in the ruts as soon as formed, and a heavy roller used, till it becomes almost consolidated, but not completely so; (the determination of this time being an important practical point, will be decided by the Executive Engineer); a second coat of 3 inches is then to be added during the rains, and subjected to the same treatment as the first coat; the final coating is then to be spread and the rolling continued until the whole is well consolidated.

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Broken Stone Roads on Stone Pavement.—The road bed is to be thoroughly drained and to be properly shaped and sloped each way from the centre; on this a bottom course or layer of stones is to be set by hand in the form of a close, firm, pavement. The stones set in the middle of the roads are to be 7 inches in depth; at 7 feet from the centre, 5 inches; at 10 feet from the centre 4 inches; and 12 feet from the centre, 3 inches. They are to be set on their *broadest edges and lengthwise across the road*, and the breadth of the upper edge is not to exceed 4 inches in any case. All the irregularities of the upper part of the said pavement are to be broken off by the hammer, and all the interstices to be filled in with stone chips, firmly wedged or packed by hand with a light hammer; so that when the whole pavement is finished, there shall be sufficient fall from centre to sides. After the pavement is laid as directed, the roads shall be metalled with broken stone as specified above. Care must be taken not to disturb the pavement whilst the road is being made; the carts bringing the broken stone must not be allowed to pass over the foundation. The stone for the pavement may be either gray basalt or porphyry; it is not essential that it should be stone of as hard a description as that used for metalling.

Repairs to moorum, sand, and sand and moorum roads, will consist, at the close of the monsoon, in clearing out the side trenches, repairing the slopes of the cuttings and embankments, filling in wheel tracks with material, and well rolling the roads; they will be paid for at a certain rate per mile. When it is necessary to add a fresh coat of sand or moorum, the same will be paid for according to the accepted rates for new work.

Repairs to Broken Stone Roads.—All ruts, deep holes and irregular projections must be filled in and levelled; the road must be put into proper shape and restored to its proper cross-section, by cutting down the sides and filling up the middle part; only a single thin coat of stone shall be applied at a time—not more than a cubic yard to a rod superficial. The surface of the old road may be lightly picked up or "lifted" (with strong short picks) merely burying the point of the pick one or two inches deep, so that the new materials may be more readily united to the old ones. This must be especially attended to on declivities, to prevent the stones rolling down the slope. When the road to be repaired is one which has been originally formed of large stones, no new material shall be brought on it, but the old stones shall be loosened with picks, gathered to the side of the roads, and there broken to the proper size. The surface of the road

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having been put in proper shape, the broken stones are to be returned to it, and scattered uniformly and thinly over the surface. Only a small space of road must be broken up at once, say 8 feet in length, and the whole width of the road. The repairs shall be made during the rains. The Contractor will be paid for the repairs, such as filling-in, levelling, breaking up stones already on the road, as day work; the broken stone will be paid for according to the distance carted at the agreed rate per 100 cubic feet, and is to include spreading, ramming and rolling until consolidated.

Bricklayers' Work.

Flooring.—Jelly in chunam floor to be of broken brick and mortar; three parts of broken brick (pieces of brick to be about 1 inch cube) and one part mortar, well mixed together and spread to a thickness of 6 inches, carefully levelled down and beaten until quite smooth, and plastered with plaster composed of one part lime and one and a half sand; the floor to be continually sprinkled with lime water until completed.

Mud flooring is to be made with *pangree muttee* (white earth) and a small quantity of sand, well mixed together with as little water as possible, to be spread and carefully levelled and well beaten down and neatly plastered with a mixture of cow-dung and clay.

Tiled Roofing.—This is of two descriptions, one with flat and pan tiles, on teakwood reepers; and the other with pan tiles, on bamboo matting, and bamboo reepers. The tiles are to be sound, hard and well burnt; each tile is to be dipped in boiling oil twice before being used; flat tiles to be 6 inches square and are to be approved of before being laid. Reepers to be $\frac{3}{8}$ of an inch thick and 2 inches wide; to be laid in long lengths, 6 inches apart from centre to centre.

Terraced Roofing.—Brick-on-edge laid diagonally; two courses of flat tiles; 3 inches brick jelly in chunam; one course flat tiles; and 3 coats of plaster. Terrace bricks to be 5 by 3 by 1 inches.

Bengal Terraced Roofing.—Two courses flat tiles; $1\frac{1}{2}$ inches jelly in chunam, the brick broken very small; one course flat tiles and 3 coats plaster; the tiles are to be dipped in water before being used, and the plastering done with great care and well rubbed down.

Slight Repairs to Terrace Roofs.—Roofs to be scraped and cleaned all over; cracks and slight damages to be filled up and repaired with fine lime,

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and brick-dust ground to an impalpable powder, mixed with a little molasses, and tempered to the consistency of stiff putty, and to be finished off in a proper manner.

Repairing Cracks in Terrace roofs with Luckium.—*Luckium*, prepared as noted below, is to be inserted in the cracks either with a trowel or a thin knife, according to the size of the crack. *Luckium* to be composed of fine cotton, two ounces; slaked lime, twenty pounds; linseed oil, ten pounds.

Carpenters' Work.

The timber used upon all work, except temporary constructions, shall be Moulmein or West Coast teak, of the best quality of the class to which they belong; the balks used for girders shall be of Moulmein teak, of sound heart-wood, hard, compact, and free from shakes, flaws, or sun cracks.

The timber for all temporary structures shall be of khair, babool or such other jungle wood as the Executive Engineer shall approve of; and to be of the best quality, sound, free from sap wood, and seasoned in every respect as well as the teak.

Boarding.—Teak wood boarded floors to be made of well seasoned planks, gauged to the thickness specified, closely fitted, and secured to the floor joints with English screws, countersunk quarter of an inch into the planks.

Teak wood weather boarding battens to be 8 inches wide, laid with an overlap of 2 inches; the rafters being properly notched to receive the battens, which will be of one-half the thickness on the lower edge, that they are on the upper edge; the battens to be fairly wrought, and to be screwed on to the rafter.

Piling.—For Bridges with timber piles and superstructure. The main piles shall consist of sound, well seasoned teak, straight, and 12 inches square; they shall be dammered with 2 coats of best dammer before they are driven, and each main pile shall be firmly shod with a wrought-iron shoe weighing not less than 12 lbs. The piles shall be driven with a monkey weighing 10 cwts., until by a blow equal to that weight, falling from a height of 18 feet, they do not penetrate the ground more than one inch. In driving the piles, a wrought-iron ring, weighing not less than 8 lbs. shall be fixed upon the head of each pile; and one ring shall be used for every six piles. The outside piles, under the fender pieces, shall be shod with shoes weighing not less than 8 lbs. each; and in driving them, the heads are to be protected by suitable wrought-iron rings.

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Smiths' Work.

All castings shall be *coated while hot, with hot linseed oil*, or shall be dipped in vessels of hot oil, and shall remain therein sufficient time for the oil, when cold, to form a hard varnish on the surface.

All the bolt holes of cast-iron work shall be drilled. All joints of cast-iron work shall be planed or otherwise brought to a true surface.

Wrought-Iron.—The wrought-iron in all trussed girders and roof trusses to be of the best description of scrap-iron, free from scales and other defects; the plates, bars and angle-iron are to be cut to the precise length, and accurately punched; the holes to be of the proper size for bolts or rivets, and the riveting to be done hot; no joints to the plates or angle-iron will be allowed but those shown on the drawings.

All nuts and screws are to be clean cut, and made to fit well. All bolts to be made from one piece, and all above $\frac{1}{8}$-inch diameter to be turned. All bolt holes to be drilled.

Lead Work.—The only plumbers work likely to be required in Berar is lead piping, the lead to be of the best quality and workmanship; all lead pipes to be drawn and are to weigh as follows (the price includes all solder joints, lead tacks, &c., and fixing complete).

$\frac{1}{2}$ inch pipe	to weigh	6 lbs.	per yard lineal.
$\frac{3}{4}$ " "		9½ lbs.	
1 " "		14 lbs.	
1¼ " "		17 lbs.	
1½ " "		21 lbs.	
2 " "		28 lbs.	

Copper and Brass Work.—In any case where it may be required to use thin sheet copper as water-tight sheathing, it is to be tinned on one side.

Tin Work.—Soldering to be 2 parts tin and 1 part lead, for tin; and $\frac{1}{3}$ tin and $\frac{2}{3}$ lead, for lead.

Painters' and Glaziers' Work.

The paints used are to be the best English paints, to be pure and free from adulteration. Oil used to be pure boiled linseed, and the color is to be well ground, and to a have due proportion of driers. All wood work generally is to be twice knotted, primed, and painted in addition, four times in oil color; and finished with such tints as shall be directed.

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In repainting wood work, the old work must first be thoroughly cleaned and rubbed with pumice stone until the old surface is perfectly smooth. All cracks, &c., to be filled in with putty.

Cleaning and Oiling Paint.—The old paint is to be washed with country soap and water, till clean and free from all smoke, stains or dirt, and to be rubbed with linseed oil.

Coal tarring to consist of one coat of well boiled coal tar, laid on hot; the surface on which it is to be laid being first well cleaned from mud or dirt.

Dammering on floor to be prepared in proportions of one part of rosin to seven parts of best coal pitch well mixed together; when boiled, to be laid on the floor half an inch thick; the thickness to be regulated by a straight edge used as a gauge, the surface to be smoothed with a hot iron and sprinkled with a small portion of sand.

Asphalte on Floors.—Prepared asphalte to be properly melted with 5 lbs. of mineral tar, to the cwt.; then laid on the floor in one coat of the specified thickness, which is to be regulated by a wooden straight edge used as a gauge; the surface to be smoothed with a hot iron.

Repairs to Asphalte Floors.—The loose asphalte to be removed, and to be replaced with fresh asphalte, boiled with mineral tar and laid on as in new work to the thickness of the old floor; the edges of the old work to be heated with a hot iron, to unite the old work with the new.

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No. CLIX.

DETAIL OF WORKING ON THE GREAT TRIGONOMETRICAL SURVEY.

[A History of the G. T. Survey of India having already been given in previous numbers of these Papers, it is thought likely to be interesting to many readers if some account is given of the actual *modus operandi*; which has been abridged from the *Practical Instructions* issued for the guidance of the Department by the late Surveyor General, Major-General Sir A. Waugh, R.E. It is of course assumed that the general principles of an ordinary Trigonometrical Survey are understood by the reader.]

The operations of the G. T. Survey of India are carried on in the form of a series of Principal Triangles, originating from, and terminated by, a well determined line,* and upon the sides of these Principal Triangles depend other minor ones, which furnish points at two or three miles asunder, thereby fixing limits to inaccuracy in topographical details.

The direction in which a series of triangles should proceed depends on the subject for which it is undertaken; but, as a general rule, it is desirable to avoid an oblique direction, and to conform strictly to a meridional or longitudinal line; of these the meridional direction is the most favorable condition for geodetical surveys, because any error in the assumed figure and dimensions of the Earth has then least influence on the computed results.

Geodetical operations may be classed under two heads, viz. :—1st, Duties

* The Great Arc and the several Longitudinal Series, which are considered the main operations of the Survey, depend on measured bases. All the other Series depend on sides of the Great Arc or Longitudinal Series (excepting the Calcutta Meridional and the Great Indus Series, which, likewise, connect measured bases. The two last mentioned Series have been executed subsequently to the writing of this paper).

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in the Field; 2nd, Duties in the Office. Under the first head are comprised the selection of the triangulation in a skilful manner, and the method of taking the final observations, with due regard to accuracy and precision. Under the second head are included the reduction of the observations, and computations of the final results.

1*st*—*Duties in the Field.*—Although the measurement of a base line is an indispensable preliminary operation in a geodetical survey, and ought, therefore, as respects order of time, to be described first, still, as the Indian bases have already been measured, and the trigonometrical operations now carrying on in the British dominions in India, are all based upon the sides of other Series, it would be needless to lay down any rules for base line measurements. Should any necessity arise for undertaking the measurement of another line, the duty will be executed under the personal superintendence of the Surveyor-General.

The next important operation in conducting a series is to determine the direction of the meridian. There are several ways in which this may be accomplished, but the method most appropriate for geodetical purposes is to measure the azimuthal angle between a fixed terrestrial mark and a circumpolar star at the time of its greatest elongation. It will be most convenient to describe this operation under the head of Final Observations. A knowledge of the approximate position of the meridian is, however, indispensable in selecting the triangulation; but the data for this purpose are generally furnished by the prior Trigonometrical Series, upon which those now in progress are based; or, at any rate, the azimuth can always be determined with sufficient accuracy for the proper selection of stations, by means of a few observations on the Sun a little after sunrise, or before sunset. This approximate method is described in all elementary books.

Selection of Stations.—The direction in which the triangulation is to proceed being known, the next step is to select the stations in a judicious manner, so as to produce the greatest accuracy in the results.

A series of Principal Triangles may be either single or double, as represented below, wherein No. 1 is a single series. A double triangulation may be arranged in several ways; for example, No. 2 is a continued double series; No. 3 is a series of successive quadrilaterals; No. 4 is a series of successive polygons. In practice it frequently happens that all these varieties of figure are combined together in various ways, according to the nature of the country, and the local facilities it affords; but as each method has its

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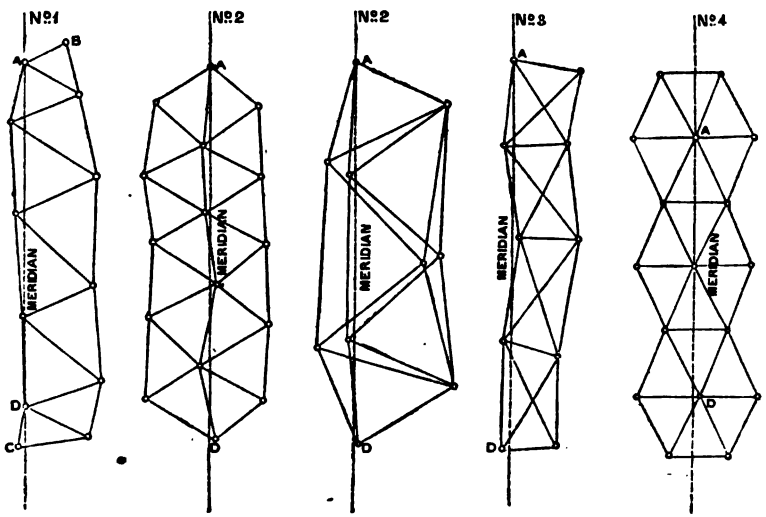
peculiar advantages and disadvantages, it is proper that their relative merits should be duly considered, in order that the most judicious selection may be made which circumstances admit of.



A Azimuth Station. D Azimuth of Verification. AB. Base. DC. Base of Verification.

The single series possesses advantages of economy of time and labor and money, as well in the field operations as in the office computations; and it is, consequently, the most proper kind of series to be adopted when circumstances impose a strict attention to these restrictions. For instance, in a level country, like the plains of Hindustan, in which, from the absence of natural elevations, trigonometrical operations are both costly and tedious, every consideration of economy combines to recommend a single series as the most eligible arrangement. On the other hand, the advantage of accuracy will always be found greatly in favor of a double series, which moreover, supplies a check of the most efficient kind at every stage of the work. The continued double series (like No. 2) is chiefly objectionable, because no part of the computations can be finally completed until the field operations are brought to a conclusion; under which state of circumstances the accumulation of arrears of office duty becomes a source of the greatest embarrassment.

This evil may be avoided by that arrangement of a double series, in which it is composed of a succession of quadrilaterals or polygons, because the

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computation of each figure can then be brought up independently from time to time, as the observations in the field are successively completed.

Of all geodetical figures the quadrilateral is theoretically the most conducive to accuracy, as well as most economical, because it requires no additional stations, and the equations from which the errors are deduced are proportionably the most numerous. For example, the relative conditions of the quadrilateral and of the usual polygons are as follows:—

	No. of Stations.		No. of Angles.		No. of Eqtns. formed.
Quadrilateral,	4	...	12	...	9
Hexagon,	6	...	18	...	8
Pentagon,	5	...	15	...	7

These circumstances are greatly in favor of a quadrilateral, both as regards economy and precision; but on the other hand, there are practical considerations of importance, which may frequently render the polygon arrangement preferable.

First, it may be remarked that it is extremely difficult to select four stations forming symmetrical triangles, and at the same time so situated, with respect to each other, that from each station the other three shall be distinctly visible. Secondly, the long diagonal rays are unfavorable equally to good observation and to rapidity of progress. The diagonal of a square bears a proportion to the side of the same figure, in the ratio of $\sqrt{8}$ to 2, and it is obvious that in practice one diagonal of a quadrilateral will generally exceed that proportion. This combination of long and short sides is therefore liable to cause detention, on account of the difficulty of observing a distant station under circumstances which form no impediment to the observation of near ones. This embarrassment, however, is not of so serious a nature in a hilly tract as in a level country, where the difficulty of observing long rays is very greatly increased by the density of the atmosphere near the ground; and as, in such circumstances, towers are required to render these stations mutually visible, these structures will become a source of greatly enhanced expense. The curvature of a globular body increases in the ratio of the square of the distance, and it is therefore obvious that the height of a tower adapted to a quadrilateral is to the height adapted to a single triangle, in the ratio of $(\sqrt{8})^2$ to 2^2, or 8 to 4. Hence, a quadrilateral arrangement is totally inapplicable in a flat country; but in a mountainous or hilly region, quadrilaterals should always be chosen when the configuration of the country and other circumstances offer no practical objections of an insuperable nature.

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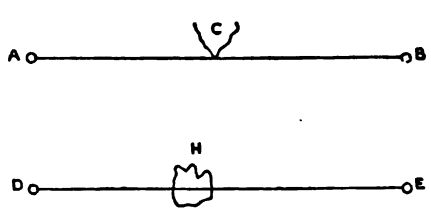
A Meridional Series, as its name implies, follows the direction of the meridian of some fundamental station (A, for example, *vide Fig.* 1), at which station the direction of the meridian must be duly determined by appropriate observations on circumpolar stars. When the Series is composed of single triangles, or of quadrilaterals, it is advantageous to select all the stations on one flank, in such a manner as to coincide as nearly as practicable with the meridian. Those stations which are situated nearest to that line are the most favorable for observing azimuths of verification, which should be taken near the termination of the series, and also at intermediate points, fifty to eighty miles apart, according to the magnitudes of the triangles; because, the larger the triangles are, the less chance there is of accumulation of error, and as the azimuths of verification are intended to detect accumulated angular errors, it is clear that the distance between the azimuth stations ought to depend on the number of intermediate triangles. When the Series is composed of polygons, the central stations of those figures should be selected on the meridian, or as near to it as possible.—(*Vide Fig.* No. 4.)

In a Longitudinal Series, on the other hand, it is desirable that one flank of the Series (or the centres of the polygons) should coincide, as nearly as circumstances will permit, with the parallel to which the Series is intended to conform, and azimuths should be taken at every alternate station, in order that the latitudes and longitudes may depend on observed azimuths alone, and not upon deduced ones, whereby the formulæ for computation will be confined within the proper limits.

In order that the observed azimuths may be as free as possible from those errors which are caused by local attractions, it is desirable that no great mass of high mountains should stand either east or west of the station of observation, nor be so situated, with respect to it, that the portion of resolved attraction in the direction of the parallel should amount to a sensible quantity.



In choosing stations it is proper to avoid intermediate obstacles situated on, or close to, the ray; because if the ray between A and B grazes the side of the mountain C, the ray will certainly be deflected by the vapours which arise from the sloping ground,

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whereby the observations at A and B will be more or less injuriously affected by lateral refraction; and if the ray grazes close over the top of the mountain H, then the angles horizontal and vertical will be greatly disturbed. If circumstances, however, concur in admitting of no other choice, it will be desirable always to provide a check by introducing a polygon or quadrilateral at that part of the work, and a secondary station should also be established on C or H, which may be treated as an auxiliary point, for taking vertical angles, whereby the comparative height of A and B may be determined independently of direct observation.

A Principal Series should consist of triangles as large as the features of the country admit of, by which arrangement the number of stations will be reduced to a minimum; moreover, as the errors which are unavoidably committed at each station have a tendency to accumulate in proportion as those stations are multiplied, it follows that the probability of accumulation will be least when triangles are large.

Considerations of economy likewise impose the same restriction, inasmuch as the additional points required for topographical purposes can be obtained at less cost by means of secondary triangles, in which accumulation of error is an evil that need not be dreaded, the limits of inaccuracy being sufficiently established by the principal triangulation. No general rule can be applied with respect to the magnitude of triangles, which must necessarily vary with the configuration of the surface of the country. In a mountainous region with gigantic features (composed of lofty peaks and deep valleys) it would be as difficult as it would be injudicious to select small triangles; and in a flat country it would be absurd to struggle against natural difficulties in the vain endeavour to establish a series of great magnitude. In hilly countries, twenty to thirty miles is a convenient distance for principal stations, and such distances can usually be observed with facility, in all ordinary conditions of atmosphere, by means of heliotropes and Argand lamps. When hills are table-topped, as is generally the case where the stratification of the rocks is horizontal, it may be necessary to shorten the sides to less than twenty miles; while, on other occasions, an open country with detached peaks may frequently afford distances of thirty to forty miles with the fairest prospect of good observations. In a level country, such as Bengal, ten miles is the most favorable length of side, and the limits should there be considered eight to fifteen miles.

The triangles selected should be symmetrical, that is, as nearly equi-

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lateral as possible, such being the best condition for ensuring accuracy when all the angles are measured, but as it is impracticable to obtain in the field, triangles exactly equilateral, the rule in practice is to admit of no angle under 30°, or above 90°. This rule applies to all the triangles which compose a series, whether principal or secondary; but, in the case of secondary triangles which do not form part of a long series, wider limits are admissible. These limits must also of necessity be extended in the case of a quadrilateral, because the four triangles of which it is composed obviously cannot be all equilateral. The best condition for that figure is when it approximates to the square, in which form no angle will be much above 90°, and none much less than 45°.

In a hilly region, it is a convenient arrangement to detach a well qualified sub-assistant in advance, to choose the stations, and construct platforms; but in a level country it is advisable that the officer in charge of the work should select the stations in the early part of the season, leaving assistants to erect towers, and clear the rays in rear. Towards the end of the season, he should return to the commencement, and begin final observations, while the assistants continue the clearing of rays, and erection of towers previously selected in advance.

These arrangements however depend entirely on the organization of the party and the peculiar capabilities of the members who compose it; but, whatever plan is adopted, with regard to the Approximate Series, the following rules should always be adhered to:—

The stations selected should be on the highest peaks, but as these are sometimes inaccessible, it may be necessary to adopt a lower point. Every effort should, of course, be made to reach the summit when practicable. In the case of a lower point being used, care must be taken that the view is clear in the direction of the stations in advance.

The first business on arriving at a principal station, where points in advance are to be chosen, is to put up the instrument as soon as the atmosphere is clear enough to allow a distinct view. Having adjusted it, you will find out the direction in which you would wish the stations in advance to be, and by means of the level you will judge what points near these directions are likely to be visible from each other, and from the stations with which they are to be connected.

To avoid the necessity of revisiting the station from which the selection is made, it will in dubious cases be found advantageous to select more than

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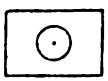
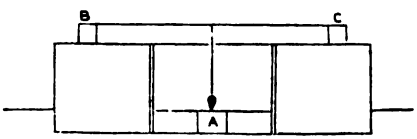
one point from each station in advance, and when you are quite decided as to your choice, the platforms may be constructed.

It is the practice to mark all spots where angles are taken, whether they be principal or secondary stations. The mark is a dot with a concentric circle, cut on stone by means of a pointed chisel. If the mark can be engraved on the rock *in situ* so much the better; otherwise, a large stone, properly marked, ought to be buried in the ground. Over this a small platform is raised, on the summit of which another mark-stone is inserted, and fixed truly vertical over the lower one. The distance between the two marks should be recorded, but all measurements and observations are usually referred to the upper mark, and are so recorded in the angle book records.

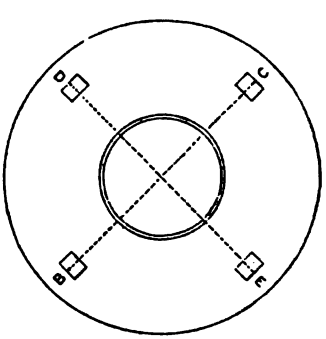


Sometimes, on account of intervening obstacles, it is necessary to raise the platform to a considerable height, in which case several mark-stones are always inserted, and their relative heights recorded.

The method of adjusting mark-stones is as follows:—Let A be the mark at the foundation, either engraved on the rock, or on a heavy embedded stone. Let the external part of the platform be built up to the intended height of the next mark, and place upon it four heavy stones, arranged in a



SECTION



PLAN

quadrilateral figure, in such wise that threads BC and DE, stretched diagonally across, may intersect near the centre. Adjust these threads to correspond with a plumb line suspended over the mark A, and when the coincidence is complete, mark the four exterior stones, by pencil lines, or lines scratched with a knife. Arrangements must now be made for protecting these stones, either by covering them over, or appointing a man to watch each, while the pillar in the centre is being built up nearly to the

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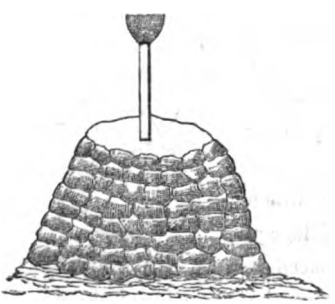
level of BC, at which height the next mark stone should be fixed and adjusted, to correspond with the cross threads before adverted to.

For Principal Stations it is necessary to make that part of the platform on which the instrument rests, separate and distinct from that on which the observer and his assistants walk. The instrument is then said to be duly isolated. Unless this precaution is taken, good angles cannot be expected, as the instrument will be liable to irregular disturbance, according to the position of the observer. The annular space between the observer's stage and the central pier should be filled up with gravel or sand, otherwise screws and other parts of the apparatus may be lost, by falling into it. Besides the upper mark-stone, it is usual to imbed in the pier three picked, flat, heavy stones, for the tripod of the instrument to stand upon. These are called "feet stones," and they should be duly levelled, which will save trouble afterwards in adjusting the instrument.

It is not usual, if it can be avoided, to make isolated platforms at secondary stations. In localities where the ground is very unsteady, such as deep, black, cotton soil, I have found it practicable to steady a theodolite by using pickets four or five feet long, and driving them into the ground, for the stand of the theodolite to rest upon. The pickets isolate themselves for at least one foot in driving. This precaution can only be taken at a new station, otherwise the mark would be disturbed by the process of driving the pickets.

As soon as all the observations have been taken at any station, and it has been observed from all the corresponding stations, it is no longer required for the purposes of the Trigonometrical Survey, and it should have a pile of stones, with a pole and brush, erected over it, in order that it may be visible, and useful, to the detail surveyors. This precaution has the further advantage of protecting the mark-stones from violent disarrangement.



The pole and brush is erected thus: a long straight pole is selected, upon the top of which a brush of twigs is fastened. The pole is placed truly perpendicular over the Station mark, and a pile of stones raised round it, by means of which it is securely fixed. The diagram in the margin will give

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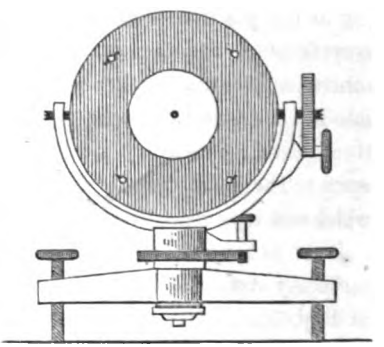
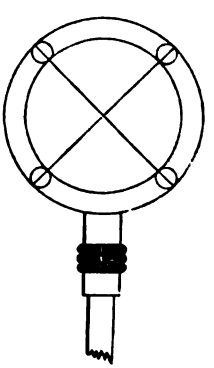
a clear idea of the signal, which is a very economical and useful opaque object for day observations. The pile of stones may be five or six feet high, and the pole about as much longer.

The signals used for the Stations of the G. T. Survey consist of Heliotropes for day observations, and Argand reverbatory lamps, or Drummond lights for night.

The Heliotrope consists of a circular piece of flat plate glass mirror, about 9 inches in diameter, with a small unsilvered aperture in the centre about 0·1 of an inch in diameter, as represented in the figure. This mirror is mounted on a frame which stands on a tripod for the sake of steadiness.



The frame admits of the looking-glass being turned on a horizontal axis as well as on a vertical axis. These two motions in altitude and azimuth are regulated by means of rack work, and they permit the reflection of the sun's rays to be turned in any required direction. In order that it may be directed truly to the observer, a ring with cross-wires, is placed at a distance of about 3 feet; the signalman then looks through the unsilvered aperture in the centre of the Heliotrope and moves the cross-wires until they intersect the distant station. Thus the centre of the Heliotrope, the centre of the wires, and the observer's station form one right line. Now, if by means of the rack work, the mirror is moved in altitude and in azimuth until the sun's rays fall on the wires, it is evident that the light will proceed straight to the observer's Station; but the pencil of rays must be duly bisected by the wires, which intersection can be managed with ease and delicacy, by means of a little circle of white paper placed at the crossing of the wires, upon which paper the reflection of the little aperture in the centre of the mirror may be seen like a small dark speck. When the weather is hazy the signalman will of course be unable to see the observer's station; in which



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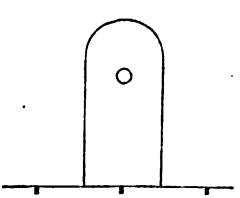
case, unless a nearer mark has been given to guide him or a directing line has been drawn for him, he will be so far helpless. Under such circumstances, the observer ought to direct one or more Heliotropes towards the man, and keep them playing until he has adjusted his apparatus. Similarly, if the man is careless, and neglects to keep the sun's rays constantly shining in the true direction, the observer has only to flash a Heliotrope at him, to keep him alert.

A Heliotrope of 9 inches, will answer for 90 or 100 miles; for nearer distances it is much too bright to be observed through a Telescope, and the light must be diminished in the following proportion. For distances of 2 or 3 miles (the usual distance of a referring mark) an aperture of 0·25 of an inch will answer, and for longer distances about 0·1 of an inch of aperture per mile of distance will suffice, viz., one inch for ten miles, two inches for 20 miles, and so on, provided always the apparatus is carefully adjusted and the man, who works it, is alert and skilful.

These apertures are cut in a board which stands upon three feet (as shown in the figure) by means of which the centre of the aperture can be adjusted plumb over the Station mark. This board is called a Sight Vane; stones are placed on the tail piece to prevent its being disturbed by the action of the wind. If this sight vane be used, the wires before described are unnecessary, because cross-hairs can be fixed in the vane, and will become a substitute for the wires. The Heliotrope is in this case placed 2 or 3 feet in rear of the Sight Vane, and moved laterally and vertically, until the eye applied to the centre unsilvered dot, views the observer's station and the cross-hairs in one line. The Heliotrope must be secured in this position, and the means of doing so will readily suggest themselves. It is needless to say that it must be quite firm.



Final Observations.—The selection of stations is merely preparatory to the final observations, and is called an Approximate Series. It is usual to choose a few triangles in advance, and then detach a party to continue the Approximate Series, and prepare the stations ahead, while the final observations are progressing in rear. This division of labor is of great advantage in accelerating progress, and, if judiciously arranged with regard to local circumstances and the organization of the party, is productive of the best results.

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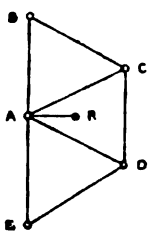
The angles at a station are taken thus: Supposing the observer at A, and the signals at BCDE are all visible, the instrument is carefully levelled and adjusted, and so fixed that some station, B for instance, reads 0°, or zero; B is then called the zero station. Suppose the telescope to be brought up from the left hand of B, and turned gently, so that B may enter the field of view, and come near the centre wire, but not pass over it. Then clamp the instrument, and complete the bisection of B, by using the tangent screw of slow motion. Read off all the micrometers, or verniers, and let your assistant record the readings, in a fair legible hand, in the Angle Book. Look again into the telescope, and see that B remains bisected. If found correct, then carefully unclamp, and move the telescope gently towards C, taking care not to overshoot it. Clamp, bisect, and read off as before, and so on for D and E. You will thus have a complete set of observations at zero 0° observed by a continuous motion of the instrument from left to right. Now, overshoot the station E, and bring the telescope back by a continuous motion from right to left, observing each station in succession, and recording the readings. This will give a second set at zero 0°, which, if accordant, will suffice for that zero. It is the practice of the Trigonometrical Survey to make at least one repetition, in order that if mistakes creep in they may not pass undiscovered.



Now turn the telescope over 180° in altitude, and round 180° in azimuth, so that if the face of the vertical circle were previously to the left hand, it will now be to the right hand; B will then read 180°, and this is called zero 180° FR, the former position being zero 0° FL, *i. e.*, face left. Proceed as before, and take two sets of observations, the motion of the instrument being in one set continuous from left to right, and in the other from right to left, as before.

Having thus obtained four sets of observations for one position of the instrument, you will now, if the number of microscopes be three,* bring 10° under micrometer A, at which position you will get four other sets, and so on for 20°, 30°, &c., up to 50°, whereby you will obviously bring every 10° of the circle under one or other of the microscopes. †

* The Great Theodolites have five microscopes, and observations are taken at every nine degrees of the limb, by means of four change of zeros; the 18-inch and 24-inch have three microscopes.

† Since this was written, Major Walker has suggested that although this method of changing zero

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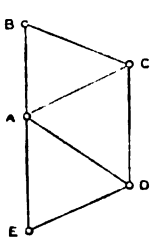
By this process you will have six changes of zeros and twenty-four readings, which will suffice for a complete set of angles, and you ought not to be satisfied with less, when carrying on work of primary importance. All operations in which these precautions are not duly taken, are considered to be of inferior order. This rule applies also to observations for azimuth taken upon circumpolar stars, which must always be taken at six zeros, or at every 10° of the limb at each elongation, as will hereafter be explained.

It has been supposed, in the foregoing instructions, that the signals at all the stations are simultaneously visible, which is not always the case. It is generally so when lamps are used at night, but when heliotropes are employed, it is evident that an eastern station will be seen with difficulty in the morning, whereas in the evening a heliotrope will shine vividly, and *vice versâ* in the case of a western station. Under these circumstances, the observations cannot be taken in regular rounds, in the simple manner before described. The best plan in this case is to use a point of reference, and connect each station therewith at such times as may be most convenient for observation.

The site selected for a referring mark should be such, that it may be visible at all times; its distance from the Principal Station should be from one and a half to three miles, and it should be nearly on the same level, in order that the elevation of the Telescope may be as little disturbed as practicable during the progress of the observations. It is also convenient that the situation of the referring mark should be central with respect to the circumjacent stations which have to be connected therewith. (*Vide* figure in the margin.)



In taking angles with the referring mark, it is often the case that the sets are observed by parts, but as it will not do to compose an angle of two parts taken at different divisions of the limb; therefore, you must be careful in taking

gives readings at equal parts of the limb round the circle, whereby the errors of graduation may be eliminated, there is no great change in the position of the axis, the defects of which may still affect the results. He proposes to obviate this by adding the arc between the microscopes to the arc by which the zero is changed. Thus, in an instrument with five microscopes, for five changes of zero the instrument will be set successively to

(0° 1′) (79° 12′) (158° 24′) (237° 36′) (316° 18′).

and for a three microscope instrument, with six changes, the zero will be set successively to

(0° 1′) (70° 12′) (140° 23′) (210° 34′) (280° 45′) (350° 56′)

By this method the axis will make nearly a complete revolution during the set of observations, and each angle will be observed at equidistant parts of the axis, as well as of the graduation. This alteration is therefore judicious, and should be carried out in future practice.

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each supplemental part, to bring successively under microscope A the divisions which stood there when you observed the first part.

These two distinct parts, when assisted by addition or subtraction, may then be treated as a whole angle; for example, the angle BAC = the ∠ BAR − the ∠ CAR, and if the former angle be observed at a different time from the latter, then the reading of the point R should be the same, within a few seconds, at both times, so that the deduced angles may be composed of entire arcs of the limb of the theodolite in the same manner as if they had been directly observed without the intervention of a referring mark. If there be among the principal stations any one so favorably situated as to hold out every prospect of being at all times visible, it may be treated as a point of reference, and the other stations may, accordingly, be connected therewith, which will save the trouble of observing a supplemental point.

No good observations can be expected if currents of air are allowed to impinge on the instrument, or if it is subjected to the influence of solar rays, or any other causes calculated to disturb the equilibrium of the expansible materials of which an instrument is composed. Independent of this evil, it is also to be remarked that, if the wind is allowed to blow on the telescope, it frequently produces a lateral deflection to the amount of a few seconds. To protect the instrument from disturbing causes of this nature, it is sheltered by a tent, called an observatory tent, the observations being taken through small windows.

(To be continued).

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No. CLX.

LAUNCHING GIRDERS ON THE JUBBULPORE RAILWAY.

Description of a Method of Launching Girders, practised on the Jubbulpore Line of the East Indian Railway. By MIDDLETON RAYNE, Esq.

THE girders to be erected on the Jubbulpore line were, (besides a number of small spans of openings ranging from 30 feet downwards,) fourteen of 110 feet, and six of 70 feet clear span, belonging to the following bridges:—The Semroul, of two 110 feet spans, at the 94th mile from the junction with the main line; the Sutna, of three similar openings at the 108th; and the Roharrie of one at the 165th mile; the Kutna, of three 70 feet, in the same mile; and the Newar, of three 110 feet spans in the 175th mile: the Hiran, of five 110 feet in the 201st mile; and the Parayet, of three 70 feet girders in the 217th mile.

The larger of these spans were lattice girders, of two systems, weighing complete about 97 tons; while the smaller were plate girders, weighing about 43 tons per span, both from the designs of Mr. Rendell.

In March 1866, Messrs. Waring, Brothers and Hunt, the contractors for the construction of the Jubbulpore line, undertook the erection of these girders, a work not included in their main contract. They stipulated for 12 months clear, in which to complete the work. Unforeseen delays in the delivery of the material having prevented their making a fair start till near the end of the year, they were urgently requested—and were themselves extremely desirous—to finish the work within the date of expiry of their main contract, the 31st of March, 1867. Great efforts were made

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to accomplish this, and the measure of success achieved—though not complete—was considered satisfactory; a train having reached to within 50 miles of Jubbulpore on the 2nd of April, and having accomplished the remainder of the distance a month later.

The most important matter for the consideration of the contractors, was of course, the nature of the staging to be adopted, on which to build the girders, *in situ*; or the mode of getting them into place, if built in the bed of the stream, or elsewhere. The streams across which they were to be thrown, were all well defined and running between steep earthen banks; but the nature of their beds varied much—from rock and sand, to silt and soft mud. In all, excepting the Roharrie, water continued to flow during the whole year. The height from river bed to girder bed, varied but little in the various bridges, ranging from 40 to 45 feet.

In all cases, there was a want of anything like enough sand to make platforms in the waterways, on which to erect the girders, as was done so successfully at the Delhi Jumna bridge. Neither was timber of a suitable character for fixed stages procurable, except from great distances and at a ruinous cost.

Mr. George Nicoll and Mr. Mark W. Carr, the representatives in India of Messrs. Waring, Brothers and Hunt, therefore came to the conclusion, that for the deeper openings, at all events, some system of lifting the girders into place should be adopted. Two designs were prepared for carrying out these views—one by means of travelling stages, running across the river bed, near to the cutwaters—the other by means of heavy cranes upon the piers themselves. Both these were however rejected, in favor of a plan for erecting the girders in complete spans, upon the formation level of the railway, behind the abutments, and launching them across the openings one after the other, by means of traversing stages.

This plan was the more suitable for the occasion, that it admitted of the girders being fully erected behind the abutments, and ready to be put into place complete, at one operation; while the masonry on the piers, and even on the abutments themselves, where requiring it, was being completed. Moreover, in the case of the lattice girders, the mode of attaching the cross girders to the bottom booms, would have rendered their being fixed at an elevation after the main girders had been separately lifted and placed, a matter of extreme difficulty.

Mr. H. P. LeMesurier, the Chief Engineer, having approved of the

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plan generally, the writer was charged to carry it out with all possible despatch on behalf of the contractors.

But the complete plan for launching the girders across—if necessary—every opening of any particular bridge could not be carried out from want of time to make the necessary preparations. Where circumstances admitted it, the land spans were filled with earth; and as from careful calculations it seemed that the piers would be liable to be overturned by the pressure of this earth, they were protected on the inside by heavy counterforts of kucha brick work. The length of time, however, taken in filling such large gaps, prevented the earth being carried up to the full height, in more than one or two instances: the deficiency being made up by stacks of sleepers.

In other places, fixed stages were adopted, or rather attempted, temporary piers of masonry being employed in the absence of timber. Owing to the treacherous nature of the nullah beds, these all failed, more or less, completely, excepting in one instance where the success was complete. This was at the Sutna river, where the foundations for the temporary piers, about 42 feet high, were to rest upon some 12 feet in depth of sludge, that had been thrown out of the foundation wells and used to fill up a large hole in the river-bed at the site of the bridge. Into this mud-bed the writer saw a crowbar go overhead with very little more than its own weight after a few strokes had sent it through the upper crust. In order to spread the weight of the piers as much as possible, the whole length of the bay, about 45 feet in width, was covered with a layer of broken stone-ballast, 4 feet thick. Upon this three temporary piers were built, 5 feet 6 inches wide at bottom, and stepped in to 2 feet 6 inches at top; their bases resting upon a layer of timber 10 feet wide and 6 inches thick, to give them an extended bearing on the ballast. The masonry was flat bedded rubble set in lime, and the piers stood without a sign of a flaw; though in every other case where ordinary *pierre perdue* foundations had been used, failure followed, notwithstanding that the flow of water was trifling, and in every instance less than at the Sutna. It should be said that the stream ran freely through the interstices of the ballast and through depressions left for the purpose alongside each permanent pier. One or two small freshes occurred while the piers were in use, when the water flowed over the general surface of the ballast. Scouring was checked by throwing in rough rubble.

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In all, five spans of 110 feet and two of 70 feet, were launched as about to be described; the remainder were built *in situ*, upon earthen banks, or fixed stages.

The girders that were to be launched were built behind the abutments, or piers, as the case might be, on a level platform of timber at a height of 3 feet 6 inches above the level of the masonry on which the cast-iron bed plates were to rest. This height was necessary to allow of trollies being afterwards placed beneath the bottom booms, on which to run the girder forward; so much would not have been necessary, but that the want of time to prepare special castings for low wheels or runners, compelled the use of ordinary railway carriage wheels.

In these trollies, as will be seen from the sketch, the whole weight—in order to save height as much as possible—was suspended below the axles; the beam bearing the girder clearing the rails by only about half an inch, and thus guarding against chance of damage through failure of any of the parts.

The front trollies were placed about 26 feet back from the fore end of the girder; so that when the whole was run forward, by the time they reached the edge of the abutment, enough of the girder projected beyond it, and beyond the travelling stage, lying close up to it, to allow of the girder being seated on its bed plates on the opposite pier, when the launch was completed.

The superstructure of the travelling stage was built of 1 foot square altic timbers, 30 feet long, securely braced, resting upon a massive framing of similar timbers, which again was supported by, and bound together, three parallel trucks, running each upon three pairs of railway carriage wheels; each truck of course having a separate line of railway.

The weight of the stage was taken upon both sides of the wheels—that is, both upon the journal outside, and upon the shaft inside, the nave. In the former case, cast-iron plummer blocks were used; in the latter, only pieces of plate-iron were needed to take the bearing.

The photograph, together with the drawing, will probably give a clearer idea of the structure of the stage than a written description.

In erecting the stage, it was intended to have run the girder forward first, so that it might be used as a jib with which to raise the frames. The backward state of the trollies prevented this, and the four frames, weighing each about 3 tons, and constituting with the braces, stages, &c., the superstructure of the stage, were separately raised by means of a jib of

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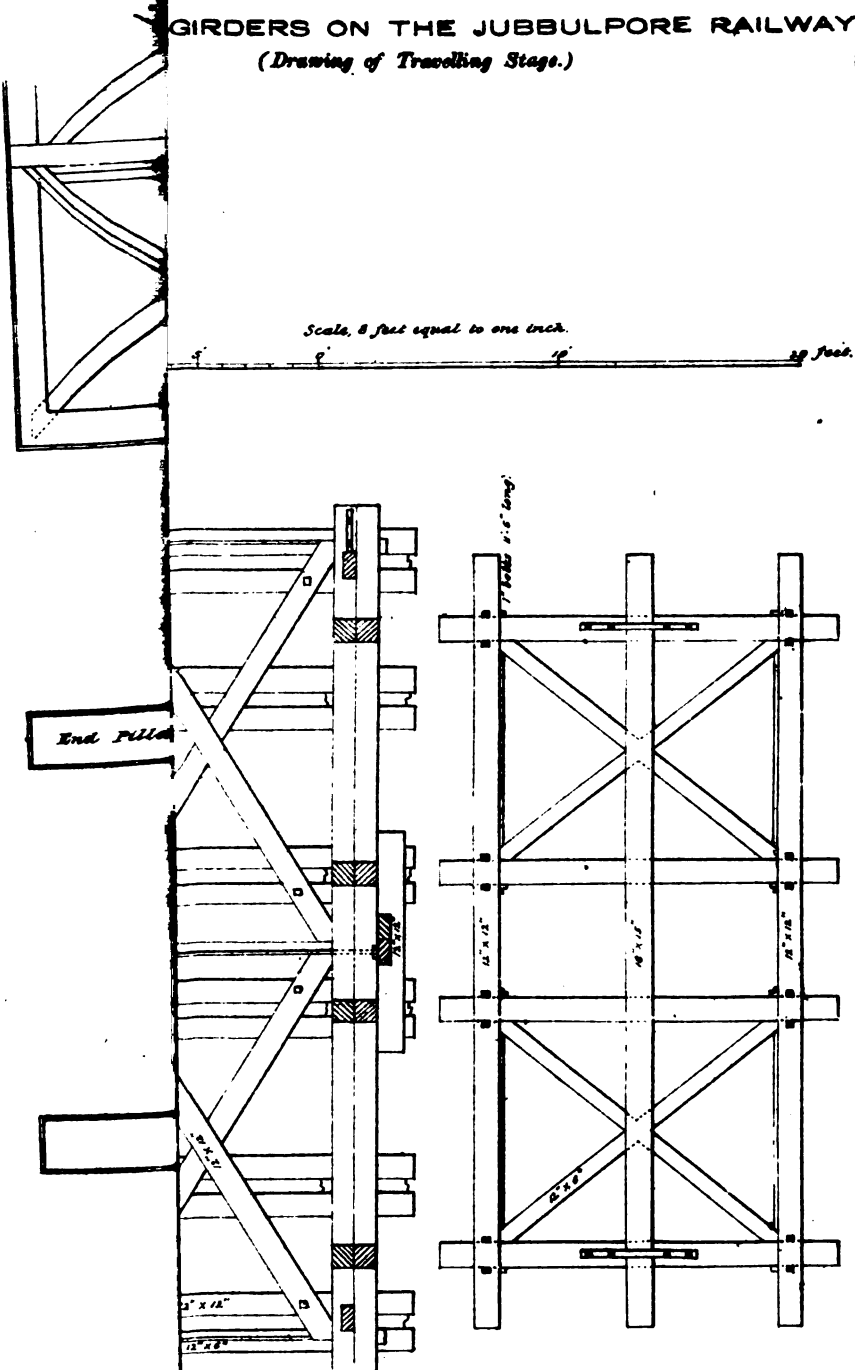
GIRDERS ON THE JUBBULPORE RAILWAY

(Drawing of Travelling Stage.)


Scale, 8 feet equal to one inch.
0
8'
16'
24 feet.
End Pillar
12" X 12"
12" X 12"
12" X 12"

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timber lashed to the lower boom of the girder and projecting some 10 feet beyond the masonry. As soon as raised, they were secured by means of the raking diagonal braces, by stages and tie-bolts; and finally by the three timbers lying across them all at the top; the middle one of these being the bearing beam, a piece of teak 18 inches by 15 inches by 30 feet long.

The whole weight of the girder carried was borne upon this beam, which rested upon the frames exactly over the apices of the main oblique struts. The object of this was to prevent any longitudinal undulations in the road from throwing the entire weight on the front or back sets of wheels, as might have happened had the beams above those wheels been loaded with only their fair share while the stage was perfectly perpendicular.

The whole stage was securely stayed with timber stays, and tied together with 1-inch and 1¼-inch through bolts, and was then remarkably rigid; so much so, that when carrying considerably more than half the weight of the girder—about 65 tons, indeed—and its own, about 35, it did not yield to the small, but unavoidable, transverse inequalities of the three lines of road. On the first occasion of its being used this was particularly noticed, when, for a short space, one of the outer pairs of rails being slightly low as compared with the others, it was observed that the truck running on that pair, did not descend to them for that space, but was borne along by the others; the wheels being clear of the rails and not revolving.

There being above 100 miles between some of the bridges at which this system of launching was to be employed, two stages were constructed—one at the Semroul and one at the Hiran. The first occupied a longer time than was expected in construction and erection—about 5 weeks—than was expected; the second—that at the Hiran—less than a month, including the four trollies, in themselves heavy pieces of work. An English sailor with a few ship's classies, was employed upon each stage, and they were found of very great service. After the first attempts, the men became accustomed to the work, managing the heavy timbers very dexterously; the whole of the launching operations having been accomplished without accident to life or limb.

The taking down of the stages for removal to another bay, was generally done in about two days, and the re-erection and placing of the trollies ready for another launch, in about 8 or 10 days more.

The first launch was fixed to take place on the 15th of February last, at the Semroul, when it was hoped everything would be in perfect readi-

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ness. The front pair of trollies were, however, incomplete at the last moment; and as time was pressing, it was resolved to attempt getting the girder forward upon the traveller by means of heavy traversing jacks, at the front end—the hinder pair of trollies being in position. This was successful to the extent of about 14 feet out of the 26 required, when it became evident that the jacks—calculated for loads of 25 tons each—were unequal to the continually increasing strains. It was determined, therefore, to substitute rollers for them, there being at hand some admirably adapted to the purpose, belonging to the expansion bed-plates of the girders themselves; they were of cast-iron 2 feet 6 inches long and 7 inches in diameter, truly turned. Three rails abreast were bolted together through the fishing holes, and lashed to the under side of the cross girders, in the middle of each bottom boom of the main girders. A platform of timbers to the required height was then made; upon it were laid several rails upon the flat, and between them and the upper rails, a couple of the rollers, some little distance apart, were placed. The girder was then lowered upon these, and hauled forward the remaining distance with great ease, by means of a pair of double purchase crabs, each assisted by a set of double sheave block tackles, carrying half-inch chain.

When the girder was in position fairly over the traveller, wedges were placed between the bearing beam and the cross girder which had been arranged to come immediately above it; and in order to get the rollers out, the girder was lifted at the back end, there being no convenient position for the jacks at the front. After this had been done, and while lowering again upon the hinder trollies, a slight accident happened, which served to show the rigidity of the girders, and at the same time, the sufficient strength of the trollies. The jacks having been unfortunately placed on unstable packings, canted, and the girder got the amount of fall—about one inch—though in an oblique direction which the safety wedges admitted. No damage whatever accrued from this—except to the jacks—which were severely crippled.

On the following day the launch was completed successfully, the time occupied in hauling the travelling stage across the bay of 110 feet being three hours. In all succeeding cases, this operation was got through within an hour, including the numerous stoppages for "fleeting" the chain upon the crab-barrels. The power employed, in addition to the pair of crabs and tackles, already mentioned as attached to the girder on the top of the bank,

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was another pair in the bed of the river, in every way similar, and attached to the travelling stage. These four crabs were simultaneously started and stopped by signals, given by the conductor of the launch, to which attention was called by striking a gong.

The Semroul girders having been launched before the large bed-stones, on which to rest the cast-iron bed-plates, were ready, the girder had to be supported in its elevated position, after the removal of the travelling stage and trollies, until they were prepared and put in place. As only 8 feet in the middle, between the two main girders, were available for the supports, from the room required for the placing of these stones, and as the end cross-girder was not calculated to sustain so great a stress accumulated near its centre, additional supports were obtained clear of everything, outside the girder, by lashing large beams across the end of it, projecting several feet on either side.

The stage and trollies had now to be removed to the Sutna—about 15 miles by kucha road—where two launches took place on the 16th and 28th March, respectively. They were then taken by rail and road to the Parayet, a distance of 110 miles, where it was intended by their means to launch two spans of 70 feet.

Owing to great delays in the transit, it became evident that this could not be accomplished within the date on which it was desired to allow an engine to pass to Jubbulpore—the 31st April—one month after the date of expiry of the main contract. Consequently, while one span was being travelled as usual, other means were devised for getting the second span into position. Four stacks of sleepers, one in each corner of a square 26 feet 6 inches by 28 feet on the sides in the middle of the bay, were built to the required height—in this case 35 feet, and bonded together at intervals of 5 or 6 feet by rails. This stage or temporary pier being 28 feet wide, left openings on either side, of 21 feet; the girder was hauled over on rollers —by means of a crab and tackles placed on the opposite pier—25 feet having been projected before hand to assist in building the sleeper stacks. The plan proved a very expeditious and economical one, for the class of girder on which it was tried.

The last span at this bridge was launched on the 27th April, and the road was laid across the bridge by the following evening ready to take a train across.

In the meantime another travelling stage, with all belongings complete,

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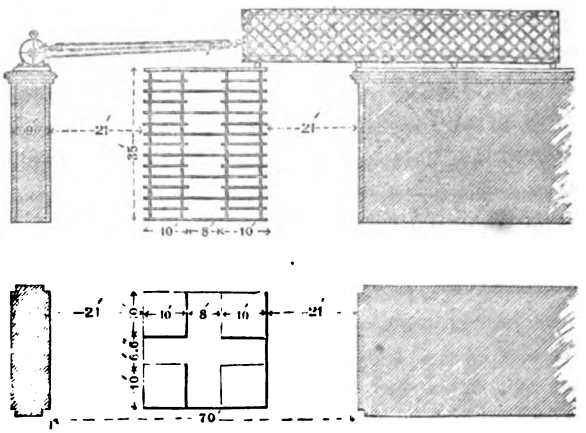
had been built at the Hiran, where the two spans there requiring it were launched on the 3rd and 20th of April.



At the second of these launches, circumstances permitted the writer's arrangements to be carried out more completely than—from the extreme pressure of time—had been possible on any previous occasion. A short description of these may not be uninteresting.

The girder having been built on packings 3 feet 6 inches high by 4 feet wide, under each boom, the rails for carrying the trollies resting upon longitudinal balks, were enabled to be laid on either side of these packings, before disturbing anything. The trollies having then been put together in their required positions—after removing as much of the packings as was necessary to admit them—greased folding wedges were driven between the bearing plates of the girder, and the bearing beams of the hinder trollies; and as many of the wedges, upon which the girder had been built, as possible having been removed at the end next these trollies, a very slight lift with the jacks at the front of the girder sufficed to ease the weight on the remaining wedges so much that they could be struck. The sand-boxes on the front trollies having then been filled as full as possible—there being under the best circumstances, no more than 3 inches of fall to be got by them—the girder was now lowered upon their plungers.

The travelling stage being in readiness, close abreast of the masonry of—in this case—the pier, the girder was now hauled forward the requir-

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ed distance. This, owing partly to a want of sufficient power in one pair of crabs and tackles, and partly to the small base covered by the front trollies, carrying so great a weight as 35 tons each, causing a sensible settlement of the roadway, was as usual, the only part of the proceedings that gave any trouble. When in its proper position over the traveller, folding wedges, well greased, were driven between the bottom booms and the plungers of sand-boxes resting upon the bearing beam of the stage; and by means of the sand-boxes on the front trollies, the weight was placed upon these—the second series of boxes. The front trollies having now done their work, were removed (in some instances they were lashed up to the girder and carried forward by it, being lowered afterwards by tackles into the river-bed, as in the instance when the photograph was taken); and the upper and lower lines of railway for the passage of the hind trollies and the traveller, being clear, the launch proper was proceeded with; and, as in each preceding case, was accomplished without the slightest hitch or difficulty; the stage moving with scarcely a perceptible vibration, even to those riding upon the girder. Large plumb bobs suspended from the top, and hanging over a mark on the lower, platform, showed but very trifling deviations from the perpendicular, laterally, but generally from 2 to 3 inches longitudinally, that is, in the direction of motion; there being invariably a tendency on the part of the stage to travel faster than the trollies—to be accounted for, as before explained, by the smaller base of the latter allowing of a greater depression in the roadway. The deviation mentioned showed no tendency to increase, and having established itself, it was not easy to reduce it by altering the powers at top and bottom.

The girder having arrived at its destination, with the bearing plates directly over the bed-plates of the piers, its weight was taken, by lowering with the stage sand-boxes, upon other sand-boxes placed upon the front pier bed-plates; these forming the 3rd series of boxes.

The traveller being now freed, was run back by hand—50 or 60 coolies managed it with ease—to its old position against the back pier. The sand-boxes upon it, having been refilled, and packings placed upon their plungers to such a height as would ensure their taking the weight of that end of the girder, while preventing its unnecessary rise, the front end of the girder was forthwith lowered into its permanent position on the bed plates by means of the pier sand-boxes; the tilt produced by this fall of 2 feet 6

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inches at the front end of the girder, throwing the weight of the back end again upon the traveller, and freeing the hind trollies, which were at once removed. The sand-boxes from the front, having been brought to the back, pier, received the weight from the traveller, and the lowering into permanent position went on there as it had done at the front. Thus the whole of the launching operations, by help of the sand-boxes, involved only trifling jacking.

The actual business of lowering the girder into its permanent position, by the sand-boxes, occupied about two hours.

It was interesting to witness the accuracy with which the projecting end of the girder advanced and slowly took up its position over the bed-plates on which it was finally to rest; the discrepancy to be corrected was frequently not more than from $\frac{1}{4}$ to $\frac{1}{2}$-inch; nor was there any tendency to increase this during the lowering by the sand-boxes—the wheels of the traveller and the trollies being securely blocked. But, whatever the discrepancy might be, it was easily corrected by forcing the girder in the required direction by screw-jacks, after resting it upon the bed plates, these having been well greased first.

The method adopted of lowering by sand-boxes was very successful. The sketches of the three sizes used will be a sufficient explanation of the mode of construction followed. The writer believes the introduction of the cup at the mouth of the holes, to be of much advantage where great weights have to be dealt with. It offers great security against untimely movement of the sand, since nothing but a deliberate scooping out of that in the cups, will cause that within the boxes, to flow. The strongest gusts of wind fail to take an appreciable amount of sand out of these cups, even when entirely unprotected, while the same gusts will nearly undermine the plunger by sweeping through the space between it and the sides of the box. It also offers facilities for regulating the flow of the sand so as to ensure the plunger's descending perpendicularly—a matter of the highest importance in this case, where great weight, amounting indeed to half the weight of a span, or nearly 50 tons, had to be carried by the end cross girder, formed of a web plate, $\frac{1}{4}$-inch thick by 18-inches deep with a pair of 3-inch angle-irons top and bottom. It is obvious that a very small deviation from the plumb in the supporting plungers, would cause this frail member to buckle, as was unpleasantly proved on one occasion.

In deciding upon the proper strength and mode of constructing these

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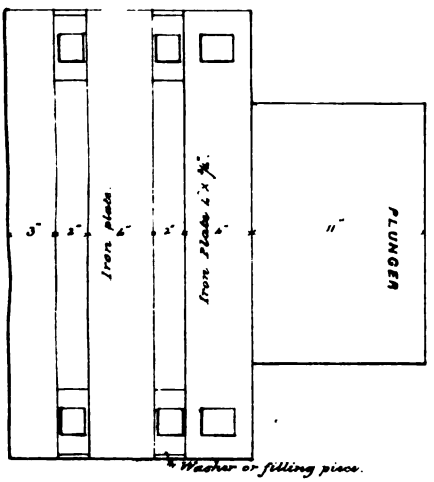
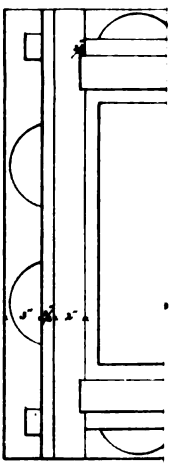
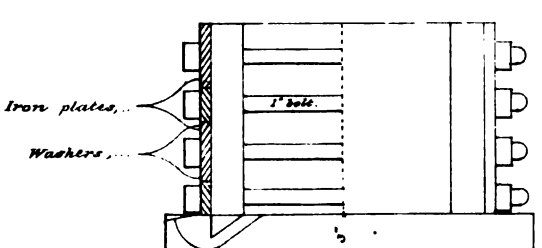
SAND-BOX

SIDE ELEVATION.





HALF SECTION, HALF ELEVATION OF END



Scale 1 foot = 1 inch.

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boxes, doubts suggested themselves to the writer as to whether the description of box commonly used in easing centres, would be equal to the work on this occasion. The weight to be borne by each, varied from 35 tons on the trollies to 25 to 30, in other places; while the weight taken upon a box in lowering the largest centres can seldom reach one-third of these amounts.

It is not easy to see, theoretically, why extra strength should have been required, since the height of box adopted is hardly greater than that in common use. However, the results appear to have justified the doubts. When the weight of half the span was first placed on the boxes at the Semroul, and before any sand had been withdrawn, a very heavy strain was seen to be taken by the sides—they were bulged out about a quarter of an inch in their length of 18 inches; and as the lowering process went on, this appeared to increase with the smallest variations in the plumbness of the plungers, the wood frequently splitting and straining to an alarming extent. At last the heads or nuts flew off the bolts in one or two instances, and this was considered sufficient proof that more strength was required. These boxes were fitted at first with only thin bolts at each end—two others at each end were afterwards added. The straps were only $2\frac{1}{2} \times \frac{3}{8}$-inch.

The second lot of boxes, made for the Hiran, were fitted with 4 bolts at each end, as shown, and with $4 \times \frac{3}{4}$-inch straps. These stood well from the first.

The plungers first used were made of Baltic fir; but they failed utterly, the fibres crushing and sliding one upon the other. Any hard jungle wood was found to answer well. The boxes themselves were made of Maulmein teak.

The larger boxes gave a clear fall of about $9\frac{1}{2}$ inches, the smaller about 5. They were always filled brimful; the plungers rested on the sand at the level of the top of the box, the weight forcing them down from $\frac{1}{2}$ to $\frac{3}{4}$-inch. Each "fleet" of $9\frac{1}{2}$ inches occupied about two minutes, the loss of time occurring in shifting the boxes and in arranging the safety wedges, which were, in all operations of raising and lowering, so placed as to prevent the girder getting a fall of more than one inch, in case of accidents.

The cost of launching by this system is less than half that necessary in erecting a fixed timber staging even of common jungle wood, in this part of India. Were the complete system of traversing carried out as originally intended, by which the necessity of taking down the traveller

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and re-erecting for each span, would be avoided, the writer believes that on bridges of, say 5 or 6 spans, this cost would be reduced to one-third. Of course the more the spans, the less would be the cost per span.

The system seems well adapted to cases where the height of the piers being from, say 40 to 50 or 60 feet, makes the filling in with sand or earth unadvisable, and fixed timber stages expensive: and also to those, where either the construction of the girder itself, or that of the bridge, presents difficulties in the way of lifting the span in separate ribs, over the ends of the piers, as is successfully practised on the G. I. P. line. There the great height of the piers—in some cases about 200 feet—would make any kind of staging difficult. But as their girders are so arranged as to carry the rails direct, there are no cross girders to be fixed afterwards, at a great elevation. Moreover, the piers there have no projecting cut-waters on the down-stream side—from which side the girders are lifted—a very important consideration where cranes or jibs have to be used.

It has the further advantage of allowing the whole of the girders of a bridge to be erected in a place of security, while the masonry works are in progress; thus not only saving the time that must otherwise be occupied in erecting the iron work, after the completion of the substructure, but allowing it to be done in a more leisurely and methodical manner than can be followed, when, as generally happens, a large girder bridge, unfinished, is the one link required to connect and utilise many miles of road.

On the subject of the erection and rivetting of the girders, the writer believes he has nothing of interest to relate. Men were drawn from Bengal, and from Oude and Delhi, besides those who could be procured in the North West. Many of them were old hands, and very expert rivetters, making work of a quality and neatness not to be surpassed. Fifteen to twenty gangs of six men each, were generally employed at a time on one of the larger spans, which they were able to complete in twenty days, when no delays from extraneous sources occurred. The better gangs would put in above 100 one-inch rivets in a day in plain work, but the average out-turn per gang, was certainly under half that number. Country hearths made of clay, each upon a plate of iron about 2 feet square by $\frac{1}{8}$-inch thick for convenience of portability, were used in preference to English forges, for heating the rivets.

Work at five bridges was in progress at once, upon each of which a first class European mechanic was employed, with generally a second to assist him.

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During the passage of the first train with an ordinary passenger engine over these girders, the vertical depression averaged $\frac{5}{8}$-inch on the 110 feet spans, and $\frac{7}{16}$-inch on the 70 feet. The latter sprung back to their original position directly the train had passed, but in the case of the lattice girders, about $\frac{1}{4}$-inch was permanently taken out of the camber.

M. R.

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No. CLXI.

CANAL DISTRIBUTARIES.

On the proper Alignment of Rajbubas or Canal Distributaries. By Captain W. Jeffreys, R.E., *Executive Engineer, Ganges Canal.*

Naturæ non imperatur, nisi parendo.
Bacon.

Among the several causes which have led to the comparative failure of the Ganges Canal as a financial speculation, none has perhaps produced more prejudicial results than the defective alignment of the distributary channels. The main canal itself being a mere channel of supply, from which little or no direct irrigation is permitted, it is only natural to suppose that the defective irrigation must in a great measure be traced to faults in the construction of those channels which are more immediately intended for the distribution of water. And this is most assuredly the case. To explain the nature of these defects and to point out the only true principle on which works of this kind can be projected is the object of this paper.

It will be necessary to review the several methods on which minor irrigating channels, or as they are termed, rajbuhas, have hitherto been projected.

The first attempt that was made to bring this class of works under any recognised sort of system will be found in Sir P. Cautley's "Report on the Ganges Canal," para. 6, page 435, which is illustrated by the following diagram. It may simply be described as a series of feeders taken out from the

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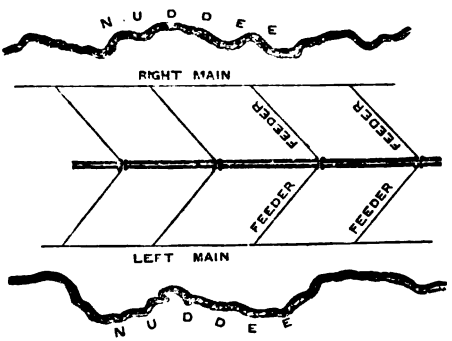
canal at an angle of 45°, and at equal distances; leading into one continuous straight channel on either bank, designated the east or west Main, and parallel, or nearly so, to the canal itself. As all the bridges below mile 113 are furnished with masonry outlets for this object, it may be assumed that in the original system the feeders were intended to be from three to four miles apart.



The most obvious objection to it on a canal in which the surface of the water is below the level of the country (and experience has shown that it is unadvisable on sanatory grounds to retain large volumes of running water in embankment), is the impossibility of distributing the water by natural flow: for any advantage in command of level that is gained by taking out a channel above a weir, or by the difference, in slope of bed of the rajbuha and that of the main canal, must be foregone at the junction with the next feeder, where the bed must be lowered to suit the levels of the latter. As there exists moreover, throughout the entire country, an extensive ramification of natural drainages (some of them of large volume and extent), it is evident that any system of channels forced to take the direction shown in the diagram must cross and recross nullas and nuddees, the passage of which must be provided for, at a large outlay, by the construction of culverts and syphons. There cannot be the faintest pretence of following the watershed of such lines of drainage, and the channels must consequently often take a course unfavorable for the distribution of water through the higher land. This system is so obviously defective that it is now never employed.

The worst example of rajbuhas constructed on this principle will be found on the right bank of the Etawah Branch, from miles 25 to 60 [*see Plate* LI.] .In designing these lines, the Engineer entirely disregarded the drainages in that part of the country, which are very numerous and plainly defined, and the result is that jheels are traversed, sand-hills intersected, and nuddees crossed and recrossed in every direction: in fact no obstacles, however formidable, appear to have induced the designer to deviate from the

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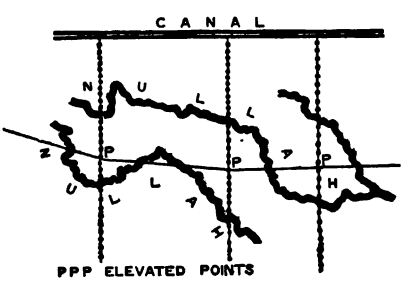
straight lines previously determined on. One of them, named the Jheyra Feeder, crosses five nullahs in a distance of four miles, necessitating the construction of three syphons for the passage of the rajbuha water under the drainage. The Right Main follows as nearly as possible the course of the Sirsa nuddee, which it crosses in no less than three places; and, notwithstanding the numerous syphons which have been constructed, the drainage is but imperfectly provided for, while in many places it is entirely intercepted. Over nine-tenths of the country thus intersected, irrigation is next to impossible, while in the remaining tenth it is attended with such drawbacks as to render it of doubtful utility.

Numerous other examples may be quoted in which the same characteristics are discernible, though in a lesser degree, and this must always follow any attempt to enforce a system of distribution, in which due regard has not been had to the physical conformation of the country and the features of the ground.

It is a leading principle in the construction of all irrigating lines that they should follow as closely as possible the course of the high ground on either bank, and to effect this, the plan generally adopted is to cover the tract it is proposed to irrigate with a series of cross levels a mile or so apart (time will seldom admit of their being taken at shorter intervals, while in many cases 3 or 4 miles apart is considered sufficient), and to connect the most elevated points by a line, which is henceforth adopted as the tracing of the proposed work.

Judging by the numerous examples that everywhere abound in which the proposed result is certainly not attained, it becomes our duty to enquire how a system so apparently sound should fail in securing the end in view?

The fact is, that owing to the numerous nullahs and drainages that intersect the country, there may often be found two or more lines of water-shed parallel, or nearly so, to each other; and unless the principal features are carefully delineated on the map, the Engineer is apt to confound one watershed with another; so that while he is under the impression that he is following one, he is in reality connecting two entirely different



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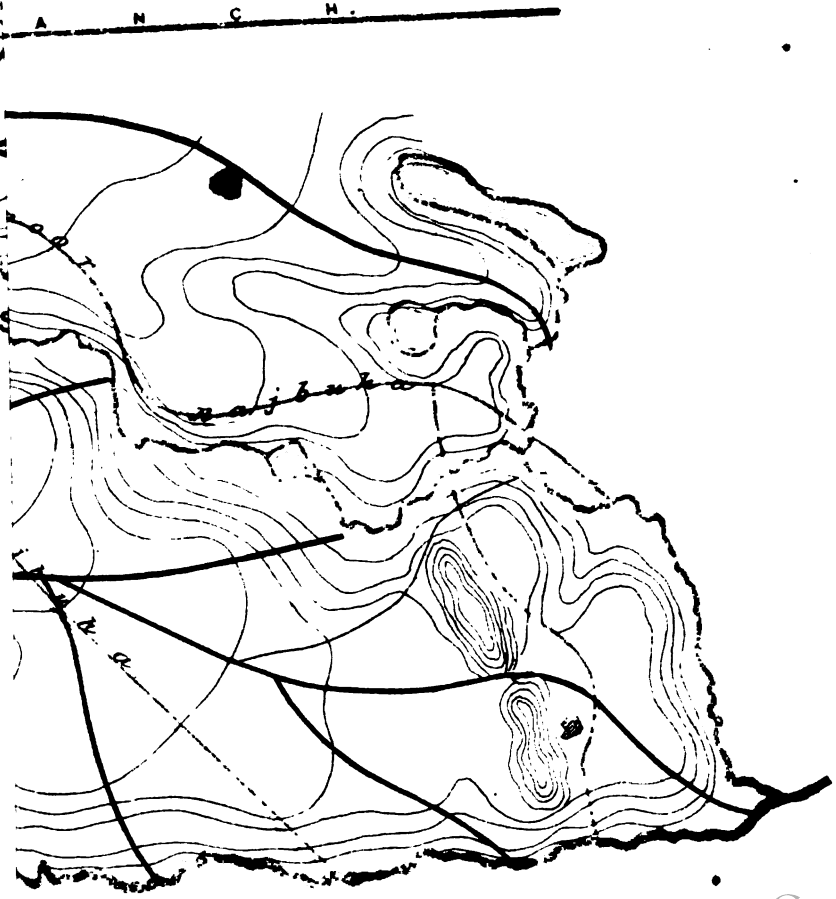

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watersheds, the connecting line, as is often the case, following the course of the intervening valley. The above diagram will illustrate the case in point.

A remarkable instance of this may here be mentioned. In 1860 a new line for the Delhi Canal was designed on an elaborate system of cross levels taken at a mile apart, and a project was drawn up on the most approved principles. The Punjab Government however directed that a survey of the drainage should first be made, and the writer has since been informed by the officer engaged on the work, that the proposed line which fulfilled all the necessary conditions in the original scheme is now found to cross several important lines of drainage, and to be about the worst that could have been selected.

In order to deliver the water under the most favorable conditions, it is clear that irrigating channels must everywhere follow the watersheds of the country drainage. The first step then is to ascertain how many features of this kind exist, their extent and relative situations. This knowledge can only be acquired from a careful survey of the country it is designed to irrigate, care being taken to delineate on the map the course of all rivers, nullahs and streams, and the position of all hollows and jheels. To each watershed should then be assigned a separate channel of a capacity apportioned to the duty it has to perform, the two bounding streams or nullahs being considered in this system as the limits to which irrigation from any single line should be carried [*Plates* L. and LI.]

Having then traced out on the drainage survey map the general course of the proposed channels, it may be found necessary to run two or three lines of cross levels in such places where, from absence of all drainage features, a doubt may arise as to the exact position of the watershed. With the aid of the information thus obtained the Engineer will be enabled, *after a careful examination of the ground*, to fix on the precise trace of the proposed lines.

For the more complete and efficient distribution of the water, branch-lines (or as they are termed minor rajbuhas), should be taken out from the main or principal channels where they may be most required; but the Engineer should in a measure be guided by the nature of the ground and the character of the soil. As in the case of larger works, he should endeavour to secure a command of level for the purpose of affording every facility for irrigation: He should avoid as far as possible crossing minor drainages or

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stumbling into hollows by which his object may in any measure be defeated: He should banish from his mind any idea he may entertain of the relative unimportance of this class of works; for he may be assured that nothing tends so directly to an economical distribution of the water as a carefully constructed system of minor rajbuhas.

Thus a principle is established which is susceptible of universal application, whether the works to be designed are of the greatest magnitude or of the smallest pretensions. Though sufficiently understood in the alignment of large canals, it has been too much ignored in the projection of minor channels, to which must in a great measure be attributed the difficulties that attend the distribution of the water.

It may help us to arrive at a due importance of the subject by considering some of the prejudicial results that must follow neglect of the rule laid down. These evils will be induced in a greater or less degree in proportion to the extent to which the principle is violated, and may be enumerated as follows:—

I. Greater original outlay on high embankments, the construction of which might have been avoided.

II. Additional yearly expenditure on maintenance and repairs.

III. Unfavorable position for the distribution of water through the higher lands.

IV. Consequent loss of revenue.

V. Intercepted drainage.

No one can inspect the irrigation channels on the Ganges Canal without being struck by the enormous expenditure incurred in many places on the construction of high embankments, the necessity for which would never have arisen had the lines in the first instance been judiciously selected; and the unfortunate part of it is that all this additional outlay is in no way compensated for by any increase in efficiency. It does not require much to show that the reverse must be the result: for where a line of watershed is departed from, it will be necessary, in order to irrigate effectually the higher lands, to keep the smaller field water-courses on the same high level as the channel of supply, which in practice is almost impossible, owing to the construction and maintenance of these works devolving on the cultivators, who can never be persuaded to bestow the necessary amount of labor for this object.

But it is from a sanitary point of view that the matter is deserving of

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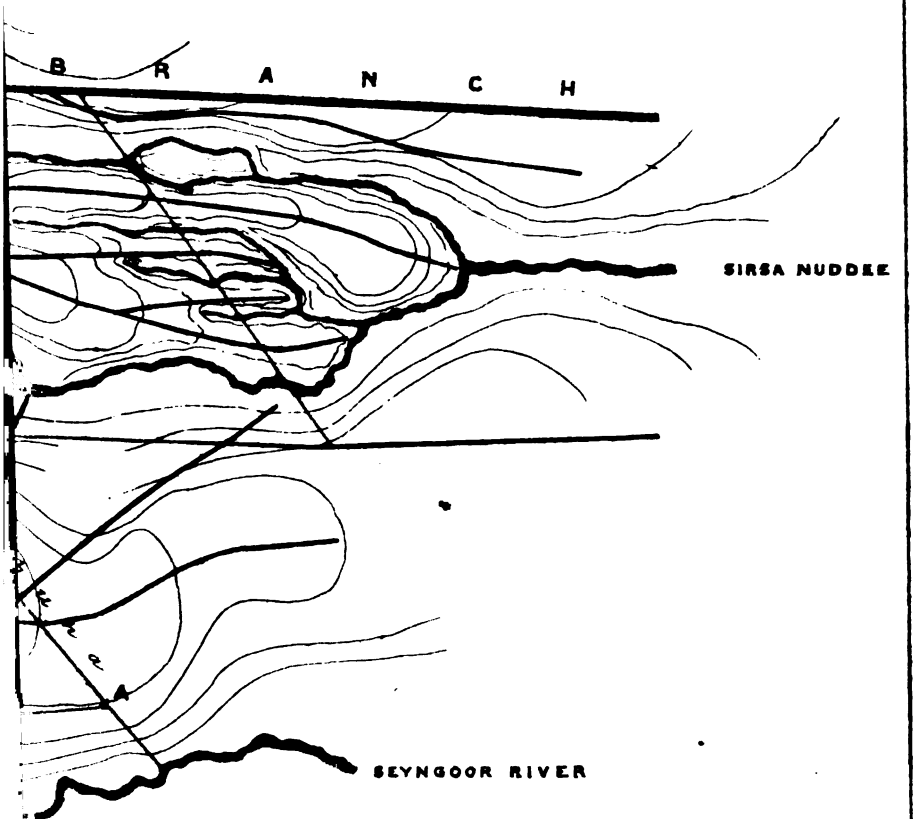

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the gravest consideration. Much has been said and written on the importance of securing a thorough system of drainage in all districts under the influence of constant irrigation. The frightful evils that have resulted from the absence of such measures in the districts bordering on the Western Jumna Canals are too well known to need any lengthened notice here, but as in all cases *prevention is better than cure*, so the first step should surely be to interfere as little as possible with the existing natural drainages of the country. The Engineer will then have no artificial obstructions of his own creation to contend with, in carrying out a system of drainage operations at any future period.

Before closing this paper, it will be necessary to say a few words on the system advocated by most Canal Engineers of tailing one irrigating channel into another, with a view of preventing waste and ensuring a greater economy in the distribution of water; the idea being that the surplus water from one rajbuha may be passed into the next and thus utilized on irrigation, instead of being allowed to escape into nuddies. It is presumed, of course, that this is only applicable to periods of diminished consumption; for, systematically to pass down at all seasons a certain quantity through long and roundabout channels to feed others that might be supplied direct from the canal, is a manifest waste of water. Except in the upper portions of the canal it may generally be assumed, for obvious reasons, that the supply is inversely proportionate to the demand; whenever a slight cessation in irrigation takes place, the supply in the canal immediately rises, the influence of which is felt in all the minor channels. The question is, whether at such times the addition of the surplus or tail water of one rajbuha to the already increasing volume of another would prove any boon to the cultivators. The writer has seen no advantage gained by this arrangement, but has often found it give rise to serious inconvenience.

It is to results, however, that we must chiefly look for the real test of the comparative advantages of the two systems. Waste is properly defined as expenditure without an equivalent, and as the irrigating duty of water is now fairly known, the actual waste in any channel can be approximately found by comparing the areas irrigated with the average working discharge. Taken by this test it has been found that the large self-feeding rajbuhas, unsupplemented by other lines, show the largest and most profitable returns; and, consequently, the supposition that the tailing of one

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irrigating channel into another is productive of greater economy is not borne out by actual experience.

In the system advocated by the writer, the capacity of an irrigating channel should everywhere be exactly apportioned to the duty it has to perform, the section decreasing as the line advances, until it loses itself in a small village water-course. A large margin should be allowed for further possible development of irrigation.

Escapes will be required at every 8 or 10 miles, but they should only be resorted to on emergencies, it being preferable to reduce the supply by partially closing the gates at the head.

It is scarcely necessary to point out the principal considerations that should guide the Engineer in the construction of works of irrigation. Economy in original cost is perhaps the most important. It may seem like a truism to say that no work, however efficient it may ultimately become, can give a fair return upon the outlay, where a reckless disregard of economy has been exhibited in its first construction; and yet the numerous examples that everywhere abound show that this axiom can scarcely be too strongly insisted on.

By following the principles we have endeavoured to explain, it is quite possible for the Engineer to realise at one and the same time the two most essential elements of success, *minimum of cost* and *maximum of efficiency*, while the first step towards reducing to a minimum the evils attendant on irrigation will have been secured. It is only by adapting the system of distribution to the natural physical conformation of the country that this result can be attained. That principle cannot be better described than by repeating the maxim, which stands at the head of these pages, "that nature can be controlled by obeying (and only by obeying) her laws."

W. J.

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No. CLXII.

RESERVOIRS FOR THE DAMOODA RIVER.

Report by LIEUT. H. W. GARNAULT, R.E., *of his exploration of the Upper Reaches of the Damooda River. Dated 24th June,* 1864.

IN Government of Bengal's letter of the 30th October, 1863, I was ordered to explore the heads of the Damooda and Burrakur rivers, with a view of finding sites suitable for reservoirs to hold the surplus water which inundates the country in the lower reaches of those rivers.

Owing to unavoidable delays I was only out about two and a half months and during this time I took a longitudinal section of the bed of the Damooda from its junction with the Burrakur to Ramghur (a distance of 100 miles) and 13 cross-sections; besides this, I reconnoitred four very suitable sites for large reservoirs and several smaller ones,—a full description of which I shall give hereafter.

The country through which my route lay is very difficult. From the Jumooneah Nuddee (the boundary of the Hazareebaugh district) to Ramghur, it is one mass of dense jungle and rocks. The few villages that exist are of the poorest description, consisting of two or three Sonthal huts, so that I experienced great difficulty in finding ground for encamping anywhere near my work, and was often compelled to send to great distances to obtain the bare necessaries of life for my camp.

Accompanying this Report are the following plans and sections:—

1 map of the basin of the Damooda and Burrakur rivers.

1 longitudinal section of Damooda from Ramghur to its junction with the Hooghly.

8 cross-sections of the Damooda (3 only printed).

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Of the section, the portion from Ramghur to junction with the Burrakur was taken by myself; the portion between the junction with the Burrakur and Raneegunge, I have put in approximately from the Railway levels; and that between Raneegunge and junction with Hooghly is from an old record in my Office, the levels of which were, I believe, taken during my predecessor's incumbency of the Division. I closed with the Railway levels at Burrakur, and took their datum, namely, the sill of Howrah Dock, but I have since reduced all the heights to mean sea level, allowing the latter to be 11·63 feet higher than the sill of Howrah Dock, according to the Great Trigonometrical Survey calculations.

In making calculations of the discharge of the river, I have used Eytelwein's formula, viz., $D = \cdot 9 \sqrt{2fd} \times s$, where D = discharge, f = fall per mile in feet, d = hydraulic mean depth, and s = area.

I have marked on my sections the flood of 26th September, 1863. Mr. Powell, Executive Engineer, was kind enough to drive in pins at the limit of the flood at two or three places near Burrakur; and in the higher reaches of the rivers, I have taken the marks on the banks: where no marks were visible, I have obtained the height from the villagers. I have assumed this flood to be a maximum; and the rain-fall which caused it, a maximum rain-fall in 24 hours over the catchment basin.

These assumptions will, I think, give very safe data for determining the size and number of the reservoirs required, as the rain-fall recorded at Hazareebaugh, on 25th September, viz., 13 inches, is 5 or 6 inches more than any fall hitherto recorded; and the flood of September 26th rose higher and lasted longer, in the lower reaches of the river especially, than any previous flood since the memorable one of 1823.

The flood of 1823 must have been extraordinarily high: the marks of it have been pointed out to me from Cowcolly Light-house to Ramghur, and it appears to have been at least 10 feet higher than any that has since occurred. In this flood, however, the Damooda and all the other rivers in Lower Bengal were held back by the very high sea-wave which came up the Bay and caused such destruction to life and property along the coast south of the Russoolpoor River.

Before describing the reservoirs, I propose giving a sketch of the Damooda river from its source.

The Damooda, or Deonud, as it is called in the higher reaches of the river, rises in Toree, about 50 miles south-west of Hazareebaugh, and 40

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miles north-west of Ranchee; it flows in an easterly direction through a wild country between high rocky steep banks covered with jungle, and over a sandy and rocky bed; the fall appears to be about 6 or 8 feet per mile as far as Ramghur.

From Ramghur to the south of Gunkee, the river still runs in an easterly direction, and through similar country; the bed, however, is more sandy, and the fall is 6·56 feet per mile.

From Gunkee the river takes a northerly course to Julla or Mirzapoor, and the fall is considerably increased, being to Gugree 17 feet 5 inches, to Gaga 10 feet 8 inches, and to Mirzapoor or Julla 14 feet 9 inches, per mile. The bed has several small breaks, and is a mass of huge boulders, which show unmistakeably the terrific velocity of the river when in flood. The banks are very high, rocky, and covered with dense jungle.

Between the junction of the Bhera Nuddee and Gugree there is a hole, or "*dhow*," in the river, for a length of a quarter of a mile, which is said to be unfathomable: the dry weather stream here is about 20 feet broad, and runs between perpendicular rocks about 18 feet high; these rocks are themselves covered in floods.

At the angle formed by the junction of the Bhera Nuddee with the Damooda, there is a stone temple (Rajarapar mut) built by one of the former Rajahs of Echak, and ministered to by a family of Brahmins who live at Hishapoora; the plinth of this temple was above the flood of 1863, but I was informed that the flood of 1863 rose up to the top sill of the doorway; it also lifted some of the stones of the steps and basement (about 8 cubic feet each), and deposited them 20 or 30 yards distant.

From Julla to Tureeo the river again runs east, and with a fall of from 5 to 6 feet per mile; the bed is principally of sand, with rock cropping out here and there: the banks are high, and a large quantity of coal is visible in them. From Julla, the timber cut from the Ramghur Hills is floated in rafts to Tureeo, where it is landed and conveyed by cart to Rungamattee; here it is again embarked, and can proceed without impediment to Calcutta by the river.

Between Tureeo and Rungamattee there is in 8 miles a fall of 100 feet, or about 32·49 feet per mile; the bed in this portion has several breaks, and is a mass of huge boulders lying about in most bewildering confusion. Opposite Rajabera there is another "*dhow*," or deep hole, similar to the one at Gugree, already described.

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From Rungamattee, or the Jumooneah Nuddee to its junction with the Gowaie, the river takes an easterly course, and has a uniform fall of about 4·5 feet per mile; the bed is sandy and rocky, and the banks are high and and almost entirely of rock. Just above Tasra for some distance they have the appearance of having been cut to a regular slope of 2 to 1. The high flood line is very distinctly marked about ¼-inch up the bank.

From Tasra to Raneegunge the slope of the bed is from 3½ to 4½ feet per mile, the banks are lower, very little rock appears in the bed; and the width between banks increases considerably.

From Raneegunge to opposite Burdwan the slope is about 2½ per mile; the bed is broad and sandy—the banks are low and alluvial. From Burdwan to Champadanga the fall is 1½ feet per mile; and from Champadanga to junction with Hooghly about half foot. From Amptah the Damooda becomes tidal.

From its rise to its junction with the Hooghly, the Damooda has altogether a course of 337 miles in length.

The principal tributaries of the Damooda are the Chundro or Gurhee, the Haharoo, the Suphee, the Koonare, the Jumoonah, the Gurgee, the Khatree, the Gowaie, the Burrakur, and the Singaron.

The whole area drained by the Damooda is about 7,600 square miles, of which 6,900 is drained just below its junction with the Burrakur. From Seilnah, or about 96 miles from its junction with the Hooghly, the river is embanked and receives little or no drainage.

In order to obtain some knowledge of the proportion of rain-fall which is drained by the river, and that which is lost by evaporation, absorption, &c., I propose making a comparison between the rain-fall of September 26th at Hazareebaugh, and the water that passed through the river at certain sections; the result will not of course be perfectly accurate, as I am dependent on the statements of the villagers for the duration of the floods; and the measure of the rain-fall is not, I think, as accurate as it might be on account of the rough instruments used in determining it.

The discharge too, is not perfectly accurate, as it has been calculated from the dry weather section of the river; there is a great deal of sand in the bed of the river now which could not possibly have existed when the river was in flood, so that the depth, and consequently the discharge, is less as here shown than it must actually have been. There is, however, to a certain extent a set-off against this error, as it is more than probable that

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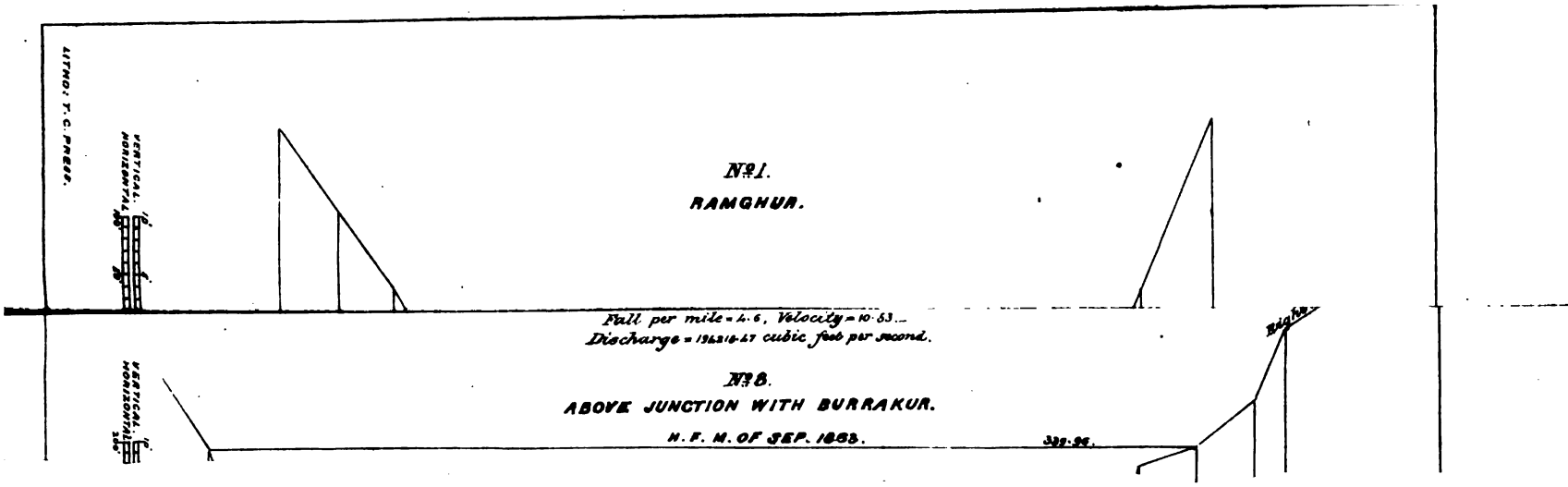

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before the flood came down, there was some water in the river, of which I have taken no account.

The sections which are, I think, most to be relied upon, are Nos. 1, 4, and 8, viz., those at Ramghur, west of Gurgee Nuddee, and above the junction with the Burrakur. At the latter, the flood limit was marked by Mr. Powell himself, and the two former sections were taken at the crossings of the Hazareebaugh and Ranchee, and Govindpoor and Ranchee roads, respectively, where the heights of flood were well known. I shall use these three sections therefore in comparing the proportion of rain-fall drained by the river.

At Ramghur the discharge per second was 102,239·73, and the flood is said to have lasted two and a half days; the whole amount of water, therefore, that passed through the river was 22,083,781,680, which is about $7\frac{1}{2}$ inches of rain over the area drained, viz., 1,000 square miles.

At the section west of Gurgee Nuddee the discharge was 194,218·47 per second; the flood lasted three days, and the water that passed through the river was 50,341,427,424 cubic feet, which is equivalent to 7·2 inches of rain over the area drained through that section, viz., 3,000 square miles.

At the section above the junction with the Burrakur, the discharge was 284,388·7 cubic feet per second; the flood is said to have lasted three days; the water that passed through the river was 73,713,551,040 cubic feet, which is equivalent to 7·5 inches over area drained, viz., 4,200 square miles.

The rain-fall that caused the flood under consideration was 13 inches, and from the above calculations we find that 7·5 of this were drained by the river; the remainder being lost in evaporation, absorption, tanks, &c., $7\frac{4}{13}$ or $\frac{2}{3}$rds say, is the proportion of rain falling on the catchment basin which passes through the river, and this is the proportion which the reservoirs must be capable of holding, whether they are constructed to shut off a weekly, monthly, or yearly rain-fall.

As the first object of the reservoirs is to save the country below from inundations which only occur three or four times a year after an unusually heavy shower of rain on the catchment basin, it will be sufficient to construct them capable of holding the greatest monthly fall: the floods run off so rapidly that ample opportunities would be afforded of emptying the reservoirs when the river is low, and so keeping them ready for receiving the next heavy shower; the last month's rain of the season might be retained in the reservoirs, either for the purposes of irrigation or for feeding canals.

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In Appendix B., I have entered all the inundating floods that have occurred during the last five years, as shown by the Edilpoor gauge; when the flood rises up to 10 feet on this gauge, it tops the right bank. From the time that elapses between two consecutive floods, it will be at once seen with what facility the reservoirs might be emptied.

In Appendix A., the rain-fall for each month, during the last five years, is recorded; the maximum in any month is 31·13; the reservoirs must be capable of holding two-thirds of this, or 21 inches over the whole area whose waters they receive.

The most suitable sites for reservoirs which I had time to examine are on the Gurhee, Haharoo, Konare, and Bokaro Nuddees. In speaking of these streams, I shall use the names given on the Revenue Survey Map, although they alter their names in each village through which they run.

The Gurhee is formed by two or three small streams which rise in the Kasiatoo and Joradug Hills; the last it receives is the Choondroo just above the town of Tendwa. In the mouth of the Choondroo there is an extraordinary natural bar of rock, through a fissure in which, the stream runs. Opposite Tendwa the Gurhee is about 5 chains broad and has very high sloping banks. About 5 miles below Tendwa, it runs between the Niree and Chiloomaree Hills, whose summits are less than a mile apart; the dam for the reservoir might be constructed in a line between the villages of Utratoo and Chiloomaree.

The drainage of 185 square miles passes through the Gurhee, so that the reservoir would be required to contain (supposing as I have said before that it is to hold the available maximum monthly rain-fall) 7,736,256,000 cubic feet, and it would cover an area of 6 square miles, and be on an average 48 feet deep; the valley through which the stream runs below Tendwa, and before it enters the gorge between the hills, is more than a mile broad and deep, so that there would be ample space for this water, the stream itself too would be ponded up for 3 or 4 miles. The valley is principally grown over with short scrubby jungle, and the only villages that would be destroyed merely consist of a few Sonthal huts.

The Haharoo, which is the site of the next reservoir, is formed of the Sikree, Gulgullea, Bukwa, and Badmahee streams, all of which rise in the Hazareebaugh plateau: the Haharoo runs close under the Mondee Hill, and then passes through a gorge about half a mile wide between the Acharoo and Angoo Hills—the former being as it were a continuation of the

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Mondee Hill; this would be a suitable site for the dam. The Acharoo and Angoo Hills are almost perpendicular for three-fourths of their height from the top, and then they slope gradually to the banks of the Haharoo, which are very steep, and about 20 feet above the bed.

About 250 square miles of drainage passes by the Haharoo to the Damooda, so that the reservoir would have to contain about 10,000,000,000 cubic feet of water, and cover an area of 7 square miles, with an average depth of about 53 feet; the valley above the dam, and the beds of the streams themselves would, I think, give us this area, but apart from this it would be quite possible to relieve the large reservoir by forming small ones on each branch of the stream before they unite. I went up the Badmahee to its source, and saw two or three such sites where a dam of 100 feet long only would be required. The smaller reservoirs would be more advantageous for irrigation, being situated higher up the valley, but it is just probable that the cost of three or four small dams, and one moderately sized one would exceed the cost of the large dam in the Haharoo itself.

By the Gurhee and Haharoo reservoirs the discharge of the Damooda at Ramghur would be reduced by about one-third.

The third reservoir would be formed by the Bokaro, which rises south of the Hazareebaugh plateau, flows easterly through the Lugie and Jollinga Hills, and joins the Konare about 4 miles west of the junction of the latter with the Damooda. A very suitable site for a dam would be about 2 miles east of Lalghur, where the gorge between the Lugie and Jelinga Hills is not more than 1,000 feet broad. The Bokaro drains 225 square miles, the reservoir would have to contain 9,400,000,000, cubic feet of water, and would cover an area of 7 square miles to a depth of 48 feet. Before passing between the Lugie and Jelinga Hills south of Leyo, the valley is very broad, and there would be no difficulty in storing this water: the villages on the banks of the stream where it enters the gorge, such as Lalghur, Dhundunya, &c., would be destroyed, but although they appear to be large villages from the map, they consist of two or three Sonthal huts only; the valley is of jungle, which is very dense between the hills.

The fourth reservoir would be on the Konare: the denseness of the jungle, and my sudden re-call to Burdwan pervented my making as complete an examination of the site for the dam as I could have wished, and as I made at the other sites; but a dam might be constructed between the Pureary Hill, which is a continuation of the Jelinga, and a ridge to the

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north of the Konare which runs along the left bank of Konare and Damooda. The Konare carries the drainage of 550 square miles of country; it would be necessary to store 20,000,000,000 cubic feet of water; this might be retained in two or three reservoirs one at the site above described and others higher up the stream.

With these four reservoirs the discharge of the Damooda just above its junction with the Burrakur, would be diminished by two-sevenths of the present discharge per second.

I have marked on the map the sites of the dams and the probable area and position that the water would occupy. I am unable to give approximately the cost of constructing the reservoir dams, but the sites are so favorable, and good stone for building so easily obtained at each site, that I would recommend the necessary sections being taken, so that estimates might be framed for two of the dams at least, and from these some idea might be obtained of the probable cost of the whole projects: the sites which would offer least obstacles for surveying and levelling would be the two westernmost reservoirs, viz., those on the Gurhee and Haharoo: the levels for these would probably occupy a good surveyor about six weeks.

The reservoirs that I have already described would not, of course, be sufficient to save the country south of Burdwan wholly from inundation but they would of themselves lower the flood level at Edilpoor by more than a foot, and of the 30 inundating floods that have occurred in the last five years, 15 would have passed innocuously down through the bed of the river and the danger caused by the remainder would have been greatly alleviated, probably sufficiently so to have allowed the villagers to stay in their huts, instead of living for two or three days in trees as they were compelled to do during the flood of September 1863.

The system of reservoirs is not unknown to the natives of the district, as on the road from Tendwa to Hazareebaugh, just below the Doongree Ghât, I saw a dam, which a Zemindar has constructed for irrigation, across the Dinia Nudee, where it issues from the hills. The dam is strongly built of stone and brick about 100 feet long, and 30 feet broad at top: there was, when I went over it on 19th March, a head of 6 feet of water on the upper side.

In the Maunbhoom District, on the left bank especially, there are numerous small streams (locally called "jhoors") which rise a little south of the

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Grand Trunk Road, and run due south to the Damooda, carrying the drainage of about 10 or 12 square miles. These could all be very easily and cheaply dammed before they empty themselves into the river: the water thus retained, while causing a diminution in the discharge of the river, would be very beneficial to the country for dry weather crops; the ryots when spoken to on the subject readily admitted the advantage, but the universal question was, who is to pay for the dam? Until the ryots, instead of being possessors, are simply cultivators of the land, such improvement by private individuals must not, I suppose, be expected. Of some of the larger of these streams which could be most easily dammed for reservoirs, I may mention the Gheejhoor, Kalajhoor, and Kaseajhoor.

After my survey during the ensuing cold weather, I feel sanguine of being able to point out more sites equally favorable both on the Damooda and Burrakur, which will enable us entirely to control the floods in the river, and at the same time afford means of irrigation to a country which is at present uncultivated for want of water. Now, that the tea producing capabilities of the Hazareebaugh District have been established the land bordering on these mountain-locked lakes will become very valuable, and the proceeds of the sale of the water for irrigation will go far towards covering the expense of the dams.

H. W. G.

Memo. by Lieut.-Col. Short, R.E. *Superintending Engineer.*

If the freshes in the Damooda only had to be dealt with, there would be no doubt as to the advisability of forming these reservoirs; more especially as several other, though smaller, sites could be found on a more thorough examination of the country, but the point is, to what extent the formation of these would affect the level of the combined flood of the Damooda and its tributary—the Burrakur, at Edlepoor, near Burdwan.

Lieutenant Garnault states that the flood level at Edlepoor, near Burdwan, would be lowered more than a foot, and he shows, that of the 30 inundating floods which have occurred during the last five years, 15 would have passed innocuously by this decrease of one foot in level, and of course the remainder would have been alleviated.

This testimony to the misery endured during seasons of excessive flood by a population scattered over such an extensive area, shows the absolute

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necessity of endeavoring to alleviate their sufferings which are intensified by the uncertainty as to the course the spill-flood may take. The country bordering the right bank may be said to be undulating—the villages being situated on the high ridges—the flood passing through the intermediate valleys. The fluctuation in the volume of spill escaping through these numerous hollows is remarkable—in one season the waters flowing at one locality 500 feet broad and 6 feet or more deep—and as they fall filling the low level with sandy deposit; the next year's flood forsaking the passage and creating a similar escape above or below. These vagaries of an uncontrolled flood threatening one village this, and an other the following, year, naturally serve to keep the population scattered over the inundated area in a state of panic.

As each case of danger to a village community is taken up on its special merits by the Government in a humane and liberal spirit, and orders are given to protect the locality by embanking against direct spill, the natural consequence is, that the flood is thrown the next season in excess on the villages above or below, and these in their turn claim equal consideration; and if similar action continues to be taken, the free spill ordered to be provided over a certain length of the right bank will be gradually and almost imperceptibly interfered with; moreover, this system of detached embankments only forces the spill to pass with greater velocity through the intermediate escapes, thereby scouring the country, and forming numerous escape channels, all which cut up the bank and country, and tend to increase the panic in the interior.

It is true that the uncertainty to life and property is not great in the Burdwan district, as there are but 96 square miles inundated; but the spill soon passes into the Hooghly district, wherein 264 square miles are flooded, the level is much lower, and the inundation intensified by the freshes being held up on all occasions of simultaneous high springs.

It has been recorded by the late Superintendent of Embankments that the battle with the Damooda has been fought and won; but dealing with the question in all its bearings, and with greater opportunities afforded to judge of results, and above all, studying the interests of the Government and the country, I venture respectfully to differ, believing as I do, that the battle is an annual one, and that embanking continuously on the left bank and forcing the excess flood over the right, has produced the undermentioned results:—

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1st.—The embankment on the left bank is but very slightly tried, the flood rising thereon but a few feet.

2nd.—The absence of scour in the lower reaches has so deteriorated the channel, that the coal traffic has been closed; that is, whereas Amptah, situated about 40 miles above mouth of river, was the great coal depôt, it has been abandoned, as large boats could no longer navigate the river.

3rd.—The decreased scour in the channel along the portion where free spill has been provided has caused a deposit in the bed, which is being gradually raised in level.

4th.—Insecurity to villages owing to vagaries of an uncontrolled flood, which entails endless petitions and necessitates re-construction of detached embankments, which interfere materially with the full escape considered necessary.

5th.—The great and increasing danger to the country to the south of the Buxee Embankment (situated between the Damooda and Roopnarain rivers) owing to the spill-flood of the Damooda standing during an extraordinary season of flood at an average height of 11¾ feet on the section for a period of two and a half to three and half days until escape is found *viâ* the Roopnarain river—such a test being excessive.

6th.—The erosion that has taken place in the Roopnarain river below the head of the Buxee Khall, and which may be expected to continue, owing to the action of the excess volume now gorging the Roopnarain channel, has demanded retired lines, and now a further considerable retirement is necessitated, all which remedial measures entail outlay and loss of property.

7th.—There is always the probability of the floods opening out on the right bank a channel similar to that at Kistopoor or Sreekistopoor (both closed at considerable expense), and escaping in volume southwards, when the consequences would be serious.

8th.—In proportion to the deterioration of the channel of the Damooda to the south within tidal influence, will be the decrease of volume passing up, and therefore a consequent loss of the power exercised by each ebb in scouring out the Hooghly at a most important point; and as the efficiency of a tidal channel is doubtless maintained by the volume ebbing in the channel itself and in the several tributaries, the deposit of sand at the mouth of the Damooda will yearly gradually increase to the detriment of the Hooghly.

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9th—The deterioration of the channel of the Damooda below Raneegunge and the difficulties in its navigation are yearly increasing, as experienced by the Coal Companies, and as the rail cannot compensate for this, the prosperity of the Coal Companies is affected.

10th.—Ten years ago since, the mouth of the Roopnarain, or rather the narrow clay-bound neck, was some 2,500 feet only broad between the embankments and 2,500 long, and the section has been slowly but imperceptibly enlarging, entailing retired lines. Any disproportionate enlargement of this neck would be a most serious matter, for being in direct continuation of the Diamond Harbour Reach, the tides would pass in excess up the Roopnarain to the detriment of the Hooghly Channel; and as the volume at ebb in the former would be in excess, that in the latter would be held back, thereby increasing the tendency to the formation of shoals from deposit.

I venture to point out the difficulties to be contended against, because I am convinced that the whole would be overcome could the excess flood be stored in reservoirs. I would, therefore, strongly recommend that some one specially adapted for such work be appointed to visit the country immediately after the flood season of 1865-66; for if sites are available, the operations can be supervised more readily than in the Damooda, and the works maintained at a less cost, as labor is more abundant in this line of country; and this is urged, as the difficulties and expense that would attend the formation and maintenance of the reservoirs on the Damooda would, from the nature of the localities, be very expensive, and if sites are found on the tributaries of the Burrakur, the immediate results would be more beneficial.

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No. CLXIII.

NOTES ON THE SLIDE RULE.

By Captain W. H. Mackesy, *Executive Engineer.*

The Slide Rule is so little known to the Officers and Subordinates of the Public Works Department, that a few remarks showing the manner in which it can be used to facilitate calculations, and solve at sight many problems of constant occurrence in estimates, &c., may prove useful. It would be difficult to exaggerate the great saving of time, in working out detailed measurements, striking rates, calculating strains, determining the strength of beams, &c., &c., which results from its use. It must, at the same time, be clearly understood that its answers are only approximate; though the error never exceeds $\frac{1}{500}$th, and will in most cases be less than this.

The Slide Rule is usually constructed of box-wood; is 12 inches long, and has a groove $\frac{3}{8}$-inch broad on its face, in which a slip of brass or box-wood slides freely, the face of the slide being flush with the face of the rule. Above and below the slide, there are two scales, marked A and D; and on the slide itself two scales, B and C. A, B and C are precisely alike, but the divisions on D are twice as large as those on A, B and C. D is termed a line of single radius; A, B and C, lines of double radii.

These scales are logarithmic scales; that is to say, the space from 1 on the left of one of the scales to any division, is proportional to the logarithm of that division—thus, if the distance from 1 to 1 (or 10) be taken = unity

The distance from 1 to 2 = ·301 or log of 2
„ „ 1 to 3 = ·477 „ 3
„ „ 1 to 7·4 = ·869 „ 7·4

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and so on. Since, therefore, multiplication or division by logarithms is performed by adding or subtracting the logarithm of the numbers, it is evident that the above described arrangement of the scales on the Slide Rule enables us to perform multiplication or division by simple inspection.

Thus, place 1 on the slide against 2 on the rule, and against 3 on the slide, will be seen 6 on the rule; or the product of 2 and 3. We have, in fact, added the space representing the log of 3 to the space representing the log of 2, and have thus obtained a space = ·301 + ·477 = ·778 = log of 6; and according to the principles upon which the scale is graduated, this space is marked 6.

Similarly, any two numbers whatever can be multiplied together. Division is performed by reversing this process; the divisor is subtracted from the dividend by placing the divisor on the slide against the dividend on the stock; and against 1 on the slide is found the quotient. Thus place 3 on B against 6 on A; and against 1 on B will be found the quotient 2 on A.

Any two numbers can be multiplied together and divided by a third, by combining these operations—thus, $\frac{2 \times 3}{4} = x = \left(\frac{2}{4}\right) \times 3$; or, by logs. Log x = log 3 − (log 4 − log 2). This is effected on the Slide Rule, by subtracting the difference between the spaces representing the logs of 4 and 2 from the space representing the log of 3. Thus, place 4 on B against 3 on A; and against 2 on B will be found 1·5 on A, = x.

It is the same thing to put 4 on B against 2 on A; for against 3 on B will be found 1·5 on A. This is evident, for $\frac{2 \times 3}{4} = x$, may be written either $\frac{2}{4} \times 3 = x$, or $\frac{3}{4} \times 2 = x$.

The spaces on D being double the spaces on A, B and C, are equal to the logarithm of the squares of the numbers on A, B and C; and if C be shut in even with D, the number on C will be found to be the squares of the numbers below them on D.

The proportions on the slide rule are as follows:—Set the slide at random—

$$\begin{cases} \begin{array}{cccc} \text{A} & a & c & e \\ \text{B} & b & d & f \end{array} \\ \begin{array}{ccccc} \text{C} & & g & & k \\ \text{D} & & h & & l \end{array} \end{cases}$$

ab, *cd*, *ef*, *gh*, *kl*, being any pairs of numbers standing against each other on the instrument—

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Then $\frac{a}{b} = \frac{c}{d} = \frac{e}{f} = \frac{k^2}{g} = \frac{l^2}{k}$; also $\frac{k}{\sqrt{g}} = \frac{l}{\sqrt{k}}$

For example, set 2 on B against 3 on A—

Then $\frac{3}{2} = \frac{4{\cdot}5}{3} = \frac{7{\cdot}5}{5} = \frac{3^2}{6} = \frac{6^2}{24}$

Also, 16 set on C against 2 on D, then $\frac{\sqrt{16}}{2} = \frac{\sqrt{36}}{3} = \frac{\sqrt{64}}{4} = \frac{\sqrt{81}}{4{\cdot}5}$

If the slide be taken out and inverted—

$$\left\{\begin{array}{cccc} \text{A} & a & c & e \\ \hline \text{C} & b & d & f \\ \text{B} & & g & k \\ \hline \text{D} & & k & l \end{array}\right.$$

ab, *cd*, *ef*, *gh*, *kl*, being any pairs of numbers standing against each other on the instrument.

Then $a \times b = c \times d = e \times f = g \times k^2 = k \times l^2$.

Also $\sqrt{g} \times k = \sqrt{k} \times l$.

For example, invert the slide and set 2 on C against 6 on A.

Then $8 \times 1{\cdot}5 = 6 \times 2 = 4 \times 3 = 12 \times 1 = 4^2 \times {\cdot}75 = 2^2 \times 3$.

Also set 81 on C against 1 on D, then $\sqrt{81} \times 1 = \sqrt{64} \times 1{\cdot}125 = \sqrt{16} \times 2{\cdot}25$.

When a question is in the form $x = \frac{ad}{b}$, or $b : a :: d : x$, all the terms being constant, or either a or d varying, the slide is not inverted; if, however, b varies, the slide should be inverted. a and d are placed in contact, and against the variable number b will be found the variable answer x.

An example of each case follows.

I. If 3,575 cubic feet of earthwork cost Rs. 15, what is the rate per 1,000 cubic feet?

$$\begin{array}{lll} \text{A} & 4{\cdot}2 = 4\text{-}3\text{-}2 & 15 \text{ rupees} \\ \hline \text{B} & 1000 \text{ c. ft.} & 3575 \text{ c. ft.} \end{array} \quad 4{\cdot}2 = \frac{15 \times 1000}{3575}; \text{ or } 3575 : 1000 :: 15 : 4{\cdot}2.$$

In this case all terms of the proportion are constant.

II. If the area of a circle, 12 inches diameter is ·7854 superficial feet; find the area of a circle n inches diameter?

$$\begin{array}{llllll} \text{C} & {\cdot}7854 & 1{\cdot}23 & 1{\cdot}77 & 4{\cdot}91 & \\ \hline \text{D} & 12 \text{ in.} & 15 \text{ in.} & 18 \text{ in.} & 30 \text{ in.} & . \end{array} \quad \text{Area, sq. ft.} = \frac{n^2 \times {\cdot}7854}{12^2}$$

$12^2 : n^2 :: {\cdot}7854 :$ area square feet.

or $12^2 : {\cdot}7854 :: n^2 :$,,

In this case one of the middle terms is variable, and is used to point out the answer.

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III. If a railway train goes a quarter of a mile in n seconds; what is its rate in miles per hour?

A	3600 sec.	60 m.	45 m.	36 m.	30 m.
C	·25 mile	15 sec.	20 sec.	25 sec.	30

n'' : $3600''$: : ·25 : rate in miles per hour.

$$\text{Rate in miles per hour} = \frac{3600'' \times \cdot 25}{n''}$$

In this case the divisor, or the first term of the proportion varies, and by inversion of the slide is used to point out the answer.

Some little difficulty is sometimes found by beginners in reading the slide, particularly between 1 and 2. Taking line A, and commencing from 1 on the left (which may be called ·01, ·1, 1, 10, 100, and so on), the readings are as follows:—Calling 1 on the left unity, we read—1·00, 1·02, 1·04, 1·06, 1·08, 1·10; then (missing the short division) 1·2, 1·3, 1·4, 1·5, 1·6, 1·7, 1·8, 1·9, 2·0, then (reading only the numbered divisions) 3·0, 4·0, 5·0, 6·0, 7·0, 8·0, 9·0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

And on D, calling 1 on the left unity, we have 1·01, 1·02, 1·03, 1·04, 1·05, 1·06, 1·07, 1·08, 1·09, 1·1, then 1·2, 1·3, 1·4, 1·5, 1·6, 1·7, 1·8, 1·9, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Should any difficulty be found in learning to read the rule, it is best overcome by setting the slide at random, and reading the numbers against each other; it will be at once seen whether the readings are correct or not as they should form equal fractions. Thus, set 2 against 21; against 1 will be found 10·5; against 12, 126—then $\frac{10\cdot5}{1} = \frac{21}{2} = \frac{126}{12}$, and so on, showing that the readings are correct.

The following formulæ will be found useful in the current work of the Department.

I. To find the contents of a log of timber by the customary rule (content = length × mean quarter girth squared). Take the length of the log in feet, and its mean girth in inches; the content is found as follows:—

C	length in feet.	content in cub. feet (answer)
D	48	girth in inches

G. P.

Example.—A log measures 27′ 6″ long, and 59″ mean girth; what number of cubic feet does it contain?

C	27·5	41·6 cubic feet
D	48	59

G. P.

Answer, 41·6 cubic feet.

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II. To find the contents of timber scantlings, length being given in feet, and breadth and depth in inches. $b \times d$ must be found either mentally or by the slide rule.

$$\begin{cases} \text{A} & b \times d & \text{content cubic feet} \\ \text{B} & 144 & \text{length in feet} \\ & \text{Divisor} & \end{cases}$$

Example.—A beam measures 17′ 9″ × 5½″ × 9″; what is its content?

$$5\tfrac{1}{2}'' \times 9'' = 49{\cdot}5$$

$$\begin{cases} \text{A} & 49{\cdot}5 & 5{\cdot}75 \\ \text{B} & 144 & 17{\cdot}75 \\ & \text{Divisor} & \end{cases}$$ Answer, 5·75 cubic feet.

Should the beam be square, the rule is as follows :—

$$\begin{cases} \text{A} & \text{content cubic feet} \\ \text{B} & \text{length in feet} \\ \text{C} & 144 \\ \text{D} & b \end{cases} \quad \text{or} \quad \begin{cases} \text{C} & \text{length in feet} & \text{Content cubic feet} \\ \text{D} & 12 & b \\ & \text{G. P.} & \end{cases}.$$

Example.—A beam measures 15′ × 5″ × 5″; what is its content?

$$\begin{cases} \text{A} & 2{\cdot}6 \text{ cubic feet} \\ \text{B} & 15 \\ \text{C} & 144 = \text{Divisor} \\ \text{D} & 5 \end{cases}$$ Answer, 2·6 cubic feet.

III. To find the weight in maunds of rectangular bar-iron. Multiply the width by the thickness (both in eighths of inches), then—

$$\begin{cases} \text{A} & & b \times d \text{ (eighths of an inch)} \\ \text{B} & & \text{maunds.} \\ \text{C} & \text{length in feet.} & \text{maunds.} \\ \text{D} & 1253 & \text{square side or mean square} \\ & \text{G. P.} & \text{in eighths of an inch.} \end{cases}$$

Example.—What is the weight of a quantity of bar-iron 2¼″ × ⅜″, aggregating 79 running feet long?

$$\text{Section} = 18 \times 3 = 54.$$

$$\begin{cases} \text{A} & 54 \\ \text{B} & 2{\cdot}73 \text{ maunds} \\ \text{C} & 79 \text{ feet} \\ \text{D} & 1253 = \text{G. P.} \end{cases}$$ Answer, 2·73 mds., or 2 md. 29 srs. 4 chs.

The seers and chittacks are found as follows :—

$$\begin{cases} \text{A} & {\cdot}73 & 29{\cdot}25 \text{ seers} \\ \text{B} & 1 & 40 \end{cases}$$

and again,

$$\begin{cases} \text{A} & {\cdot}25 & 4 \text{ chittacks} \\ \text{B} & 1 & 16 \end{cases}$$

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Example.—What does 107 running feet of $\frac{3}{4}$-inch square bar-iron weigh?

$\frac{3}{4}$-inch = $\frac{1}{4}$-inch.

C	107	2·45 maunds	
D	1253	6	Answer, 2·45 maunds.
	G. P.		

IV. In round bar-iron the constant or G. P. (gauge point) is 1415.

Example.—What does 305 cubic feet of $\frac{1}{2}$-inch rod-iron weigh?

$\frac{1}{2}$-inch = $\frac{1}{4}$-inch.

C	305	2·45 maunds	
D	1415	4	Answer, 2·45 maunds.
	G. P.		

Note.—The above constants are calculated on the supposition that a cubic inch of bar-iron weighs ·2754 lbs., and that there are 82·286 pounds in a maund.

For other metals, multiply the constants by—

$$\sqrt{\frac{481}{\text{Weight in lbs. of 1 cubic foot of the metal}}}\ ;\ \text{or}\ \sqrt{\frac{\text{Sp. grav. of iron}}{\text{Sp. grav. of metal}}}$$

This can be done by the slide.

V.

C	481	weight of cubic foot (in pounds) of metal	; or	C	7·7 = spec. grav. of iron.	spec. grav. of metal.
D	constant for metal.	constant or G. P. for iron.		D	G. P. for metal.	G. P. for iron

Example.—Weight of 1 cubic foot of bar copper is about 560 lbs.; find a new G. P. for rectangular bar copper.

C	481	560	; or	C	7·7	8·96
D	1164	1253		D	1162	1253
	G. P.				G. P.	

Example.—What is the weight of a bar of copper 25 feet long, and 1 inch square.

C	25	1·182 maunds	
D	1164	8	Answer, 1·182 maunds.
	G. P.		

In this example it will be observed that on setting 25 against 1164, the slide is outside 8, so that no answer is obtainable; it is, therefore, necessary to shift the slide one radius; this is done by shifting the slide until the same number is over 10 on the *right* of D, that was over 1 on the *left* of D before making the shift. In the present case the number over 1 is 1846 on

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the first radius; shift the slide until 1846 on the second radius is over 10, the answer can then be read over 8, *i. e.*, 1·182.

VI. Given the cost of any metal in shillings per cwt.; find cost in rupees per maund.

A	·3673	multiplier	rupees per maund
B	1		shillings per cwt., or pounds per ton.

Example.—The last London price current for the following metals quotes following rates per ton. Give the equivalent rates per maund in rupees.

		R.	A.	P.
Copper, sheet, £91, - - -	= rupees per maund,	33	8	0
Staffordshire bar-iron, £8 15*s.*, -	= „	3	3	6
Swedish ditto, £11 15*s.*, -	= „	4	4	6
White Lead, £32, -	= „	11	12	4

VII. Given the uniform load on a beam of timber; to determine its scantling, so that it shall not deflect more than $\frac{1}{40}$-inch per foot of span.

From the formula $E = \frac{5}{8} \frac{l^3 W}{bd^3 \delta}$, putting $d = rh$ we obtain the formulæ—

$$b = B \sqrt[4]{W l^3}, \text{ and } d = D \sqrt[4]{W l^3}.$$

$$\text{where } B = \sqrt[4]{\frac{1}{r^3} \times \frac{25}{E}}, \text{ and } D = \sqrt[4]{r \times \frac{25}{E}}.$$

Some of the values of B and D for sál are given in following table, taking value of E for sál at 4209.

Wood.	E.	$\sqrt[4]{\frac{25}{E}}$	Values of r.				
			1 : 1	$\sqrt{2}$: 1	3 : 2	5 : 3	2 : 1
Values of $\sqrt[4]{\frac{1}{r^3}}$.			1	·7712	·7378	·6817	·5946
Values of $\sqrt[4]{r}$.			1	1·092	1·107	1·136	1·1992
Sál, ... B	4209	·2776	·278	·214	·205	·189	·165
„ ... ... D			·278	·303	·307	·315	·330

An example will be given after VIII. Value of E was taken from Conductor Skinner's table, in the "Roorkee Treatise of Civil Engineering." If Rankine's formula be used, his value of E for sál, 2,420,000, will be

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found to give nearly the same results, the constant 2776 becoming ·2585. Rankine's formula for the deflection of a beam under an equally distributed load is $\delta = \frac{5}{4\,E} \times \frac{W\left(\frac{l}{2}\right)^3}{bd^3}$, all the dimensions being in inches.

VIII. To determine the scantling of a beam of timber to break with any fixed multiple of the uniformly distributed load.

If f be the co-efficient of safety, $W = \frac{bd^2}{l} \times \frac{2c}{f}$; and if $d = rb$, $b = B\sqrt[3]{Wl}$, and $d = D\sqrt[3]{Wl}$, when $B = \sqrt[3]{\frac{f}{2c}} \times \sqrt[3]{\frac{1}{r^2}}$, and $D = \sqrt[3]{\frac{f}{2c}} \times \sqrt[3]{r}$.

Some of the values of B and D for sál are given in the following table :—

Wood.	f	c	$\sqrt[3]{\frac{f}{2c}}$	Values of r.				
				1 : 1	$\sqrt{2}$: 1	3 : 2	5 : 3	2 : 1
Values of, ...			$\sqrt[3]{\frac{1}{r^2}}$	1	·7937	·7632	·7114	·6299
			$\sqrt[3]{r}$	1	1·122	1·145	1·186	1·2598
Sál, ... B	10	880	·1785	·179	·142	·136	·127	·112
„ ... ... D	„	„	„	·179	·200	·204	·213	·225
„ ... ... B	5	„	·1416	·142	·112	·108	·1005	·089
„ ... ... D	„	„	„	·142	·159	·162	·168	·177

Example.—A beam for a flat roof, span 19′ 6″, has to carry a uniformly distributed load of 4,500 pounds. What scantling should be given to it—1st, That it may not deflect more than $\frac{1}{480}$ of its length under the load; 2nd, That it may just break under 10 times its permanent load; and 3rd, That it may just break under 5 times its permanent load?

1*st*. b or d = (B or D) $\times \sqrt[4]{WL^3}$

a

A		$1{,}710{,}000 = WL^3$
B		$4{,}500 = W$
C	1	
D	$19{\cdot}5 = l$	

b

C	1	$1{,}710{,}000 = Wl^3$	$1{,}809 = \sqrt{Wl^3}$
D	1	$1{,}809 = \sqrt{Wl^3}$	$36{\cdot}28 = \sqrt[4]{Wl^3}$

$\sqrt[4]{Wl^3}$ is obtained by simple inspection, as shown in *b*.

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c

A	36·28	10·02	7·78	11	7·43	11·2	scantlings
B	1	278	·214	·303	·205	·307	multipliers
		1 : 1	$\sqrt{2}$: 1		3 : 2		

The scantlings of equal stiffness are given by inspection $10''{\cdot}02 \times 10''{\cdot}02$, or $7''{\cdot}78 \times 11''$, or $7''{\cdot}43 \times 11''{\cdot}2$, or $6''{\cdot}85 \times 11''{\cdot}44$, or $6'' \times 12''$.

2nd. b or $d = (B \times D) \times \sqrt[3]{WL}$

a

A	4,500 = W	87,750 = WL
B	1	19·5 = L

b

A		87·750 = WL	
B		44·4	
C	1	·032 = ·179²	squares of multipliers
D	44·4 $\sqrt[3]{WL}$	7·95 inches	scantlings

The first figure of the cube root of 87,750 is evidently 4, set 1 a little beyond 4 on D, and by successive trials, move the slide until the same number is under 1 or D; that is, under the cube whose root is required on A, this number will be the required cube root; *e. g.*, setting 1 on 43, it is seen that 47·5 is under 8775. Shifting 1 to 44, under 8775 is found 45·4, and at last, shifting 1 to 44·4, the same number is found under 8775; 44·4 is therefore the approximate root. If now the squares of the constants be taken on C; the scantlings will be found on D; or otherwise, set as in *d*, and the scantlings will be found by simple inspection.

d

A	44·4 = $\sqrt[3]{WL}$	7·95	6·31 × 8·9		6·04 × 9·05	
B	1	·179	·142	·200	·136	·204
			$\sqrt{2}$: 1		3 : 2	

5·64 × 9·45		4·97 × 10		scantlings
·127	·213	·112	·225	multipliers
5 : 3		2 : 1		

3rd. That the beam may just break under 5 times the permanent load. $\sqrt[3]{\frac{1}{2}WL}$ is found, as before, and the setting is

A	44·4		6·3	4·98 × 7·05		4·8 × 7·2	
B	1		·142	·112	·159	·108	·162
				$\sqrt{2}$: 1		3 : 2	

4·49 × 7·45		3·96 × 7·84		scantlings
·1005	·168	·089	·177	multipliers
5 : 3		2 : 1		

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Comparing the results the scantlings are as follows:—

	Inches.	Inches.	Inches.	Inches.	Inches.
For stiffness, ...	10 × 10	7½ × 11	7½ × 11½	6⅞ × 11½	6 × 12
Factor of safety, 10, for strength,	8 × 8	6⅝ × 9	6 × 9	5⅝ × 9½	5 × 10
Factor of safety, 5, ...	6⅜ × 6⅜	5 × 7	4⅞ × 7½	4½ × 7½	4 × 7½

E and c being known, multipliers may be calculated for any wood or any proportion of breadth to depth.

IX. To multiply three numbers together, set the reciprocal of one of the numbers on C against one of the remaining numbers on A, and against the third number on C, will be found the product.

Example.—What is the content of a wall, measuring 274′ × 2′ 6″ × 5′ 3″?

The reciprocal of 2′ 6″, or 2·5 is ·4.

A	274		3,600
B	·4		5·25

The slide gives the answer 3,600. The correct product (omitting fraction) is 3,596—error is $\frac{4}{3,596} = \frac{1}{899}$, say $\frac{1}{900}$.

This rule will often be found very useful in checking calculations.

X. On most slide rules, tables of *Gauge Points* and *Divisors*, will be found engraved. Their use and explanation is as follows:—In the formulæ, $x = \frac{a \times B}{C}$; $x = \frac{a \times b}{C}$; $x = \frac{a \times b}{\sqrt{C^3}}$; B and C being constants, B is termed a multiplier, C a *Divisor*, and $\sqrt{C}$ a *Gauge Point*, being the square root of the divisor, and used only on D.

In page 355, ·3673 is a multiplier.

In page 353, 144 is a divisor. Taking the second example, find the content of a beam 15′ long × 5″ × 5″, the rule might have been set

C	15 ft. long		2·6 cubic feet
D	12 = ($\sqrt{144}$)		5 inches

In this case 12 is a Gauge Point, being the only root of the divisor 144.

The divisors are usually engraved in a tabular form, as under—F, F, F, means all dimensions in feet; F, I, I, means two dimensions in inches; and I, I, I, means all dimensions in inches.

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Divisors.	Parallelopipeds.			Cylinders.		Spheres.	
	F, F, F.	F, I, I.	I, I, I.	F, I.	I, I.	F.	I.
Cubic feet, ...	100	144	1728	183	220	191	330
Gallons, ...	160	231	277	294	353	306	530
lbs. Wrought-iron, ...	205	296	355	377	452	392	678
lbs. Wrought-copper, ..	180	259	311	330	396	344	594

Example.—Find the weight of a sphere of copper, $6\frac{1}{2}$ inches in diameter.

A	594 divisor	
B	6·5	
C		46 lbs.
D	6·5	

Here $x = \frac{(6{\cdot}5)^3 \times 6{\cdot}5}{594}$.

Example.—Find the weight of a wrought-iron pillar, 11 feet long, $4\frac{1}{4}$ inches diameter.

A	377 divisor	
B	11 feet	
C		523 lbs.
D	$4\frac{1}{4}$ in. diameter	

Here $x = \frac{11 \times \overline{4{\cdot}25^2}}{377}$

How many gallons are there in a cistern, 7 feet long, 66 broad, and 31 inches deep.

By slide rule $66 \times 31 = 2046$, or $\sqrt{66 \times 31} = 45{\cdot}3$.

This last mean square is found thus—

C	31	66	
D	31	45·3 = mean square	

A	231 divisor		2046 = 66 × 31
B	7 feet		622 } gallons.
C			622 }
D			45·3 (mean square)

The foregoing examples and explanation will establish the utility of the slide rule. Those wishing to make themselves master of the instrument, should procure "Bayley's Hand-Book of the Slide Rule," price 6*s*., published by "Bell and Daldy," Fleet-Street. This work contains an immense number of useful formulæ, and a complete explanation of the instrument.

The best Slide Rule is made by Elliott, 449, Strand. He charges 14*s*. for the two slide rule, and 7*s*. for the single slide. The second slide

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of the two slide rule contains lines of sines and tangents; and all cases of right-angled and oblique plane triangles can be solved approximately by it at sight. The back of the slide has a line of sines to radius D on it (this is really useless, as it only serves the purpose of a table of natural sines. The short printed table in Molesworth (and other) Pocket-Books, is in every way superior to it), and an extra line of tangents above 45°: this line is also of very little use. It would be better to suppress these lines and substitute a line of 5th powers to be used with D. This line would be found useful in solving hydraulic problems.

On the back of the slide AB, there is a line marked *Num.*, which, shut in even with D, gives the logs of the number under it; it is quite useless, as logs can only be taken out to the third figure, that is only approximately. The short 4 figure table in Molesworth is far more useful in every way. There is also a line E, which, when shut in even with D, gives the cube of the number under it. This line also is of little use, as all questions regarding which can be solved by the lines D and C. It would be far better to omit these lines and substitute a double line D to unite with A and D; with such a line the first example in VIII. would be solved as follows, in two settings of the rule:—

a

A	4500 = W		1,710,000 = WL^2
D	1		19·5 = L
D			

b

A		WL^2 = 1,710,000				
D	1	19·5	278	214	803	multipliers
D	19·5 = $\sqrt[4]{WL^2}$		10·02	7·78 × 11		scantlings

Only the following cases can be solved with the lines ABCD; $x = \frac{a^2 b}{c^2}$ or $x = \frac{a \times b}{\sqrt{c}}$; it is evident, that *all* possible cases of square and square roots could be solved by the proposed lines ADD. Common Engineer's slide rules of box, with brass slides, can be obtained from Thompson & Co., Calcutta, for Rs. 3 or 4, the divisions are stamped and not cut. A superior kind can be got from Newman or Lepage for about Rs. 10. They are both in every way inferior to the regular box-wood slide rule with box-wood slide made by Elliott, as the brass slide invariably sticks in the hot weather, and is very liable to injury. A very superior instrument, called the "Engineer's Circular Slide Rule," can be obtained from Newman for about Rs. 20. It is a brass disk about 3½ inches diameter, with a white

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metal slide inlaid on its face. It is very correctly divided, and is very portable and convenient; the only objection to it is, that the slide cannot be inverted. No other pattern of slide rules are procurable in Calcutta.

The article, by Professor De Morgan, on the "Slide Rule" in the "English Cyclopædia," division Arts and Sciences, contains a great deal of information on the subject, and is well worth referring to. A quotation from this article will appropriately conclude these remarks.

"This instrument (*the slide rule*) has been greatly undervalued in our country, in which it was invented, and is very little known on the Continent; for though a French work on the subject, published in 1825, which is followed by the writer of a more recent mathematical dictionary in the same language, assures us that in England the sliding rule is taught at schools, at the same time with the letters of the alphabet; we believe it would be more correct to say, that nine Englishmen out of ten would not know what the instrument was for if they saw it, and that of those who even knew what it is for, not one in a hundred would be able to work a simple question by means of it. For a few shillings most persons might put into their pockets some hundred times as much power of calculation as they have in their heads, and the use of the instrument is attainable without any knowledge of the properties of logarithms, on which its principle depends."

9th August, 1867. W. H. M.

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No. CLXIV.

MILROY'S EXCAVATING APPARATUS.

(From "Engineering" of March 29th, 1867.)

The following description of an apparatus for sinking foundations in Sand is given as likely to be well adapted for many cases of Indian rivers :—

A railway bridge of some magnitude is now in course of erection at Glasgow for carrying the City of Glasgow Union Railways over the river Clyde. The bridge, which is on the wrought-iron lattice girder principle, will consist of five water spans, each 75 feet in the clear, and two land spans of 65 feet each. The girders will be 8 feet deep and the bridge will be laid with a double line of way. The girders will rest upon granite columns, and the abutments will be of masonry. The superstructure will be carried on cast-iron cylinders 8 feet 4 inches in diameter, some of which have already been sunk to a depth of 85 feet through the sand down to the solid rock which forms the bed of the river. When down to the necessary depth the cylinders are filled in with concrete to about the ground level; the water is then pumped out and brick-work is built up to high-water level, at which point the granite columns commence.

The process of sinking the cylinders has been shortened and the operation greatly facilitated by the adoption of an excavating apparatus, the invention of Mr. John Milroy. This apparatus is shown in [*Plate* LIV.], in which *Fig.* 1 represents a side elevation, partly in vertical section, of the principal part of the machine, which is termed the excavator; *Fig.* 2 being a plan view. A series of spades or digging and lifting blades, *a*, are hinged to an octagonal iron framework, *b*, into which they exactly fit when

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LITHO. F.G. PARSS.

MILROY'S. EXCAVATING APPARATUS.

Fig. 1.

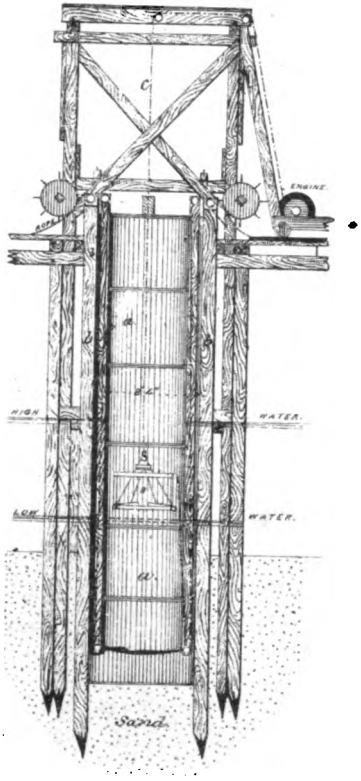
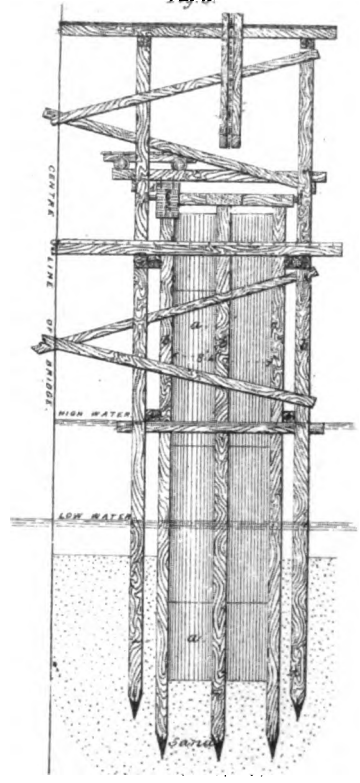


Fig. 3.



Scale, 16 feet = 1 inch.

Fig. 1. ELEVATION.

Half in Section, half complete.

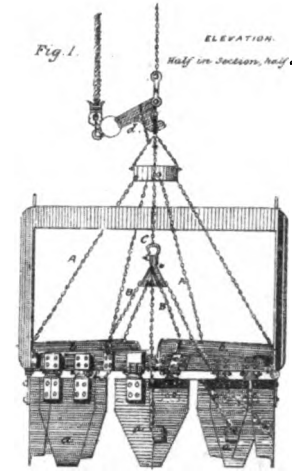
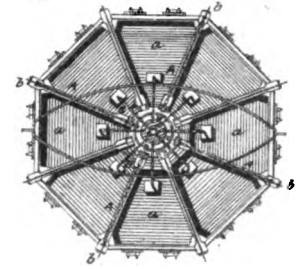


Fig. 2. PLAN.



Scale, 4 feet = 1 inch.

PLATE LIV.

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closed. The spades are hinged to the outer side or rim of the frame, and are formed with sides projecting inwards, which enable them to take better hold of the earth. When the apparatus is being lowered over the spot to be excavated the spades are open and hang in the position shown in *Fig.* 1. With the spades hanging thus the apparatus is lowered as far as it will go, and the spades having entered the soil are drawn inwards through the ground each into its own opening in the frame, bringing the earth with it. The frame and spades thus brought together form a close vessel, and in this condition the apparatus is drawn to surface, full of the soil. To prevent leakage and to make good joints, strips of India-rubber are attached to the underside of the inner octagonal portion of the framework and the T-iron arms connecting the inner and outer framing. Against this India-rubber, the edges of the spades press, and, when working in soft soils, leakage is thus prevented.

We now come to the working of this apparatus as carried out on the Clyde Bridge works, to illustrate which we have shown, at *Fig.* 3 in the *Plate*, a side-elevation of one of the cylinders now being sunk, and the necessary timber structure, and at *Fig.* 4, a vertical section through the centre of *Fig.* 3. The cylinders *a*, *a*, are 8 feet 4 inches in diameter, cast in 6 feet lengths, and are kept in position by four guide piles *b*, *b*. The outer piles are for carrying the platform, gantry, &c., in the usual manner. The main chain *c*, is worked by an engine placed as indicated in *Fig.* 4, which is employed to raise or lower the apparatus. The excavator is attached to this main chain by two sets of chains A and B, *Fig.* 1. The chains of set A, all of equal length, are each fixed to the outer frame of the excavator, and after uniting upon a ring are joined to the main chain a short distance above its junction with the other set of chains B, by a length of single chain *d*. When the apparatus is descending, this length of chain is looped up by the monkey hook. There are eight chains to set B, all of equal length, and attached at their upper ends to the main chain in the way we have shown. These last chains are for the purpose of pulling in the spades up to the frame with the soil which they drag with them, and for raising the apparatus bodily to the staging above. When lowering the excavator, the connecting chain *d*, of the outer set of chains A, is looped up by means of the monkey hook, the chains of set B, being thereby rendered quite slack—until the excavator reaches the bottom. The monkey hook is then thrown out of gear by means of the rope shown at *e*,

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which slackens the outer set of chains, and, upon the hoisting being commenced, the inner set of chains is brought into tension, the spades drawn in and the whole machine raised to surface.

In order to ensure the excavator being both kept and forced down at the moment when the spades are being drawn into their places in the frame, a very effective arrangement, shown in *Fig.* 4, is adopted. Two holding-down chains are fixed to opposite sides of the spade frame, and which pass under pulleys held down near the bottom of the excavation, and thence up to winding axles placed on the staging above. These winding axles are formed with enlarged drums, and also with handles for turning them by; and the holding-down chains are hauled up quickly by drawing ropes off the drums, on which they are re-wound by the operation of drawing up the excavator. The bottom pulleys for the holding-down chains are carried by timber spars or leaders, placed vertically, and which are held inside the cylinders. They are kept apart at their lower ends by a stout iron hoop, to the opposite sides of which the leaders are fixed, whilst their upper ends are made fast to the cylinder itself. As the excavation proceeds these leaders move downwards with the cylinders, being lengthened from above. The holding-down chains are hauled tight as the excavator descends, and when it has reached the ground surface, sufficient strain is put on them to force the spades into the earth, to keep the frame from rising whilst they are being drawn inwards, and to ensure their taking hold of the ground. As soon as the workmen feel that the spades are drawn close in, the holding-down chains are released and the excavator is raised up to be emptied. This is effected by running a lorry under the excavator and on which it rests; the outer set of chains A, are then hooked up, and the excavator being raised a little, the spades fall open and the soil is discharged into the lorry. Mr. Milroy's apparatus has been found to effect considerable economy in the Clyde Bridge works from the simple and expeditious manner in which it performs its duties. Mr. J. F. Blair, the engineer of the works, has expressed to us his high appreciation of this excavator, and his thorough satisfaction with the results of its working.

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No. CLXV.

GANGES CANAL WORK RATES.

By T. Login, *Esquire, C.E., late Superintendent, Northern Division, Ganges Canal.*

These rates were prepared at the request of Sir P. T. Cautley, while the works were in progress, but were kept back at the time as the Director was desirous to have the rates of Block sinking at Dhunowrie added to them. Press of work prevented this being done, and it is only now, when examining some old records, that these rates have turned up.

As they are obtained from *actual* measurements of large quantities of work, they may be considered of some value in showing what work a man can perform where task-work is introduced. Every evening the *moonshee* had to measure the work done, and report any deficiency, and at the same time the *mistrie* gave out the tasks for the following day.

If it was thought necessary, the workmen on the following morning were made aware that the full quantity of work was not done; and at the end of the month, the necessary deductions were made from their pay, while those who did good work were at the same time rewarded; the deductions being generally over one per cent. on the whole work done and the rewards a little under it.

Boulder Masonry of Puttree Works.—In forming the standard of mason's wages, two rates have been taken, viz., Rs. 8 per month and Rs. 4; the former for masons and the latter for beldar masons. The former had not only to work themselves, but also to superintend the work done by the beldar masons, a certain number being told off to each mason.

At first there were nearly as many masons as beldars; but the latter being picked men, soon became expert workmen, so that latterly only a few masons were employed in keeping the work in line and horizontal.

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As these mason beldars improved, their wages increased in due proportion, but in the rates, I have classed all masons by *trade* under the higher rate of pay, and the beldar masons under the lower.*

The advantage of having beldar masons was, that whenever a sufficient supply of boulders could not be had, they were employed in digging; and, also, we were in a manner independent of masons.

Average Cost of Men and Materials required for 100 *cubic feet of* BOULDER MASONRY.

Workmen.	Average number.	Amount of wages per mensem.	Cost.			Remarks.
		RS. A. P.	RS.	A.	P.	
Masons, ..	0·092	8 0 0	0	0	4·633	30½ days in the month.
Beldar masons, ..	1·365	4 0 0	0	2	10·371	
Beldars, ..	0·221	6 0 0	0	0	8·347	
Ditto, ..	6·631	4 0 0	0	13	10·971	
Total cost Labor, ..			1	1	10·322	

Description of materials.	Number or quantity.	Rate.	Cost.			Remarks.
		RS. A. P.	RS.	A.	P.	
Boulders, maunds, ...	102·984	4 0 0 per 100 mds.	4	1	10·917	100 cubic feet of boulders, when not less than one cubic foot each stone, equal 112 maunds, bazar weight, of 90 Rs. to the seer. If less than 1 foot, 110 maunds.
Broken bricks, cub. ft.,	27·870	900 0 0 per lakh.	0	0	4·159	
Lime, "	15·591	17 0 0 per 100 c. f.	2	10	4·890	
Soorkee, "	14·279	11 8 0 per 100 c. f.	0	10	3·280	
Sand, "	17·000	1 4 0 per 100 c. f.	0	3	4·800	
Lime sifting, "	2·229	6 0 0 per 100 c. f.	0	2	1·678	
Soorkee, "	3·541	8 0 0 per 100 c. f.	0	4	6·390	
Oil, chittacks,	0·0·277	5 0 0	0	0	0·415	
Twine, seers,	0·0·003	1 0 0	0	0	0·360	
Total cost Materials, ...			9	1	0·889	
Total cost for 100 cubic feet, ..:			10	2	11·211	

This rate is procured from 3,09,104 cubic feet of boulder masonry in the flooring and foundations of the Puttrie Superpassage, consisting of a large flat surface of about 80,000 square feet, the greatest thickness not exceed-

* In 1863, one of these beldar masons was still employed, and received Rs. 9 a month, he having become an expert mason.

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ing 4½ feet; all the work was executed from 16 to 21 feet below the natural spring level. The use of bheesties was not requisite, the greatest difficulty being to keep the foundations sufficiently dry during the progress of the work.

The rate of boulders is the price they cost, and not the office rate; so it shows what boulders can be carted for, at an average distance of six miles; and all the sand is charged at the rate it was carted, a distance of 1¼ miles, to the works; though a limited quantity was found 1,000 feet from the work, the cost of removing which is included in the labor. Particular care was also taken in having the sand *well washed*—which has also been charged on labor—those who were employed on this duty having also to mix the mortar. The broken bricks were used to fill up the spaces between the boulders, thereby getting rid of the broken bricks that were too hard for being pounded into soorkee, and saving a considerable quantity of mortar.

The rate of labor in a great measure depended on the distance the materials had to be carried. One month the average distance being 400 feet, the labor was Rs. 1-7-6 per 100 cubic feet; and another occasion the carters were able to bring the boulders to within 50 feet of where they were required, and the rate was only Rs. 0-12-7 per 100 cubic feet.

The mean distance for the whole work was 175 feet.

To prevent mistakes in the progress, the whole work done was measured up monthly, and the progress given in former months deducted from this total; thus, on the completion of the work to some certain height, the quantities done each month were added together, and had to agree with the total progress.

Rates obtained from the Masonry of the superstructure of a portion of the Puttrie works during November and December 1852, *and January, February, March, April and May* 1853.

LABOR.

Description.	Average number.	Wages per month.			Cost.			Remarks.
		RS.	A.	P.	RS.	A.	P.	
Masons, ...	3·442	8	0	0	0	14	5·3	30½ days in the month.
Bheesties, ...	0·325	4	8	0	0	0	9·8	
Beldars, ...	0·161	6	0	0	0	0	6·1	
Ditto, ...	4·838	4	0	0	0	10	1·8	
Total cost Labor, ...					1	9	11·0	

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MATERIALS.

Description of materials.	Average quantity.	Rate.	Cost. RS.	A.	P.	Remarks.
Bricks, ..	875·00	Rs. 1000 per lakh.	8	12	0	
Lime, cubic feet,	15·02	Rs. 18 per 100 c. f.	2	11	3·1	
Soorkee, ditto, ..	30·04	Rs. 11-8 per 100 c. f.	3	7	3·3	Bricks measured 12″ × 6″ × 2½″.
Oil, chittacks, ..	00·41	Rs. 5.	0	0	0·6	
Twine, seers, ..	00·05	Rs. 1.	0	0	0 6	
Total cost Materials, ...			14	8	6·4	
Total cost per 100 cubic feet, ..			16	8	6·4	

The above rate is got from a progress of 1,40,615 cubic feet of masonry of the superstructure of the Puttrie Superpassage and abutments; the piers being walls each 310 feet long by 4½ thick, the arch springing 12 feet above the flooring. The abutments were 6 feet thick. Particular care had to be taken that the surfaces were smooth and straight, as they had to be plastered* with plaster not exceeding ¼ of an inch at the thickest part, so that the outside bricks had their faces dressed, and all the bricks of the skew backs had also to be dressed.

The materials had to be brought from an average distance of nearly 200 feet, as it was impossible to cart the bricks nearer, on account of the extent of the work, covering 80,000 square feet in area; so as to not overcrowd the works, there being boulder masonry, plastering, excavation and piling, all carried on at the same time. The proportion of bricks in 100 cubic feet masonry when set, is 80·33, and of mortar 19·67 per cent., and the thickness of joints from ¼ to ⅛ of an inch; also a large proportion of the bricks were half bricks.

Rate obtained from the Masonry of the Puttrie Superpassage superstructure, built of English sized bricks, 10″ × 4½″ × 3″, during December 1852, January and February 1853.

LABOR.

Description.	Average number.	Rate per month. RS.	A.	P.	Cost. RS.	A.	P.	Remarks.
Masons, ...	3·121	8	0	0	0	13	1·1	
Bhecsties, ...	0·171	4	8	0	0	0	4·9	
Beldars, ...	0·163	6	0	0	0	0	6·1	
Ditto, ...	4·000	4	0	0	0	8	4·7	
Total cost Labor, ...					1	6	4·8	

* *See* Plaster rate.

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MATERIALS.

Description.	Average quantity.	Rate.	Cost. RS.	A.	P.	Remarks.
Bricks, 10-inch, ...	1·200	Rs. 729-2-8 per lakh.	8	12	0	
Lime, cubic feet,	14·081	Rs. 18-0-0 per 100 c. f.	2	8	6·6	
Soorkee, „ ...	28·161	Rs. 11-8-0 per 100 c. f.	3	3	9·8	
Oil, chittacks, ...	00·1·30	Rs. 5.	0	0	1·9	
Twine, seers, ...	0·00·114	Rs. 40.	0	0	1·4	
Total cost Materials, ...			14	8	7·7	
Total cost for 100 cubic feet, ...			15	15	0·5	

The above rate is got from 12,272 cubic feet of superstructure masonry of Puttrie works, built of 10-inch bricks, under the same circumstances as the former. Workmen not employed on Sundays, but receiving pay for that day.

Average of men and materials required for 100 *cubic feet of* BRICK-ON-EDGE MASONRY *of the flooring of the Puttrie Superpassage of* 12″ × 6″ × 2½″ *bricks.*

LABOR.

Description.	Average number.	Rate per month. RS.	A.	P.	Cost. RS.	A.	P.	Remarks.
Mason, ...	8·083	8	0	0	2	1	11·0	30½ days in the month. Average wages of masons, Rupees 7-3-2 per month.
Bheestie, ...	0·448	4	8	0	0	1	0·8	
Beldar, ...	0·214	6	0	0	0	0	8·1	
Ditto, ...	6·355	4	0	0	0	13	4·0	
Bullocks, each, ...	0·636	0	6	0	0	3	9·7	
Total cost Labor, ...					3	4	9·6	

MATERIALS.

Description.	Average quantity.	Rate.	Cost. RS.	A.	P.	Remarks.
Bricks 2½ inches,	875	Rs. 1000-0-0 lakh.	8	12	0	
Lime, cubic feet,	11·848	Rs. 18-0-0 per 100 c. f.	2	2	1·5	
Soorkee, „ ...	23·696	Rs. 11-8-0 per 100 c. f.	2	7	4·2	
Oil, chittacks, ...	0·0·8	Rs. 5.	0	0	1·2	
Twine, seers, ...	0·0·08	Rs. 1.	0	0	0·0	
Total cost Material, ..			13	6	2·3	
Total cost of 100 cubic feet, ..			16	10	11·9	

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The above rate is got from a progress 23,885 cubic feet, or 57,770 superficial feet of flooring of the Puttrie Superpassage; all the bricks were selected, and none but those of the best quality used; hence the extra labor in supplying the masons and dressing the bricks.*

Rates obtained from the PLASTERING *of the Puttrie Superpassage during the months of January, February and March*, 1853.

Description.	Average number.	Rate per month.	Cost.			Remarks.
		RS. A. P.				
Masons, ...	1·637	8 0 0	0	6	10·4	
Bheesties, ...	0·086	4 8 0	0	0	2·4	
Mates, ...	0·046	6 0 0	0	0	1·6	
Beldars, ...	1·378	4 0 0	0	2	10·6	
Total cost Labor, ...			0	10	1·0	

Description.	Average number.	Rate.	Cost.			Remarks.
		RS. A. P.	RS.	A.	P.	
Lime, cubic feet, ...	1	17 0 0 per 100 c. f.	0	2	8·64	
Soorkee, „ ...	2	11 8 0 per 100 c. f.	0	3	8·16	
Oil, chittacks, ...	0·165	5 0 0	0	0	3·75	
Total cost Materials, ...			0	6	8·55	
Total cost for 100 superficial feet, ...			1	0	9·55	

The progress for the above three months was 1,45,806·5 square feet of plaster. The brick-work being face dressed, the mortar was simply rubbed on the brick-work by beldars and polished up by masons. This work is to be seen on the interior of the lock chamber and the sides of piers.

EXCAVATION *by rail of Dhunowrie works by servant Beldars.—First case.*—Labor, @ 1-4-5 per 1,000 c. ft. by rail; ditto, @ 2-1-1 per 1,000 c. ft. in baskets.

* Six of the bays of the superpassage had the bricks for this brick-on-edge work, from native kilns

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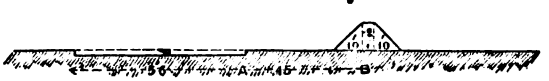
The rail is on a slope of 1 foot per 400. Four beldars to one wagon, whose duty is to load the wagon, carrying the earth an average distance of 50 feet, and to propel the wagon a distance of 900 feet, unload, and bring it back. The earth contains a large proportion of sand, and is easily dug. Keeping the line clear and oiling the wagons, &c., not included in the above rates.

In the *Second case* the beldars have to remove the earth brought by rail a distance of 250 feet, and at a height of 15 feet.

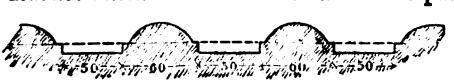
Cost of Excavating 1,000 *cubic feet of Earth by contract.*

Depth.	First.	Second.
	R. A. P.	R. A. P.
Not exceeding 5 feet, ...	1 4 6	..
„ „ 7½ feet,..	..	1 4 6

Puttree Bunds.—Work done by contract. In the 1*st* case the earth was taken from the Puttrie bunds, and a little care had to be taken in forming the slopes; but it was not required that they should be carefully dressed. All the measurments varied according to the height of bund, except breadth at top, and from A to B.



Rutmoo Inlet.—The 2*nd* case was three parallel cuts, for the new course of the Rutmoo, of 50 feet each, leaving spaces of 60 feet breath for the earth to be thrown on.



The excavation in both cases in ordinary soil.

at Ghur. The remaining two bays nearest the lock, down-stream, were of the best to be had from Sallamipoor, but which were inferior to those from Ghur. The grinding down of the brick-on-edge in these latter two bays is the greatest.

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PILE-DRIVING 15 *feet piles of* 5 *inches square*; *average cost of driving one pile.*

Description.	Average number.	Rate.	Cost.			Remarks.
		RS. A. P.	RS.	A.	P.	
Carpenters, ...	0·155	7 0 0	0	0	6·8	Labor for making tramways for pile engines, for each pile, rupees 0-0-2·88.
Smiths, ...	0·008	7 0 0	0	0	0·3	
Beldars, ...	0·050	6 0 0	0	0	1·9	
Ditto, ...	1·550	4 0 0	0	3	3·0	
Total cost Labor, ..			0	4	0	
15 feet piles, ...	1	1 0 0	1	0	0	
Iron ropes, oil, &c., &c., ..	0	0 0 0	0	0	4	
Total cost Materials, ..			1	0	4	
Total cost per pile driven, ...			1	4	4	

The rates are taken from one month's progress, during which 1,700 were driven.

A portion of the piles were driven by old engines at a rate of not less than 5 annas per pile, so that 4 annas is rather above what the rate should be with good working engines. The task with the new engines was 1 pile per beldar per day, or six per week. Smiths were employed in repairing rings for pile heads, &c., &c.

GRASSING *Puttrie Bunds. Progress in July* 1852.

100 feet distance.	6,24,790 superficial feet sirkundah, @	0	2	2	per 1,000.
50 „ „	3,58,900 „ doob, @ ..	0	10	1	„
Total Rupees, ..		310	8	3	

Progress in August 1852.

150 feet distance.	42,548 superficial feet sirkundah, @	0	3	8	„
50 „ „	6,21,804 „ doob, @ ..	0	7	11	„
Total Rupees, ..		316	0	0	

Grassing slope of mile 10; distance 300 feet. 14,145 superficial feet grassing with *doob*, @ 1-3-3 per 1000.

Navigable Canal slope.—Distance 400 feet. 3,634 superficial feet grassing with *doob*, @ 1-10-0 per 1000.

UMBALLAH,
10*th July*, 1867. } T. L.

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No. CLXVI.

THE HINDOSTAN AND THIBET ROAD.

By Archibald Cregeen, Esq., C.E., *Executive Engineer.*

In the year 1850, when the new Kalka and Simla road was commenced, Mr. (now Sir) H. Edwardes, the then Superintendent of Hill States, submitted to Government a project for developing our commercial relations with Central Asia by way of the Sutlej Valley. Major (now Colonel) Kennedy, then Military Secretary to his Excellency the Commander-in-Chief, proffered his services as temporary Superintendent of the Hill Roads. An examination of the country north of Simla was immediately commenced: Colonel Kennedy reserving to himself the examination of the hills between Simla and Nagkunda, while Lieutenant (now Major) Briggs was deputed to report upon the country between Nagkunda and Thibet. The result of their joint examinations was, that a mathematical line of road, with especial reference to levels, was practicable; but that the construction of it would necessitate an enormous outlay.

As far as Soongri, seven marches beyond Simla, the line of country selected for the road appears to have offered little difficulty in determining. Advantage was taken of the continuation of the Cis-Sutlej main axis of snow; which, dividing the two great mountain torrents, the Sutlej and the Pabur, terminates in the plains at Kalka. It will be easily imagined that a continuation of this range must consist of very irregular peaks and depressions, diminishing irregularly as the plains are approached. One of the chief objects in the prosecution of the work was to keep as near as possible on the line of watershed; but this could not be done without forsaking the principle

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laid down by Colonel Kennedy, viz., that the road should never rise or fall unnecessarily.

The original idea was to construct a road with a maximum gradient of 3 in 100, so as to be available at any future time for wheeled traffic. From Simla to Soongri, no bold features occurred (with the exception of the Sidhpùr cliffs) to interfere with the tracing of a line with a gradient of from 1 in 33 to 1 in 40. Beyond Soongri the main range had to be abandoned, for to follow it further only led to regions of snow; and it was now clear that the continuation of the road must conform, to a greater extent, to the contour of the spurs running out from the snowy range; while, at the same time, the intention of adhering to the watershed line would have to be abandoned.

Soongri ghât being a peculiarly obligatory point, Major Briggs endeavored to run a dead level line to the Nogrì river; but was met by cliffs of "adamantine granite," of 2 and 3,000 feet in depth. Failing in this he selected a site at an altitude to correspond with a site already fixed for the bridge across the Sutlej at Wangtù. This line necessitated the carrying of the road *viâ* Bàlì to the Nogrì river, for the last 7 miles of which it was to descend at a gradient of 1 in 33. From this point it was clearly Major Briggs' intention to run the road at a gradient of 1 in 35, so as to attain an altitude of about 6,000 feet,* whence, taking advantage of an easy line of country, he proposed to round the spur on which the city of Rampùr is built, but at an elevation of 3,000 feet superior to it; thence by a dead level line to the Syldung river, a distance of 25 miles, and finally by an easy descent to the Sutlej, a further distance of 8 miles, at a maximum gradient of 1 in 36.

Col. Kennedy's short but useful superintendence terminated between September and December 1850, and in the latter month Major Briggs assumed the direction. In the winter of 1851-52, the tunnel, 2½ miles north of Simla, 560 feet in length, along with several miles of road, was completed. This tunnel was driven through the solid rock, and was constructed almost entirely by prisoners, the night coolies only being free laborers, and a few of these assisted the prisoners in wheeling barrows during the day. In the excavation of this tunnel 10,000 prisoners and 8,450 free laborers were employed: "and taking," as Major Briggs writes, "the cubical contents of this excavation at 50,000 cubic feet (for it has not yet attained its ultimate dimensions

* The site fixed for the bridge was about 5,000 feet above the level of the sea.

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of 12 feet in breadth and 20 feet in height), we have 2·71 cubic feet as the average work for each man. It must be remembered that every foot of excavation was through solid rock, of an unfavorable description for blasting, the geological formation of the hill being an indurated clay slate; and at the market rate the labor would have cost Rs. 1,057, but as a large amount of it was furnished as tribute, it only cost Rs. 391; a further sum of Rs. 220 was expended on artificers, so that the total cost of the tunnel to Government was Rs. 611." This work at the present day would cost little less than Rs. 15,000.

In October 1852, Major Briggs left for England, and Captain Montgomery officiated as superintendent. His report on the progress of the work in September 1854, states that on the 118 miles, from Simla to Seràhàn, divided into eleven sections, the state of the work was as follows:—

I. To Mahassù—10 miles; completed by Major Briggs.

II. Meog—11 miles; 2 miles completed by Major Briggs, and the rest by Capt. Montgomery.

III. Muttiànà—11 miles; finished partly by each officer.

IV. Nakunda—12 miles; finished partly by each officer; Captain Montgomery doing work on Muttiànà cliffs.

V. Bagì—9 miles; completed by Major Briggs.

VI. Kundrèla—9 miles; ditto.

VII. Soongrì—9 miles; 7 miles finished by Major Briggs, and 2 miles by Captain Montgomery.

VIII. Bàlì—12 miles; postponed.

IX. Nogrì—12 miles; completed by Captain Montgomery; continual bridging across chasms, cliffs, &c.

X. Dàrun—10 miles; cutting commenced. Nogrì river bridged by Captain Montgomery with red pine logs; spans of 60 feet. Blasting discontinued on cliffs near Nogrì, as heating the rocks with wood furnaces and pouring on cold water was found a more successful operation.

XI. Seràhàn—In progress.

Or, in other words, 80 miles completed and 35 miles in progress.

Major Briggs' intention to carry the road round the Rampùr spur was now abandoned; and Capt. Montgomery decided upon a series of zig-zags up the face of the entire hill to cross the Darum pass, urging at the same time the construction of a branch line to Rampùr.

Major Briggs, on his return from England, finished the road to 4

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miles beyond Seràhàn, with bungalows at a distance of 12 miles apart, when the mutiny in 1857 put an end to operations.

Major Briggs' road for reasons above explained, did not touch at Rampùr, the capital of Bussahir, where is annually held one of the largest fairs in the N. W. Himálayas; and as all commodities from Spiti, Yarkand, and Thibet, &c., brought through Bussahir are transported to Rampùr, and there exchanged or sold to merchants from the plains, it is clear that any line of communication to develope the resources of these frontier districts should pass through this city.

Our relations with these distant regions will never extend so rapidly, as to require a road adapted to wheeled vehicles, while for generations to come, the transport of all merchandize will be effected by goats, donkeys, mules and yàks. Accustomed as these animals are to travel roads of every practicable gradient, without diminution of load, a direct line of road on the reverse of the principle advocated by Colonel Kennedy has been decided upon as more economical and better suited to the wants of all classes; and the Government on resuming the work determined to construct a mule road by the old line *viâ* Rampùr to join Major Briggs' road at Seràhàn.

This road is called the Sutlej Valley line, and in 1861 Major Nightingale was appointed to carry out this work. It descended with a very good alignment with an easy gradient of 1 in 10 to the left bank of the Sutlej, where on crossing the Bìrà stream it enters the territory of Bussahir; and following the course of the Sutlej through Nirt, Duttnuggur and Rampùr, abruptly ascends to Gaora; then crossing the spur on which the cluster of villages is built, descends into the Mungìàd, and rises by a steep gradient of 1 in 5 to 1 in 3 to its junction with Major Briggs' road at Deo, two miles this side of Seràhàn.

With the exception of the new alignment of road from Sidhpùr to the bank of the Sutlej, this branch line, now the direct road, is merely a widening out of the old track that existed; and on the Gaora incline, where the gradients are steep, an entirely new alignment is desirable.

In 1862, Major Nightingale being compelled to proceed to England on medical certificate, Captain Lang, R.E., was appointed to the charge; and arrangements on a very large scale were made for completing the road to the frontier with the least possible delay. Large gangs of workmen and supplies were transported from the plains to Bussahir; and the works were, probably for the first time in their history, in full swing.

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As far as Seràhàn it can scarcely be said that there were any difficulties encountered. The old track had been adhered to, and though the road passes through a very wild and rugged part of the country along the left bank of the Sutlej, where precipitous and barren hill sides are seen for miles, yet the line of country on the whole was favorable for road making. Beyond Seràhàn, however, every feature is changed. Where the old native track existed, it was found that along difficult and dangerous cliffs, natural ledges, projections or artificial staircases, winding up the face of a cliff, were the only means of communication available, the natives themselves having neither the appliances nor the inclination to make any improvements. On the easier portions of the road; even where there was no rock cutting new alignments were necessary, as the gradients adapted for goats were not suited for mules. In advance of Seràhàn, therefore, nearly one-half of the road is an entirely new alignment, remote from the old native track.

For a distance of 4 miles beyond Seràhàn, Major Briggs' road is retained. This road traverses the Hoomtì and Drali cliffs, and the cliffs in the Badar glens, and by the mule road, the Drali gallery, of 405 feet long, was the first one met with. By reference to *Plate* LV., the construction of a gallery will be readily understood. It consists of either 3 or 4 jumpers (according to the breadth of the cradle), let into the face of the cliff at an angle of about 45°. The jumpers should have a fair hold in the cliff of at least 2 feet or 2 feet 6 inches, and a projection from the face of the cliff of about 2 feet 6 inches or 3 feet, against which the struts of the cradles must rest, and if necessary be secured by a large spike passing through the end (flattened in this case) into the timber. For ordinary purposes, when the gallery passes along the face of the cliff, the section and scantlings, &c., as shown, will be ample, and it is only in such cases as a recess in the rock, or where a pier for a bridge is required on the face of a cliff, and the road inclines to it at an angle, that any modification of the example given is necessary. Such modifications as these can of course only be determined from an examination of the spot. The stirrups and horizontal pieces connecting the struts with the uprights should all be secured by iron straps or bands let into the cliff, and secured by lead. The cradles may be put up at convenient distances apart, there being no necessity for adhering to the same spans for the bays, provided that the distance be not so far increased as to necessitate heavier scantlings for some of the girders than for others. For a 6 feet road, there should be three girders, which

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may either be placed the same distance apart, or the two inside ones placed closer to each other; for on the face of the cliff it will be found that decay will set in earlier in the inside one than in the outside one, on account of dripping water, &c., and it should always be an object to relieve it as much as possible of weight. The planked roadway should have a sprinkling of fine gravel thrown on to it; but as this is not always to be procured in the hills, a very thin layer of fine broken stone mixed with earth should be spread. If the gallery is not constructed with a uniform level throughout, but undulates according to the facilities for rapid construction offered by the cliff, thin strips of wood should be laid across, before having the earth spread; so as to render traffic more secure in wet weather.

Constructed as these galleries are on the worst description of cliffs, it is possible to get even large lengths of timber girders placed, but as the difficulty increases in proportion to the length of girder, it will be found seldom advantageous to use a greater span than 18 feet, while it is not improbable that in very bad places 15 feet will be more convenient. For expedition and simplicity of construction these galleries are admirably adapted for opening communication aross difficult cliffs. The great objection to their construction, however, if they are to remain semi-permanent structures to last a certain number of years, is, that from the perishable nature of the materials and their exposure to smashes, shakes and fractures from overhanging portions of cliff falling on them during the winter months, they require constant examination every year; and it is not always possible to detect any slight injury done them. They are, therefore, ill adapted for quick traffic. For slow traffic, however, they may be considered excellent substitutes for permanent roadways, and can be strongly recommended for adoption in a hilly country, where it is desirable to tap the recources of frontier districts; when, having secured the primary objects of the road, they could at any time be gradually dismantled and make way for solid roadways.

The crossing decided upon for the construction of a gallery across any cliff should be the one that contains the greatest number of broad natural ledges of a few feet in width, as the work can then be completed to each one of these ledges, thus forming a roadway for the transport of materials to the portion of cliff beyond. Having selected a crossing, the next operation will be to set men to work to fix the jumpers from which to suspend ropes and planks. Let it be required to cross a rugged perpendicular cliff,

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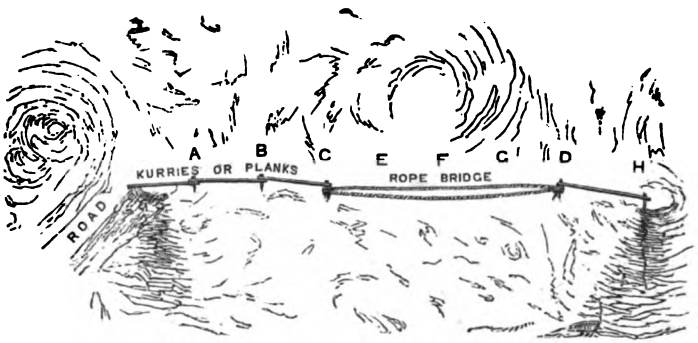
say 100 or 150 feet to the first ledge. The first thing to be done is to get a good cliff climber to get out to A, where a hole will be bored in the cliff and a jumper let in. The cliff-climber will then endeavor to get to B, and repeat the operation, and so on with C. Between these jumpers, and



resting on them, a kurrie will be placed. But, supposing, there are fifty or sixty feet of smooth perpendicular cliff in advance of C, then the cliff-climber will scale the cliff to get to a place where there is standing room at D. At this point another bar will be let in, and a rope bridge suspended between these two points will enable men to be set to work to bore and let in bars at E, F, G, while the bar H will be secured at the same time; and thus a temporary line of communication will be opened across this portion of the cliff, and in advance of H the same operation will go on. Though this is an exceedingly dangerous operation, there are few good cliff-climbers who pride themselves on their activity and powers to climb to apparently inacessible places, that will ever hesitate to go wherever they can hang only their fingers and toes: and when once the temporary footpath, from 4 to 10 inches wide is opened across the cliff, an officer can then go and select the sites for the cradles. In some places perhaps, a kurree cannot be laid, and it will be necessary to lower or raise oneself by a rope secured to an iron bar let into the rock, some height above the proposed level of crossing. Great care must always be exercised in crossing this temporary footpath, for it not unfrequently happens that there is a sheer perpendicular drop of 500 or 1,000 feet below.

Beyond Seràhàn it is no unusual circumstance to find very precipitous cliffs, rising several thousands of feet above the Sutlej. Of these the Taranda, Wangtù, Neoza, Kashti, Maizong and Rogi cliffs are fine examples, and

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"were more grand and dangerous than anything that had been before attacked in the construction of the Hindostan and Thibet road; and the first passage of the smooth water-worn granite face of the Wangtù cliff, rising like a wall from the foaming waves of the Sutlej as it rushes through the narrow Wangtù gorge, was a feat possible to but few men in the world, though unhesitatingly executed by the celebrated (in Bussahir) Bhulkù, who fixed in the crevices of the cliff all the first irons for the attachment of the ropes and planking, on which, suspended above the Sutlej, worked the coolies, who constructed the viaducts. Near Rogi also are precipices of stupendous height, scarcely to be surpassed in grandeur by any in the Himálayas; and to carry a road across their apparently inacessible face required bold and active hill men, careless of being perched on dizzy pinnacles boring for blasts; of being suspended on narrow planks, over "infinite space," or of crawling or creeping where there seemed no place for hand or foot to advance the work" *

The Wangtù cliff is very different from either the Rogi or the Maizong. The former, at the present crossing of the road, is perfectly water worn, and where in all probability the Sutlej rushed along some 500 or 600 years ago † with all the wildness and fury of the present day. After crossing the Wangtù bridge, this cliff is crossed at an elevation of from 80 to 120 feet above the Sutlej. The great difficulty in working this cliff was the comparative absence of all crevices, projections, ledges, &c., and the slippery surface along which men had to crawl. If a man had the misfortune to slip or make a false step, the chances were very considerably against his ever having an opportunity for another attempt. There is really and literally nothing on the face of the cliff that a man could hope to clutch, if he found himself in an awkward position; nor could assistance be rendered him if he fell. In an instant, the waters of the Sutlej would hurl him along, and he would be either dashed to pieces against a rock or large boulder, or be jammed between a couple of them. The Rogi or Maizong cliffs, on the other hand, are at an elevation of several thousands of feet above the Sutlej. They have, doubtless, been caused by immense landslips, and are very precipitous. On the Maizongs, a few sturdy pines are met with, but on the Rogi there is no vegetation visible excepting low down. These cliffs are rugged, many parts overhanging, and there are in many places drops of 500 feet, before touching another projection.

* *Vide* Capt. Lang's Report, dated August 1864, on Hindostan and Thibet road.

† The bed of the Sutlej I believe is lowered from 2 to 3 inches a year at Wangtù.

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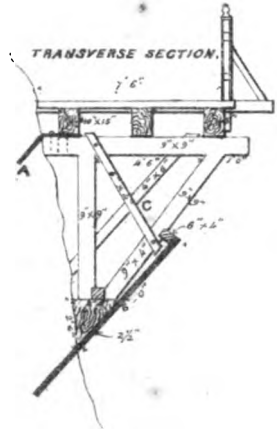
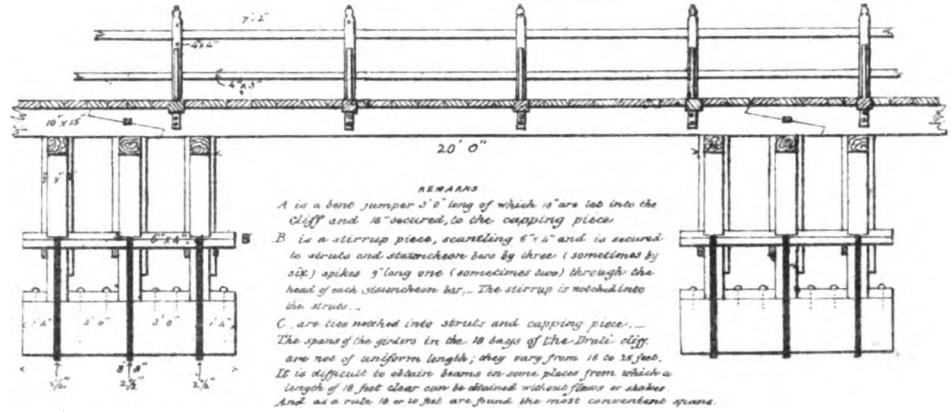
HINDOSTAN AND THIBET ROAD.

ELEVATION AND SECTION OF A GALLERY.





REMARKS

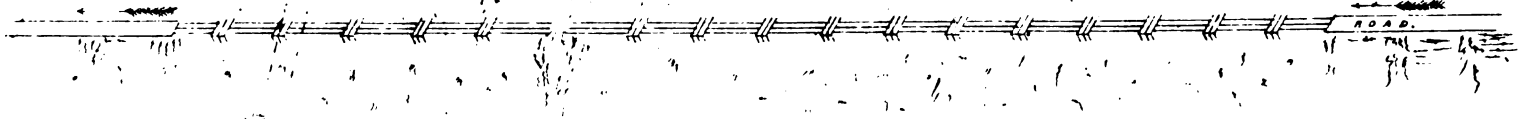
A is a bent jumper 3'0" long of which 15" are let into the cliff and 18" secured to the capping piece.

B is a stirrup piece, scantling 6"x4" and is secured to struts and staunchheon bars by three (sometimes by six) spikes 9" long one (sometimes two) through the head of each staunchheon bar. The stirrup is notched into the struts.

C are ties notched into struts and capping piece.

The spans of the girders in the 18 bays of the Drali cliff are not of uniform length; they vary from 16 to 25 feet. It is difficult to obtain beams in some places from which a length of 18 feet clear can be obtained without flaws or shakes. And as a route 18 or 20 feet are found the most convenient spans.

Diagram of Gallery running along the face of the Drali cliff.



Scale, 8 feet equal to one inch

10' 0' 10' 20 feet.

PLATE LV.

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I have known an instance of a man from below Seràhàn walking across a portion of the Rogi cliffs on a 6 feet roadway, and falling over the cliff from dizziness in all probability;* but such accidents are rare. In these cliffs, though very perpendicular, there are numerous crevices in which to secure spikes; but then there is little or no standing room; in many places not more than is sufficient to rest part of the foot on. The great difficulty in crossing this cliff by galleries must have been the great liability of the men to accidents.

When it is known that the above-mentioned are only the finest specimens of cliffs between Simla and Pangi, and that there are numerous others more or less difficult to be crossed, it will be seen that in the distribution of large gangs of workmen along several miles of the road beyond Seràhàn, the necessity for rapid communication across the cliffs, for the transport of supplies to the party working in advance, it was imperatively necessary that this system of galleries should be resorted to. By this substitute for a solid roadway, cliffs likely to occupy the whole of the working season (only 7 months) in the construction of a solid and permanent roadway could be opened to traffic in a couple of months. This enabled the extension of the road to Pangi being vigorously pushed forward; and, accordingly, in the two seasons of 1863 and 1864, Captain Lang opened 57 miles of road, including seven bridges, numbered from 5 to 12 in Appendix B.

In *Bridges* that require more than simple wooden girders, one principle has hitherto been followed in their construction. This principle consists in supporting the roadway by large cantilevers built out of the abutments. The principle is one that has existed from time immemorial, throughout the N. W. Himálayas, where the want of skilled branches of trade has compelled the inhabitants to adopt the simplest forms of construction in their bridges or "sanghos." Very large and rapid rivers can be crossed very expeditiously, and more especially in bridges constructed by the natives, for these consist in having two large logs (round) laid between the cantilevers, 2 or 3 feet apart, over which loose slabs of wood or thick shingles are laid; and suspended, as they not unfrequently are, about 100 feet above the torrent below, they are sometimes unpleasantly elastic.

The accompanying drawing of the Wangtù bridge, built by Captain Lang, will best illustrate the construction of all works of a similar nature on the Hindostan and Thibet road. The span is 120 feet, divided into three bays

* In 1865.

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of 40 feet each, the two end ones being supported by the cantilevers projecting from the abutments. The centre bay is an American truss, 45 feet in length, 5½ feet deep, and uniting with the wooden railings over the other two bays. The abutments are of dry stone very substantially bonded throughout by layers of wood running through the structure, not only strengthening the masonry, but keeping the ends of the cantilevers rigidly fixed. The foundations are on rock. At the toe of the right abutment a row of jumpers let into the rock secures the wood work from the effects of any sudden or extraordinary flood, such as that of 1866, which rose 26 feet higher than any flood previously known. Owing to the very awkward nature of the rock on the right bank, a cradle with heavy wood work and jumpers has been introduced. The elevation of the roadway of the bridge over the cold weather level of the Sutlej is about 70 feet; but in the rains this river rises to a height of 20 feet over winter level. From about 5 miles above the bridge, the Sutlej comes down with a frightful rush, the velocity in the rains being frequently over 20 miles an hour. This bridge is 120 miles beyond Simla and 176 miles from Kalka, at the foot of the hills, and considering the absence of skilled labor, and that nails, screws, and every little requisite had to be imported from the plains, the present structure appears to me to be the simplest that could be put up. The cost of the bridge with approaches, &c., was Rs. 10,000 only.

The year after this bridge was built, it was very nearly being destroyed by the falling of a large mass of detached rock, which destroyed the left abutment and approach. The rock in falling broke into smaller pieces, one of which fell upon the bridge itself. The rock fell from a perpendicular cliff about 1,500 feet above the bridge, and in situations like these, where it is impossible to provide against contingencies of this sort, it is very necessary in constructing a bridge, to put up one that can be easily renewed or repaired.

The road having been opened to Pangi, 157 miles beyond Simla, it was determined by the Government of India to limit expenditure on this road to the consolidation of the wooden galleries by blasted roadways, and Captain Lang having been transferred to Oude, I was appointed to the charge.

It was not proposed to dismantle or to substitute a solid roadway for the Wangtù gallery, and the Rogi cliff* being the most difficult on the line,

* The altitude of the roadway on this cliff is about 9,500 feet above sea level. In my official report it was stated at 1,000, which is an error.

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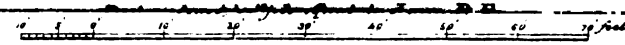
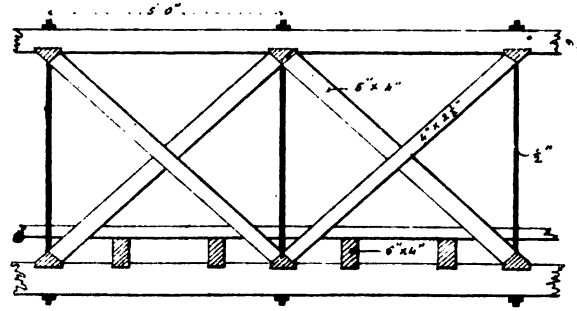
LITHO: T.C.PRESS.

HINDOSTAN AND THIBET ROAD.

WANGTU BRIDGE OVER THE SUTLEJ

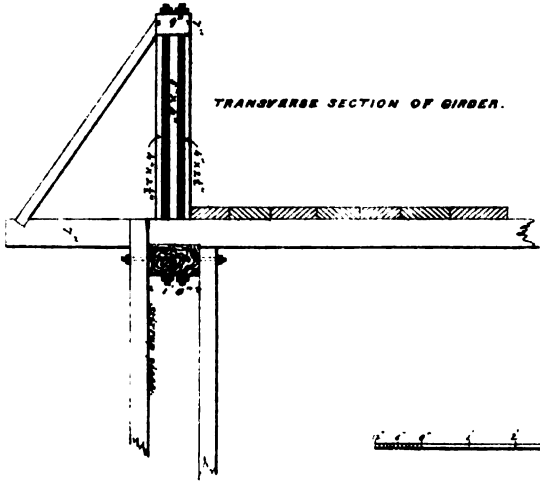


SIDE ELEVATION.



Note - The Cantilevers consist of
4 beams projecting in lowest course.
5 " " " third " "
6 " " " second " "
7 " " " first or top " "

TRANSVERSE SECTION OF GIRDER.



Scale, 4 feet equal to 1 inch.

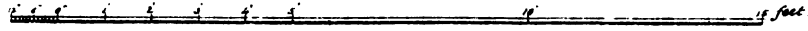


PLATE LVI.

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it was determined to commence with it first. Previous to Captain Lang's departure, he had arranged for the blasting out of a pathway across the most difficult portion of the cliff, so as to keep open communication. In a distance of little over 400 feet, eight hundred mines, 2 feet apart, in vertical distance, were bored in 8 rows parallel to each other, and sunk at such an angle as to give a line of least resistance of about 2 feet. Along the level of the proposed roadway, a continuous row of mines,* 2 feet deep, and 1 foot 6 inches apart were bored, so as to determine if possible a continuous line of fracture. By the simultaneous firing of these mines, it was hoped that a break would be produced, and that we should be spared the necessity of resorting to very dangerous methods of working the cliff. How far we succeeded in our expectations may be realized from the fact that, instead of producing an impression upon the cliff, the cradles were smashed, and the staunchion bars twisted† and bent so as to be of no possible convenience to us. Immense quantities of overhanging rock were brought down from above, and the cliff itself was in as bad a state as at the commencement. In some places, a layer of rock, about 5 feet thick, gave way, and scaled down to a point considerably below the level at which the crossing for the road had been decided upon. Fortunately, however, from the method adopted in first constructing galleries along the cliff, there were several holes bored for holding jumpers, from which ropes were at once suspended and men set to work to bore as many more as were necessary to suspend sufficient men for the proper working of the cliff. When we succeeded in getting in a row of jumpers, from which to suspend the men, we crowded as many as possible on the work. The total length of this cliff in hand at the same time was between 300 and 400 feet, on the face of which from 4 to 600 men were suspended for a period of nearly four months, the number gradually decreasing as the roadway was worked out.

The Rogi cliff is of very compact gneiss. Its lamination is found in every direction, being either horizontal, circular, vertical or oblique. The most provoking part was that, for a long time, work it as we might, nothing but continual scaling occurred, which was trying to both temper and patience. It was certainly a magnificent sight to sit opposite to the cliff and watch these men working with apparently as much ease as if they were on a 6 feet roadway. But how much, indeed, depended upon the ropes on which

* These mines were not charged.

† The girders and planks were taken up before firing the mines.

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they were suspended, for as many as fourteen men were sometimes on one plank and we were not over abundantly provided with rope to supply the place of pieces considered unsafe. Along the proposed level of roadway a row of crowbars was sunk, on which a kurrie or plank footway rested so as to allow of our crossing to inspect the work, as well as to enable the men to go backward and forwards. This footway was never wider than the breadth of a plank, and very frequently not wider than the breadth of a kurrie. Every day the direction at the mines had to be altered according to the result of the previous day's work; and, as a rule, nearly every yard in length required a different treatment.

Working as the men were on the face of the cliff and distorted as the lamination was, it was impossible to sink mines to suit each peculiar feature in the stratification; nor could the men themselves work in this position with much effect. The consequence was, that for a long time we had to submit patiently to a waste of powder, and a fruitless attempt to make an impression on the cliff.

As before stated, similar treatment could not be adopted throughout; where scaling went on, it was necessary to abandon any attempt at tunnelling or scooping out, and to cut down from a height of about 20 feet. The first mine by this arrangement generally produced a little scaling; another sunk immeditately behind, increased the line of least resistance; and after two or three mines were fired, scaling may be said to have stopped, and small mines and weak charges were then resorted to.

In places where the lamination was horizontal, the scooping out or half tunnelling commenced from near the level of the roadway upwards. But it was not always that the effect of the mines on the cliff could be noticed; and, as might be expected from the nature of the cliff, many mines were fired without the slightest result.

Our charges for blasting in ordinary places were $\frac{\text{L. L. R.}^3}{15}$ = charge in lbs., but as it was desirable that every stone disturbed in the cliffs should be got rid of, so as to reduce the necessity for the use of crowbars, which in many places could not be used, and in others not without the risk of their falling on one of the workmen, the charges were increased to $\frac{\text{L. L. R.}^3}{10}$, which worked with excellent effect, splitting the gneiss generally into small blocks, and throwing them clear of the work.

The result of my experience on the Rogi cliffs is, that it is always pre-

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ferable to work from a certain height above the level of the proposed roadway; not only for the purpose of tunnelling out, but because the men are so much sooner able to obtain a footing on the cliff. This plan of cutting from a height of about 20 feet above the proposed level of roadway has been tried with excellent effect upon the Maizong and other cliffs, and is now generally adopted by us in all rock cuttings.

The Wangtù gallery is the only one existing on the road, and it is not proposed to substitute a solid road for this at present. In a road across any hilly tract of country, I hold it to be most important to place all galleries that are ever likely hereafter to be dismantled to make way for permanent roadways, at least 30 feet above the level of the proper crossing. By doing so there is no necessity for dismantling the roadway, and stopping the traffic, while from the staunchion bars on which the cradles rest, the men could all be suspended, and there would be a capital road for the transport of tools, &c., to any point upon the work. It is scarcely probable that the Wangtù gallery will be allowed to remain more than eight or ten years, when its place will then be supplied with a solid roadway. But it ought, unquestionably, I think, to be dismantled piece by piece (when the solid roadway is in hand), and reconstructed about 30 feet above its present level; for it would never do on a cliff of this sort to run the risk of any failure in even the smallest arrangements for the work. If the great advantages to be derived from reconstructing the galleries above the intended level of the solid roadway had been known to me before the work had proceeded so far, I should, without the slightest hesitation, as regards cost, have adopted this plan; for, after all, the cost would not have been large with the facilities afforded by the existing roadway for carrying out the work. It is impossible to over-rate the advantages to be gained from a good road in work of this kind, when there is a difficulty in carrying even a large jumper to some places.

With this exception (the Wangtù gallery) the road from Simla to Pangi is now consolidated throughout its entire length, and though liable to accident and injury from the falling of detached pieces of rock during the winter months, yet the cost of maintenance and repair will never be a large item of expense.

Appended will be found a list of all the galleries and viaducts dismantled, and the following are the quantities of work executed:—

Walling,	.. ..	870,123 cubic feet.
Blasting,	.. ..	348,570 „

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the total cost of which has been Rs. 72,000. The blasting on the Rogi cliffs cost on an average Rs. 20 per running foot for the whole of the cliff; but there were portions that cost over Rs. 40; whilst the average of the Maizong cliff, of the same material, but differently stratified, was Rs. 12 to 15 per running foot. On these cliffs there were a few places where the cost was about Rs. 30 per running foot. By cubic measurement, the cost of blasting on the cliffs was nearly Rs. 15 per hundred cubic feet, and of walling from Rs. 5 to 8 per 100 cubic feet.

The cost of the 57 miles executed by Capt. Lang, was	Rs.	3,38,835	0	0
The cost of improvements to 40 miles from Sidhpùr, to Seràhàn, was - - - - - - - - -	„	22,500	0	0
Cost of replacing galleries by solid roadways, was	„	72,000	0	0
Making a total expenditure of	Rs.	4,33,335	0	0

or of Rs. 4,333 per mile. When it is considered that the pay of a coolie is Rs. 8 and 10 per month, and skilled labor proportionally large, the cost per mile is not great. No records exist to show the expenditure on the 44 miles from Simla; in those days labor was cheap, and the cost of the 44 miles may be taken at about Rs. 1,500 per mile.

Beyond Seràhàn the bridges over the torrents are liable to be washed away at any time, for they have to accommodate the passage of large avalanches in their descent from the snows above. In 1866, the Chownda bridge, of 35 feet span, was carried away during the night. It was built on two immense blocks of stones for abutments, and though the weather was all that could be desired, yet no one ever found out the cause of the sudden disappearance of this structure. In the morning a well defined water line about 8 feet high was visible on the banks; and the abutment boulders, about 25 or 30 feet in diameter, and the bridge were gone. The only cause that I can suggest for this is, the probability of a large avalanche having become wedged in between two cliffs in the snowy ridge which supplies this torrent; and the pressure of a large body of water dammed up, must have caused it to burst and come down with overwhelming violence, and wash everything into the Sutlej. The Yoola bridge, of 40 feet span, was carried away in 1865 by an avalanche more than half a mile long, and over 100 feet thick, which remained below the site for 12 months before it melted. As it gradually disappeared large trees, and rocks were constantly exposed, while the forest above, through which it had passed, had the appearance of having lost many a fine deodar. The

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trees were cut off nearly level with the ground, and in the distance the section appeared as clean as though they had been sawn. While this avalanche remained in the bed of the torrent, the Yoola had worked an arch out for the passage of its waters, and during its existence it formed, what is frequently met with in the interior, a snow bridge. It was also a favourite halting place for shepherds and traders, and on the surface might be seen several groups of figures sitting around their respective fires.

It is not improbable that before long, the extension of the Hindostan and Thibet road to the frontier will be again vigorously pushed forward. Indeed, it can scarcely be imagined how little utility there is in the road in its present state, excepting to the villages through which it passes; these it has benefitted to a very considerable degree, and considering that 7 or 8 more marches only require to be done to carry the road to the Shipki terminus, no return for the outlay can ever be realized until the objects of the road are partially developed.

In the construction of this road beyond Pangi there will not be the necessity for the steep gradients that exist on some portions of the road between Rampûr and Wangtù. Before adverting to the line of country to be traversed beyond Pangi it will be necessary for me to state the conditions to be fulfilled in the construction of a mule road across the Himálayas. 1st, Shortest distance, with a maximum gradient of 1 in 5 to 1 in 3, the latter for short lengths only; 2nd, The avoidance of zig-zags where possible; 3rd, That where it is necessary to cross a spur or ridge on account of cliff, and steep gradients are resorted to, it is desirable to break the gradients by horizontal runs, so as to ease the beasts of burden; for it should be remembered that the natives of these parts do not regulate the loads on their animals upon any calculation of the steepest hill. Rather, they consider the difficulty of the march before them, put on a maximum load, and make due allowance for the time to be occupied on the journey. As they only travel a march a day, it matters little whether the time occupied is four or twelve hours; 4th, A road to be of the greatest utility to a hilly country should be constructed at such elevations as are below the limit of snow, which may be assumed at 12,000 feet above the mean sea level.

I must not omit to state that large flocks of goats are infinitely more destructive to roads than mules; and if a Kunnawurì can find out a path likely to shorten distance ever so little (no matter how steep the gradi-

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ents so long as the loads have not to be taken off the animals) portions of a level road will be abandoned. But though they are always ready to forsake an easy portion of road, their own tracks are not always the shortest; for unable as they are to open communication across a cliff, they will dodge in and out in a very circuitous way so as to take advantage of the least difficult portions; and the construction of a road along the face of one formidable cliff will often save endless smaller difficulties, and be more economical. It would, however, be impossible to lay down any rules for guidance in a country of this sort, where every spur presents an entirely new scene; and the several difficulties should in every case be disposed of by an officer on the spot, whose observation and knowledge of the principles on which the construction of the road is based, will nearly always ensure the best direction and the most economical route.

In order that the road may never attain to a greater elevation than the limit of snow, it will be necessary in advance of Pangi to follow the course of the Sutlej throughout its entire length to Shipki. Otherwise, there is at present a very fair track for goats (with the exception of the passes) by way of the Gongra, Rohung and Hungrung passes, of 13,500, 14,350 and 14,530, feet, respectively, above the sea level. This, however, never can form a route for a trunk line of communication. When I returned from the frontier at the end of May this year, and although there had been an exceedingly mild winter, yet yáks could not ascend the snow with even light loads upon them, and though the snow early in the morning was exceedingly hard. Snow begins to fall upon these passes in November, and if we assume that in ordinary seasons the snow is not melted away until the end of July, there are only three months remaining during which animals larger than goats could cross the passes. A road by way of these passes, would, however, to be of utility for three months in the year, have to be considerably lengthened; and if the gradients were under 10 in 100, according to Captain Lang, the present distance would be increased 8 times;* while if the gradients were 1 in 8, the length by this route would be longer than the continuation of the road by the Sutlej.† By the Sutlej valley route the highest elevation that would be attained is 10,100 feet above the level of sea, and this at Chango, the N. W. terminus of the road. At intermediate points, the level or altitude of the road would range be-

* *Vide* Captain Lang's Report, August 1864.
† *Vide* Colonel Hutchinson's No. 626, dated 26th September, 1864.

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tween 8,700 and 9,300 feet above the level of sea.* Between these limits too, snows falls very lightly; and with the exception of a month or so in severe weather, the road will be available for traffic throughout the year. This is an object of such importance that the summer route *viâ* the passes could never be of any practical utility in developing our commercial relations with Chinese Tartary, and any attempt to continue the road by this route must be given up.

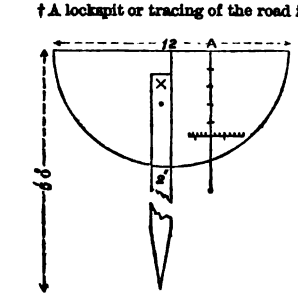
By the Sutlej valley, the Hindostan and Thibet road will pass through the large and populous villages of Rarung, Akpa, Yangi, Lubrung, Kànam, below Shassù, Spooi Khàb and Numgea with a line to Shipki, and a branch line up the Spiti river below Nàko into Chango. With the branch line to Chango, the total length of road yet to be constructed will be about 90 miles, and as far as gradients are concerned will be exceedingly easy.

In the first march from Pangi to Rarung the road will start at an elevation of 8,971 feet above the sea, and will undulate throughout its entire length. The gradient will, however, be very easy—the steepest occurring where difficult cliffs are met with, and these will not exceed 10 in 100. The road across the Kashung cliffs, as, indeed, the whole march, was lockspitted† by Capt. Lang before leaving the road, and the solid roadways are now being worked out across them, and by the end of November 3½ miles of road will be completed. On this march there will be only one torrent to bridge, which will be crossed by a bridge of wooden girders resting on cantilevers. Beyond the Kashung torrent, the road will cross cliffs for another couple of miles, and then descend into Rarung at an elevation of 8,792 feet above sea level. With the exception of about 5 miles, the remainder of this march will traverse a fair line of country.

In the second march from Rarung to Tangi, the road will pass through

* By boiling apparatus. These heights will be found to be pretty correct.

† A lockspit or tracing of the road is set out by an exceedingly simple instrument, a sketch of which I give. The semi-circular portion is made out of the head of a *powder barrel*, or ¾-inch plank and may be 12 or 13 inches in diameter. It is fitted into an upright and secured by a screw, so that the centre of the semi-circular piece may be on a line with the inside of the upright. At right angles to the diameter of the semi-circle there is a scale of 5 inches divided into 20 parts to the inch, or 100 parts in all. At right angles, and at the end of the 5 inches, a scale of 1 or 2 inches on each side, similarly divided should be made. From a little notch in the top suspend a plumb-bob, and by moving the semi-circular piece on its axis a gradient of any number of parts in 100 can be attained. The addition of a couple of spirit bulbs would make this a very handy instrument. For setting out steep gradients for a mule road it is practically correct, a simple cross headed staff is all that is required, and gradients can be set out wherever a man can stand.



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a country favorable in every way to road making. From Rarung to Akpa the road will be constructed in the *debris* of one continuous landslip of about 4 miles in length. The road will flank the Gongra range, and far up the mountain side nearly all the way to Jangi continuous unbroken lines of mural cliff can be observed, which, judging from the appearances of the trees, must have been occasioned by immense landslips about 100 years ago. The road will descend on this march about 200 feet in 10 miles, and will enter Jangi at an elevation of about 8,500 feet above the sea.

In the third march from Jangi to Kanàm, the road will descend to the Asrung river at a gradient of from 0 to 10 in 100. Here a cantilever bridge, about 50 or 60 feet span will be necessary. The road should then avoid any zig-zags up the Toolnurrung pass, as the hill side is exceedingly steep, and should flank the spur overlooking the Sutlej at a gradient of about 1 in 10; then descend for a short distance and again ascend into the village of Lubrung, and on, at nearly a level, to Kanàm, a large town containing six prettily situated hamlets. The elevation of the road at this point will be about 9,000 above the sea.

In the fourth march from Kanàm to Shassù, the great object will be to run the road for 7 miles at a dead level, or with a very slight descending gradient, so as to touch the confluence of the Thanam with the Sutlej. The road should pass below the Keelnarung pass, or winter route, and will, up to this point, be easy. At the turning into the Thanam river, and for several miles up the right bank are the Nardhung (*dhung* being cliff) cliffs, of stupendous height, rivalling the famous Rogi cliffs. These cliffs should be avoided at all risk, for it is my opinion that nothing short of a road entirely blasted out of the cliff without any walling will ever remain long upon them. On the march between Shassù and Spooi, I had a fine opportunity for reconnoitring these cliffs, and during the night at Shassù and the morning of the following day, piece after piece of detached cliff was bounding down the hill side; anything save the most solid and durable work would stand a poor chance of a long existence. On these cliffs there is no earth or vegetation, save a few stumpy deodars and Neoza pines (*Pinus Gerardinana*), which are stern and strong enough to withstand the severity of the weather. On this march, as, indeed, on the previous one also, the trees are very dwarfish, and high up, are only the size of large bushes. To the deodars (*Cedrus deodora*) there are no straight stems and wide spreading branches. They are dwarfed from their roots, and spread out into 4 or 5 stems, all stunted in their growth,

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and of little or no use for building purposes. The cost of a permanent road across these cliffs, so as to bridge the Thanam higher up and to touch at Shassù, would be enormous. It will, therefore, be better to cross the Thanam river somewhere near to its junction with the Sutlej by a bridge of one span of about 180 or 200 feet; and then to run a branch road at a very trifling expense to Shassù. The elevation of road at this point will be a little under 9,000 feet.

In the fifth march to Spooi, the road must be taken across the cliffs, which here line the right bank of the Sutlej in magnificient wildness. The native track across these cliffs, about 1,500 feet above the crossing for the Hindostan and Thibet road is considered the worst footpath in Bussahir. This march, will, I think, be the most expensive on the road; the whole of the cutting will be through hard rock, which will be difficult and tedious; the length of it will probably be about 6 or 7 miles. Along this march the road will undulate and finally descend to the Sutlej below Spooi (about 900 feet) at the Namptu Sangho, or cantilever bridge, at an altitude of about 8,500 feet above the level of the sea.

In the sixth march to Numgea, the Sutlej must be crossed—the site for this will be the present site of the Namptu Sangho, the span will be 115 or 120 feet, at an elevation above the winter level of this river of 120 feet. The road will traverse a fair line of country along the left bank of the Sutlej. The scenery on this march is very wild; the right bank being large mural cliffs of granite without a blade of vegetation upon them, and rising almost perpendicular from the Sutlej to the confluence of the Spiti river, and then extending up this river almost the whole way to Li. At Dabling, I believe, there are a few deodars and poplars (the latter is not indigenous) of fair size, but with this exception wood is exceedingly scarce. The mountains all around are very high and precipitous, and in front are the Perguil peaks, the frontier boundary with Thibet, rising to a height of 22,227 feet above the sea. The absence of the fine lofty pines Lower of Kunawar* gives the scenery in these regions a peculiarly cold and wild appearance. The road will ascend to the village of Khah, and then descend to Numgea, at an elevation of about 9,200 feet above sea level.

In the seventh march to Shipki in Thibet, the road will be carried along very precipitous cliffs. At present the terminal point is not decided upon, as the road will only pass for a distance of four miles in the territory of Bussahir; the remainder of the march will be in Little Thibet. This portion of the road will be difficult.

* Bussahir is divided into two provinces, Upper and Lower Kunawar.

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The branch line to Chango will leave Numgea, descend to the Sutlej, and crossing that river will run through some stiff granite cliffs that line the right bank of the mouth of the Spiti river; thence through an easy line of country with an ascending gradient passing about 1,500 feet below Nako (elevation 11,741 feet above sea level), a large village built at the limit of snow, and finally into Chango, at an elevation of about 10,000 feet above the level of the sea.

Here there is a large fair held in September, and it is proposed to give facilities by an easy road to merchants from the Punjab to go thither and make their own purchases of "pushm," a fine sort of down obtained from Thibetian sheep and goats, and used extensively in the manufacture of Cashmere shawls, &c. At present the trade passes through Cashmere.

In the extension of the road to the frontier there will only be three bridges of importance, viz., the Thanam of 200 feet span; the Namptù of 115 feet; and the Numgea of 90 or 100 feet span. In a country destitute of timber, where its importation would be not only an expensive item, but almost an impossibility in large and heavy scantlings, light iron suspension bridges are, I think, unquestionably the proper things. For the Namptù and Numgea sites, there can be no question about their adaptability, for the former is far removed from any cliffs where the descent of a detached piece of rock would be likely to damage it, and the latter would I thing be quite safe, since the present twig bridge has existed long enough to rot without sustaining a single accident. For the Thanam bridge, however, there will I apprehend be some difficulty in selecting a favorable site, but it should only be decided upon after careful observation, extending over a period of at least a couple of years.

The extension of this road is now in hand for the current year, on a small scale. If the Government of India lend their full support to the carrying out of this project to the frontier, without interruption to the work, the year 1870 or 1871 will, I hope, see the work completed. There will then be two points of communication with Chinese Tartary, and two outlets for the trade which is now carried northwards through Ladak and Cashmere, for want of proper communication on this side of the Punjab. Without the extension of this road there is no inducement for traders to export in very limited quantities their *real* pushm *vid* Bussahir; hence the so called pushm met with at the Rampùr fair is no more worthy of that name, than hair is worthy of being called wool. The fact is, that this pushm is nothing more than the fine down obtained from Kunawar goats and sheep, and mixed with the outside hair and wool, and the whole transported to

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Rampûr under the name of "pushm." This fine down obtained from the Thibetan goats is much finer than can be obtained from any other sheep or goats in the neighbouring hills, and the staple is longer. These are two important points in real pushm, and can only be obtained from animals that are fed on rich pasture lands with a high elevation and dry climate. Besides pushm, there will be a large trade done in borax, wool, Yarkand churrus, blankets and goodmàs, when once a through line of communication is established across the N. W. Himálaya. A road of this kind cannot fail to develope the trade of a country whose race is unknown to us, and the fact that the border men will be only too ready to avail themselves of the facilities offered for transport will do much to facilitate and enhance the value of our commercial relations with Thibet.

It is impossible to frame an estimate for the continuation of the road, but the probable expenditure will be about 5,00,000 Rs.

A. C. C.

SUBATHOO, 10*th August*, 1867.

APPENDIX A.

List of Galleries and Viaducts dismantled on the Hindostan and Thibet Road during 1866-67.

Mile from plains.	Mile from Simla.	Name.	Gallery length.	Viaduct length.	Remarks.
				cub ft.	
153	97	Hoomtí cliff, ...	...	43	
154	98	Drali ditto, ...	405	...	
155	99 to 102	Badàr glens, ...	180	243	
158					
159	103	Chòra cliff, ...	90	...	
165	109	Tarunda ditto, ...	247	168	
166	110	Ditto, ...	...	81	
170	114	Soongri ditto, ...	150	...	
176	120	Wangtù ditto, ...	...	45	
177	121	Wungur, ...	40	...	
178	122	Sutlej bank, ...	150	...	
185	129	Ditto, ...	...	22	
187	131	Oorni cliff, ...	...	100	
189	133	Mèrù,...	...	84	
190	134	Kashti, ...	...	190	
191	135	Kashti cliff, ...	60	...	
194	138	Maisong, ...	469	319	
195	139 to 140	Ditto,...	336	639	
196					
198	142	Rogi, ...	420	312	
		Total, ...	2,547	2,246	

2,547 Running feet of galleries dismantled.
2,246 " viaducts ditto.
4,793 " wooden structures replaced by solid roadways.

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List of Bridges on the Hindostan and Thibet Road.

Number.	Name of bridge.	Span. (feet).	Remarks.
1	Bera, ...	30	Cantilevers from abutments, built in 1866.
2	Muchara, ...	35	Do., do., do., 1866.
3	Nogri, ...	68	Do., from Rampùr abutments, built in 1864.
4	Pushàda, ...	50	Do., do. do. 1864.
5	Mungiàd, ...	56	Do., from Serâhân abutments, built in 1863.
6	Chownda, ...	36	Do., Tarunuda abutment, ditto 1866.
7	Syldung, ...	58	Do., do. do., 1863.
8	Wangtù, ...	120	Do., both abutments, one span, ditto 1864.
9	Wungur, ...	140	In three spans, built in 1864.
10	Yula, ...	40	Built in 1865.
11	Runung, ...	47	In two spans of 12 and 35 feet, 1866.
12	Mulgaon, ...	90	In three spans 20, 40, and 30 feet, 1864.

Specification for Consolidating Wooden Galleries, by Capt. A. M. Lang, R.E.

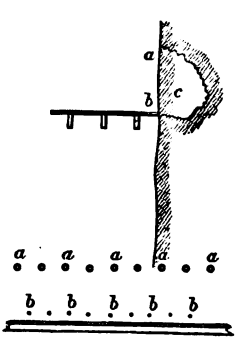
Masonry.—In all localities where, in the following detail of measurements, the work "to be done" is specified as "to be built up;" the first operation will be to lower men to the specified depth, either by scaffolding from below, or on planks, or by ropes secured to the bridging above, and to carefully blast out a ledge or succession of ledges at least 3 feet wide, on which to found the lower courses of masonry.

Walling.—When the foundation ledges are constructed to the satisfaction of the officer in charge of the work, the walling will be commenced and carried up course by course, truly level, facing and backing identically built and brought up level together: the largest stones to be used in the lowest courses, and the lightest for the highest.

Stone.—Stone employed to be granite, gneiss, or hard durable mica schist, according to the nature of rock existing in such locality. Stones to be roughly hammer-dressed, and laid truly on their natural beds.

Batter or Bond.—The walling will be built either with a batter produced by 3-inch off-sets in every 2 feet of height without timber bonding; or (in case of very high walling) with a smooth face, and deodar timber bonding of heavy scantling, as decided in each case by the Executive Engineer.

Blasting out Roadway.—Where in the detail of work it is stated that the new work is "to blast out the roadway;" a new roadway 7 feet clear in width is to be provided on the present level, and shall have the cliff on the inside so scarped or tunnelled out to such a height as to admit of the safe and convenient passage of a man on horseback. Meanwhile, the roadway (in every case, a timber gallery projecting over the cliff or a timber viaduct bridge spanning some bend in the cliff) must be retained passable for traffic.



The conditions above specified must be rigidly complied with, but the exact mode of operation will differ almost in every case, and must be decided upon and superintended by the officer in charge of the work. In some cases the work will be commenced with very small mines, bored 2½ or 2 feet above the roadway, and bored obliquely into the rock, which will be fired one by one, the roadway about the spot being guarded by logs of trees, and very small charges being used in the mines, to compel the rock to split true to the road level; horizontal mines *b*, *b*, will be driven

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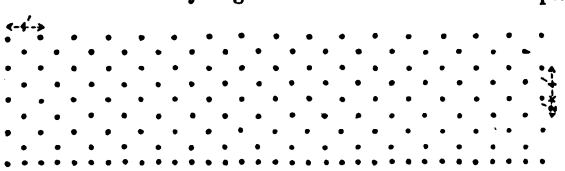
in at road level, but not loaded, the charge being put into the oblique mines, *a*, above them, so placed that an oblique mine, *a*, shall be bored in the interval between two horizontal bores, *b*, *b*.

In other cases a very large number of horizontal and oblique mines will be bored into the cliff from the road level to 15 or 20 feet above it; and when all the mines have been bored and loaded, the planks and girders of the gallery will be removed, and all the mines fired in large batches, until the whole number have been discharged. The shattered rock will be removed by crowbars, sledge hammers, &c., and the roadway of the gallery will be again constructed for traffic while additional mines are being bored to complete the blasting out of the road.



ABSTRACT OF ESTIMATE.

Sub-head.	Quantity.	Rate.	Cost.			Remarks.
			Amount.	Total.	Grand Total.	
	c. ft.	Rs.	Rs.	Rs.	Rs.	
Blasting out roadway, ...	2,32,340	12 per 100	27,881			
Walling, ...	2,46,749	8 per 100	19,740	47,621		
Contingencies, at 5 per cent., ...			2,380	2,380	50,001	

Rs. 20,000 to be paid in cash.
„ 30,000 to be paid in supplies.

THE WANGTU BRIDGE—*Report.*—The point at which the road through the Sutlej valley, from Simla, Rampùr, &c., to Shipha, Shialkur, and the Chinese Frontier, crosses from the left to the right bank of the river, is named Wangtù. At this point there is no village, but two routes here meet the Sutlej valley road. One, from the north, leads over the Tarie pass from Spiti; the other (but seldom used), from the south, leads from Pahu and Tonse valleys, and over the Shaitoot pass. At Wangtù the altitude of the river above sea level is 5,600 feet. The river rushes with violence through a narrow gorge between cliffs of granite and gneiss, which gorge at its narrowest point is about 90 feet in width. The cliffs are very lofty, perpendicular and smooth; water-worn for many hundred feet above the present level of the river. The present bridge is erected at an admirable site: not at the narrowest spot, where the precipitous cliffs preclude any easy approach, and afford no room for building operations; but at a point where the span is 136 feet, and the natural rock abutments stand well above flood levels, and are ledges, distinct, and far from the cliffs, which recede from one another rapidly below the lower (western) end of the gorge: the present bridge is of "sangho" construction, old and in decay, narrow, and too weak to bear anything but foot traffic, goats, &c.

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The question of a site for a new bridge has been carefully considered and discussed, and probably no better site could be selected than that now decided upon.

It is about 100 feet lower down stream than the present one, on the same ledges of granite rock, and at a point where these approach within 102 feet of each other.

No site affording any reasonable span, and sound foundations, occurs near Wangtù lower down the river; and higher up the stream no span of less than 200 feet could be obtained, except in the middle of the gorge, where there is no room for building. *Above* the gorge (except at the site below noted) high cliffs rise abruptly from the river on the left bank, and no object would be gained by blasting a road across them, with a view of crossing higher up the river, where no decrease in width occurs for many marches.

Just above the gorge, a site could be obtained of somewhat over 200 feet span, and were a bridge built here, the passage of the Wungur and the cliffs beyond would be saved. But the traffic of the Tarie pass route from Spiti would be lost; and, moreover, the saving of the cost of these works would be counterbalanced by that of the bridge of double span, which would occupy two or three years in construction; would need skilled labor of all kinds imported from the plains: and would require masonry abutments of the very best stone and lime (resting as they would on shingle and boulder foundations, exposed to the action of the stream instead of being raised above flood level on granite rocks). Under these circumstances, considerations of economy would lead to the preference of a bridge of 102 feet span over the Sutlej, another over the Wungur, and the passage of the cliffs, to a bridge of 200 feet (or more) span, with the inferior advantages of foundation site. Considerations of rapid execution are entirely in favor of the former, which could all be completed in one working season.

The site being thus decided, the style of construction remains to be settled.

Under the circumstances—viz., timber of large scantling in abundance, and want of skilled labor, the employment of the *sangho* principle suggests itself as most feasible. But to improve the defects of the untied cantilevers of the hill construction, and of its sloping roadway, it is proposed to tie the extremities of the upper cantilevers to the abutments, by horizontal (lattice) girders; and to span the interval also by lattice girders. The violent hurricanes of wind which rush through the gorge render the employment of a deep and heavy lattice dangerous: a low American "resultant truss" is therefore proposed, with all the ties of iron. Calculations for all the scantlings of the truss are annexed; and also for the compression of the cantilevers. To render the cantilevers more rigid, and to form them into a system of framed levers, vertical stirrup pieces are attached to the outer cantilever at intervals of 10 feet. The lower tier of cantilevers is placed at an inclination of 25° for greater strength; but to lower the elevation of the roadway, the two upper tiers are placed at the minimum incline for struts, viz., 11°. Heavy scantlings of deodar are to be laid across the cantilevers throughout the whole width of the abutment, and tied down to the rock by iron stays.

On the left bank of the river, the section of the rock is as in *Plate* LVII. It is thought advisable to refrain from throwing the whole weight of the abutment above the projection B; and yet the great advantage of 10 feet less bearing cannot be foregone. Consequently, while the abutment is built at A, a system of staunchion frames is erected at B, to carry the lower tier of cantilevers. All further details are shown in the *Plate* and specifications.

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HINDOSTAN AND THIBET ROAD.

THE WANGTU BRIDGE.

Fig. 1.

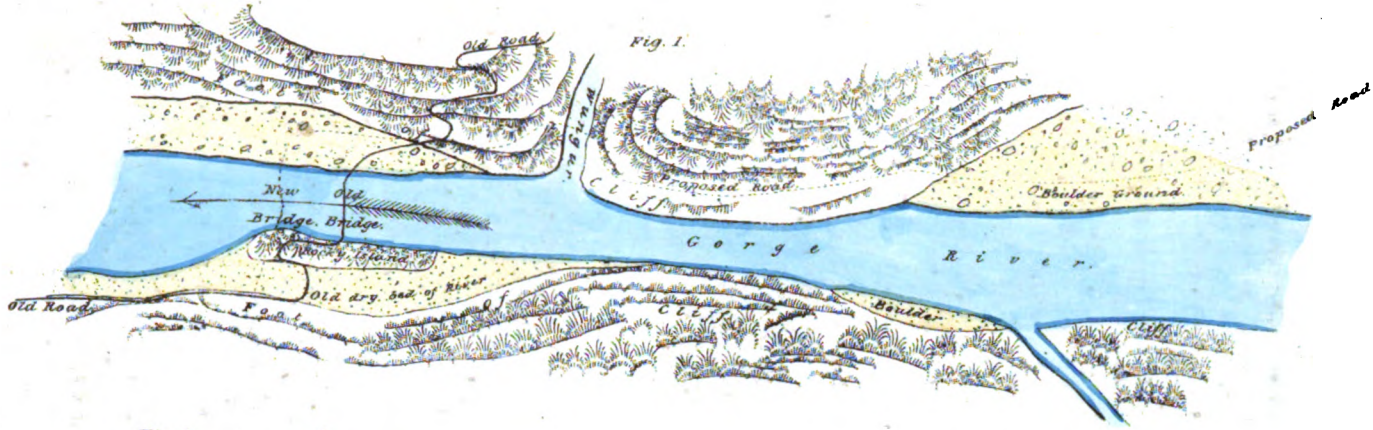

Fig. 2.

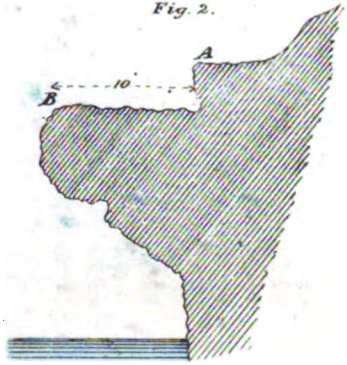

Fig. 3.

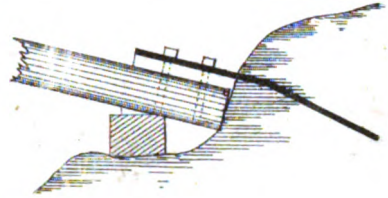

Fig. 4.

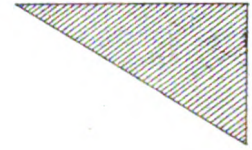

Fig. 5.

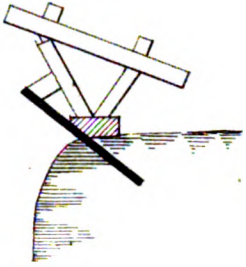

PLATE LVII

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The *rates* of the estimate are as low as can be possible assumed; all the timber having to be brought several miles from the Shaitool pass forests by *no* roads; and labor being now more than double that obtaining in Captain Brigg's time.

SPECIFICATION.

Blasting.—For the foundations of the abutments, the surface of the rock at site to be blasted, until a tolerably even surface, countersloping from the river, is obtained. The largest and best of the stones detached by blasting (granite) are to be roughly dressed, for employment in the outer course of masonry.

Masonry.—To be throughout of granite, bonded with deodar. No timber to be introduced until the masonry is 8 feet high: the largest dressed stones being used for the lower courses; carefully laid horizontally and breaking joint. Abutments, approaches, &c., to be of the dimension specified in details and *Plate.*

Cantilevers.—To be of round deodar timber, of well grown, sound, mature trees, of the exact length shown in *Plate:* none to be of less mean girth than 3½ feet, or of less small-end girth than 3 feet. The lowest tier to contain trees of not less than 4½ feet mean girth. The lowest tiers to be laid at 25° inclination. The two upper tiers to be laid at 11°. A bearing plate, 12 × 12 inches, to be laid across the heads of each tier of cantilevers, one foot from their extremities, to carry the next tier. All tiers to be connected, at 10 feet intervals with vertical stirrup pieces, as shown in *Plate,* strapped to the outer cantilevers by bands of iron 3 inches wide by ½-inch thick. All to be pinned to wall plates (two or more) 12 × 16 inches, imbedded in the masonry, and to have their extremities tied into the natural rock by 1¼-inch iron bars.

Lattice Girders.—The cantilevers to project 34 feet from the right, and 33 feet from the left, abutment, and across the space then left of 40 feet, two lattice girders to be thrown, and carried continuously to the abutment: to be 9 feet apart in the clear. Dimensions of chords, braces, and ties, to be exactly as fully specified in detailed drawings, calculation and estimate.

Timber.—The timber throughout the bridge to be of deodar: excepting only the abutting pieces of the lattice, which are to be of *yew.*

Iron.—The iron ties to be of ¾ inch and ½-inch round iron, driven through slightly smaller augur holes. Heads to be 2 inches square by ¾-inch thick, and to be firmly fastened on. Nuts of same dimensions as heads, and each provided with a washer 3 inches diameter and ¼-inch thick.

Roadway.—To be of 3-inch deodar planks, spiked on to joists, 7 × 4 inches, which shall rest on, and be spiked to, the lower stringer of each lattice girder.

Staunchion Frames.—On the projecting ledge below left abutment, the lowest tier of cantilevers to be laid on a set of 7 staunchion frames: their lower ends being connected by a heavy beam laid on them, and pinned down to the rock by 1¼-inch iron bars. The staunchion frames to be formed as shown in *Plate.*

At 2 feet intervals, iron staunchions, 3 inches diameter and 8 feet long, to be driven as jumpers to a depth of 3 feet into the rock, at an inclination of 45°: a beam 8 × 6 inches, is to connect their upper ends. Within, and at the foot of these, a beam 24 × 24 inches and 14 feet long, to be laid on the rock, and pinned down by 1¼-inch iron stays. On this beam to be framed 7 pairs of diverging struts, 12 × 12 inches, each pair opposite to a staunchion: the heads of each pair of struts being connected by a tie 12 × 7 inches and 8 feet long. Two bearing plates to be

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laid across the heads of the struts: on to these the lower tier of cantilevers to be bolted.

Approaches.—On the right bank the approaches to be carried across the present level of rock: but on the left bank a masonry wall, 12 feet wide, to be carried across the low ground between the present road and the island rock, on which the left abutment is built. This will be 150 feet long, at a gentle curve and of height varying from 6 feet or 24 feet in height.

The bridge was completed for about Rs. 10,000.

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No. CLXVII.

DISTRIBUTION OF CANAL WATER.

To the Editor.

DEAR SIR,—The enclosed paper, on the distribution of canal water, was written two years ago. At that time, however, I had scarcely a six months acquaintance with canal work, so I thought it premature to make public suggestions that further experience might show to be impracticable; but I still find that my ideas on the subject have undergone but a slight change. I do not *now* advocate that any one scheme to the exclusion of all others should be adopted in the distribution of canal water; on the contrary, the irrigation of each village should be arranged for separately, so that every advantage might be taken of local peculiarities; for this reason, the scheme here set forth would appear applicable only to cases where the full supply line of the rajbuha is scarcely above the natural surface. I purpose to treat of arrangements for the distribution—(i), Where the water has to be raised; and (ii), Where the rajbuha is wholly in embankment, in a separate paper.

To the objection that it would be a gigantic task to go into details for each village, I would answer that the improved methods should be introduced gradually, and first in the older irrigating villages, where the men have had experience in managing water, and knowing what they wanted, could afford valuable assistance to canal officers in carrying out a new scheme. Besides, an inspection of existing water-courses would diminish the work considerably.

If a few villages were brought under the new arrangements, year by year, and duplicate copies made, where there were any modifications of the ordinary procedure, no confusion need be the result. And having found

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out practically what systems were most adapted to particular localities, one of the establishment, with a few Irrigation Surveyors, might be specially deputed to the re-modelling of the irrigation of every village.

E. S.

May, 1867.

Distribution of Canal Water.—The different plans proposed for realizing water-rents may be divided into two classes—(i), Those having for their object a cheap and expeditious method of charging for water supplied, according to the area irrigated, with or without discriminating rates; (ii), Those by which the volume of water actually taken is charged for at a fixed rate for a certain volume, as 1 rupee per 40,000 cubic feet.

The systems at present in force, on all canals in the North West and the Punjab, belong to the 1st Class, and with unimportant and slight differences in detail, the following sketch may apply to all.

The zemindar pays a certain sum per crop, proportioned to the area irrigated; the number of waterings and the quantity expended in each watering, are not taken into consideration. Each rajbuha is divided into beats, varying in length according to the demand for water. On each of these a chokedar is placed, whose duty it is to keep an account of every field irrigated, and to report any infringement of the canal regulations. A chokedar's beat varies from 5 to 8 miles in length; and taking into consideration that the irrigating outlets in many of these beats often number as many as 25 to 35, with water-courses from 1 to 2 and even 3 miles in length, and that the boundaries between the different fields are often scarcely noticeable, and always changing, it may be imagined how untrustworthy the results obtainable are. After each season, or "fasl," measuring parties are sent out. In the case of the rubbee crops, the work begins about the middle of January; and for the khureef about the middle of August. In each party there is one mohurrir and two chainmen, and they are accompanied by the lumberdar and patwarri of the village, the owners of the fields and the chokedar. Each day's work is signed by the lumberdar, chokedar and mohurrir; then sent on to the zillahdar, who after verifying the papers, signs and forwards them on to the Executive Engineer, in whose office an abstract is prepared of the amount due by each irrigator; and on these abstracts the Deputy Commissioner of the district realizes the revenue, in instalments at stated periods.

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DISTRIBUTION OF CANAL WATER.

Fig. 1

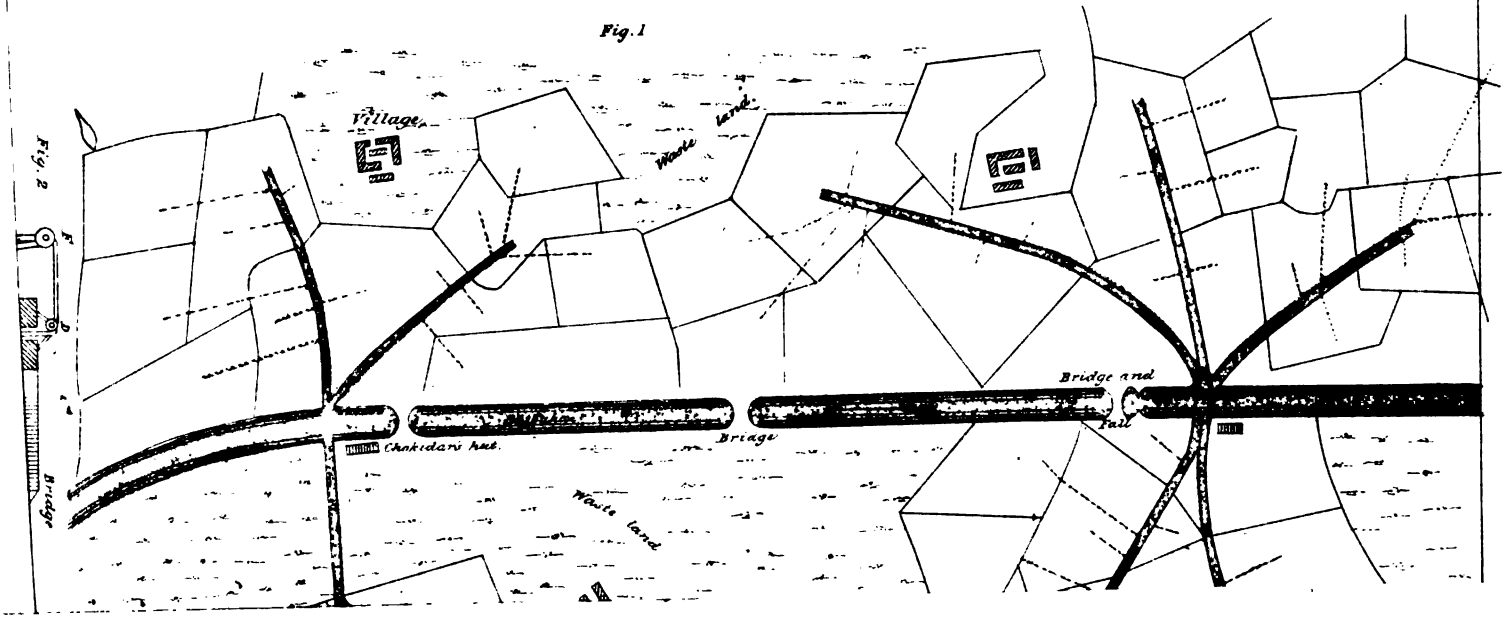

Fig. 2

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UNIV. OF WIGN.

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The disadvantages of this system are evident; for there is scarcely a satisfactory check on the work of any one of the many men employed. Nor is any inducement held out to the zemindar to make the most of the water. Besides, it entails the keeping up of a large revenue establishment, and gives rise to numerous law-suits and disputes. And when the supply in the canal is not sufficient to meet the demand, any amount of care and energy will not ensure a fair division, and every inducement is given to bribery and corruption.

It has been suggested that it would be preferable to make *accurate* surveys of the lands receiving canal water, on a scale sufficient to show each field distinctly, so that all that would be necessary is, for the chokedar to note the number of the field, and the area could be calculated from the map. This certainly does not make it the zemindar's interest to economize the water any more than the present system does. Besides, the surveys to be of any use must be extremely minute, and consequently, expensive. Again, the boundaries between fields are not permanent, so that this would entail the making of new and costly maps every few years. I believe that this plan is to have a fair trial on the Baree Doab Canal.

Another suggestion was, to run a mud wall round each portion of irrigated land, and charge a certain water-rate for it yearly; this does not appear to require any argument to show that it is not practicable.

The Italian system of irrigation belongs to the 2nd Class; as also the plan proposed by Col. Goodwyn. An account of the former will be found at page 200 of Vol. II. of the Proceedings of the Society of Civil Engineers; and the latter is described in No. X., of the Thomason College Papers.

But, supposing we have contrivances giving a uniform discharge under varying heads, how are they to be regulated? For it would be absurd to suppose that the irrigator, who only requires water at intervals, should be expected to pay for an outlet constantly running; and as each man does not irrigate to the same extent, we should require the outlets to be of *all sizes*, which would probably throw everything into confusion.

[Plan of distribution proposed where bed of rajbuha is below, and full supply line above, water surface, is given in the *plate*].

From what has been stated, it appears that the element of time requires also to be taken into consideration. Now, as everything depends upon the time the outlet is open, it is evident that, unless there was an agent of the canal constantly present, the irrigator would be tempted to take more

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than his due: therefore, to render the supervision free from this objection, the outlets in each beat must be confined to a certain point, and that there the chokedar should constantly reside. Supposing this plan to be adopted, to allow each zemindar to have a separate water-course and outlet from the rajbuha, would prove very inconvenient. To remedy this there should be one or more outlets on each bank at the head-quarters of the chokedar; from these Government kúls should be taken out and run for any distance that may appear necessary. The zemindars should connect their fields with the Government water-courses by the shortest cuts. At such points little masonry heads should be built, so that each man in turn may turn the whole of the supply into his own lands. The claims of the irrigators to take water can be easily adjusted by giving the largest and oldest irrigators the preference. From what has been already put forward, it would appear that the following afford the requisites for a satisfactory system for distributing the water and realizing the revenue, cheaply and fairly.

I.—The outlets must be confined to certain points, and here the chokedars should reside.

II.—Government kúls should be run out, as far as may be necessary, for each outlet, and irrigation should be carried on from these, and not direct from the rajbuha; this will do away with a large number of unsightly ditches, and as comparatively short cuts will connect the fields with the kúl, disputes about taking kúls through each others lands will be almost unknown.

III.—Some simple method of noting the time is necessary, and it should be such that any error (intentional or not) may be easily detected.

IV.—Half, at least, of the whole number of outlets should be capable of managing the largest supply that can be sent down.

As regards the 1st requirement, that all the outlets in a beat should be in the same place, no general rule could be laid down for their size, these depending on the wants of the irrigation and the size of the rajbuhas. However, their number must certainly be limited, or else the chief merit of the scheme, viz., its compactness, will be sacrificed. Again, the dimensions of the outlets must be limited, so that the discharges may not be so great as to prove unmanageable in the hands of a single irrigator, or so small that there results a great loss of time in watering each field.

As to the 2nd requirement, Government should construct the outlets and dig the kúls, the irrigators defraying the cost. All outlets and regu-

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lating heads should be built on a standard plan, so as to avoid any chance of confusion in making up the revenue papers. On the judicious selection of sites for outlets depends the efficiency of the scheme. *Plate* LVIII. illustrates the method of lining out. Here the Government kúls, are shown by double ink lines, the short cuts made by the zemindars by dotted lines, and the single lines show the boundaries of the different irrigated plots.

To meet the 3rd requirement, a clepsydra should be so constructed that any error of time would be at once noticed on looking over the returns. This check might be a *double register*, with some sort of an arithmetical relation between the two. The theory of numbers would enable one to devise any number of such checks, that any but a very smart chokedar would would not be able to comprehend. To simplify matters, the clepsydra might be constructed to run continuously for 24 hours, and the time denoted in a decimal of a day. Any discharge from an ordinary sized outlet for a period not exceeding $\frac{1}{100}$ of a day, or 14·4 minutes, would irrigate but to a very small extent; therefore, the irrigator should be prohibited from using the outlet for less than 14·4 minutes. This would do away with any inclination on their part for making vexatious demands for petty supplies of water. Two equal cones of sheet-iron connected by a pipe, and fitted into a stout wooden frame, would give a clepsydra, cheap and substantial. It is proposed that something like the following form should be sent in by the chokedar daily or weekly. They might be arranged and used like ordinary cheque-books, or Form No. V. of the D. P. Works.

Name of irrigator.	Reading on clepsydra.			Gauge readings.			Signature or seal.	Remarks.
	On opening.	On shutting.	Difference.	On opening.	On shutting.	Difference.		
Abdoolla,	1 / 1_a	2 / 2_a	3	4 / 4_b	5 / 5_b	6	Lumberdar Khoda Bux's seal. Abdoolla's seal.	Watered rice crops, by 3rd head from outlet, &c., &c.

Unless complaints are made, we have only to deal with columns 5 and 6. Taking the gauge reading, we look into the table of discharges for the discharge corresponding to this head of pressure, and multiplying it by the

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time, we find the quantity that is to be debited to the irrigator's account. To save the last calculation, tables in the following form might be drawn up:—

0 Foot.										30 A
	0	1	2	3	4	5	6	7	8	9
·05										
0·10										
0·15										
0·20										
0·25										
0·30										
0·35										
0·40										
0·45										
0·50										
0·55										
0·60										
0·65										
0·70										
0·75	...	...	...	...	...	...	A			
0·80										
0·85										
0·90										
0·95										
1·00										

Now, supposing a zemindar has had the use of the outlet for 0·36 of 24 hours, the mean head of pressure during the time it was opened being 0·75 feet. Turning over the pages of our book of tables till we see 1 foot (in big letters) in the left hand, and 30 A in the right hand corner of a page, we find that A^x is the value of what he has received, and this, in the case of making up the revenue papers, may show the money value, and for working out discharges, the actual volume.

By the head of pressure, I mean the difference between the level of water in the kúl and rajbuha, and supposing this head never exceeded 3·0 feet, 300 calculations of discharges would give the work done per unit of time to every hundredth of a foot; the value to every tenth of a foot might be checked by actual experiment and the rest interpolated. These 300 calculations × the 100 units of time (0·24 of 24 hours) would give a total of 30,000 products, or a set of tables showing the discharge under heads varying from 0 to 3·0 feet, and for any length of time not exceeding 24 hours.

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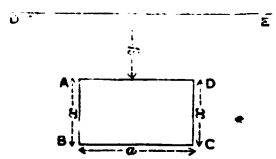
The checks necessary for verifying the correctness of the chokedar's reports have been already considered. We may now examine the relative value of simple orifices, whose discharge varies as the square of the head pressure, and outlets contrived to discharge equal volumes in equal spaces of time. The objections to the latter are, that requiring certain mechanism more or less elaborate, it is probable that men in charge would be always putting them out of order; and it is also very likely that the silt would injure them or cause them to give incorrect results. In the case of rectangular or triangular orifices whose areas vary inversely as the head of water, the complicated nature of the mechanism required would render their use almost impracticable. The following may be taken as an illustration. Here ABCD is a rectangular orifice, whose base BC is constant and equal to a; AB its height varies inversely as the square root of the head of pressure, and is put $= x$; DE, which shows surface level of water in rajbuha; and $y =$ depth to upper edge of orifice—putting the discharge $=$ D, we have



$$D = ax \times \sqrt{2g\,(y + \tfrac{1}{2}x)\,c}$$

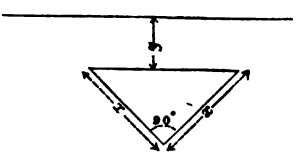
where x and y are the unknown terms, c the co-efficient of discharge, and $g = 32{\cdot}2$.

Fig. 2, will show the practical application of this equation.

Here ACB is the curve of which x and y are the co-ordinates, x being measured along BE and y along DE. C is a float sliding freely on the curve and on the vertical bar, FG, of the regulating apparatus. For calculation, the above equation may be reduced to the form—

$$y + \tfrac{1}{2}x = \frac{B}{x^2}, \text{ where } B = \frac{D^2}{2a^2gc} - a, \text{ a constant quantity.}$$

Again, if we take a right-angled triangular orifice, as shown in figure, the equation would be $D = \frac{1}{2}\,x\sqrt{2g\,(y + \frac{1}{2}\sin 45^\circ)\,c}$ which reduced to the form $y + \frac{1}{2\sqrt{2}}x = \frac{2\,D^2}{2gc^{\,2}x^4}$ gives an equation more complicated than the former.



The simplest module is an iron shutter with a slit in it—working in water-tight grooves, and rising and falling by means of floats with the

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supply in the rajbuha. To give accurate results this would require a clear fall.

As, however, all complex mechanical contrivances are liable to get out of order, it is believed that the simple outlet and a good set of tables would prove the most suitable. With such a system it is probable that the irrigating capabilities of canals would be developed to the utmost extent —it would entail scarcely any interference with the zemeendars, and act as a spur to the more enterprizing. If given a fair trial, many of the details could certainly be greatly simplified and improved by the suggestion of experience.

E. S.

Sept. 28th, 1865.

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No. CLXVIII.

SUPERSTRUCTURE OF BOAT BRIDGES.

Design for an improved Superstructure for the Boat Bridges on the Lahore and Peshawur Road. By Col. A. Taylor, R.E., C.B., *Superintending Engineer.*

To the Secretary to the Punjab Government, P. W. Department. 28*th May*, 1867.

When boats and superstructure were first prepared for boat-bridges over the Ravee, Chenab, Jhelum and Indus rivers, on the line of the Grand Trunk Road, the pattern of beam, which came up from Bombay with the teak built boats in 1845, was adhered to.

The beams were made 30 feet long and 10 × 6 inches scantling, and each beam crossed one boat and one bay. Their ends overlapped one foot, and each boat therefore supported 28 running feet of roadway.

Even in those early days, however, when our deodar forests were in full vigor, great difficulty was experienced in getting sound beams 30 feet in length, and recourse was had to scarfing, which was attended with two serious objections, viz., the scarfed beam was much weaker than the natural beam, and frequently gave way; and, again, the iron work used to form the scarf, necessarily projected above the level of the wood-work and prevented the roadway planks from bearing evenly on all the beams, and this was a cause of damage to them; there was also the further objection, that the boats were amply buoyant enough to support a much longer piece of roadway than 28 feet, and so they unnecessarily blocked up the surface of the river.

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These evils were most appreciated and felt at Attock, and gradually trussed beams were introduced there, of 30 feet in length, which gave a clear water-way between the boats of 28 feet instead of 16 feet. This was found to be a great improvement, for which Major Sandilands deserves the chief credit. It was, however, accompanied by a drawback—the weight of passing loads was thrown entirely on one gunwale at a time, and the rocking motion of the boats was greater than was desirable.

Lately these trussed beams have been introduced on the Chenab and Jhelum—and, I think, on the Ravee and Beas—and being alive to the necessity of reducing the amount of the rocking motion which their use has hitherto entailed, I made several experiments, when at Wuzeerabad, in the last winter, in concert with the Executive Engineer, Mr. Willson, which have resulted in an amount of success that was not quite anticipated.

I have now drawn up a sheet of drawings giving the full details of a system of superstructure, the result of these experiments, which developes the full advantage of the trussed roadway beams, and at the sametime entirely stops the objectionable rocking motion of the boats under a heavy concentrated moving load, which their use has hitherto entailed. It differs little from that in use on the Indus, at Attock, and in part at the bridge over the Chenab, at Goojrat, excepting in the introduction of stiffening planks and stiffening chains [*Figs.* 2, 4, and 8, and 6, 7, and 8], which prevent the boats from rocking.

I introduced these stiffening chains and planks when I was at Wuzeerabad in the early part of February last, and Mr. Willson informs me that they have not given the very least trouble since.

This system of Boat Bridge Superstructure, besides its superior efficiency and durability as compared with that hitherto in use, has the advantage of considerable economy, amounting to about Rs. 6 per foot run of bridge; or to Rs. 16,800 in the first cost of a bridge of 100 boats.

I would strongly recommend its introduction on all the ferries on the Trunk Road, from Lahore upwards.

I may, perhaps, with advantage, add, that all the boats and superstructure in use at the bridges in question were built and prepared on designs which I drew up many years ago, under Sir Robert Napier's instructions; so that my present recommendations merely supersede those which I myself made in 1850, after long experience of their working.

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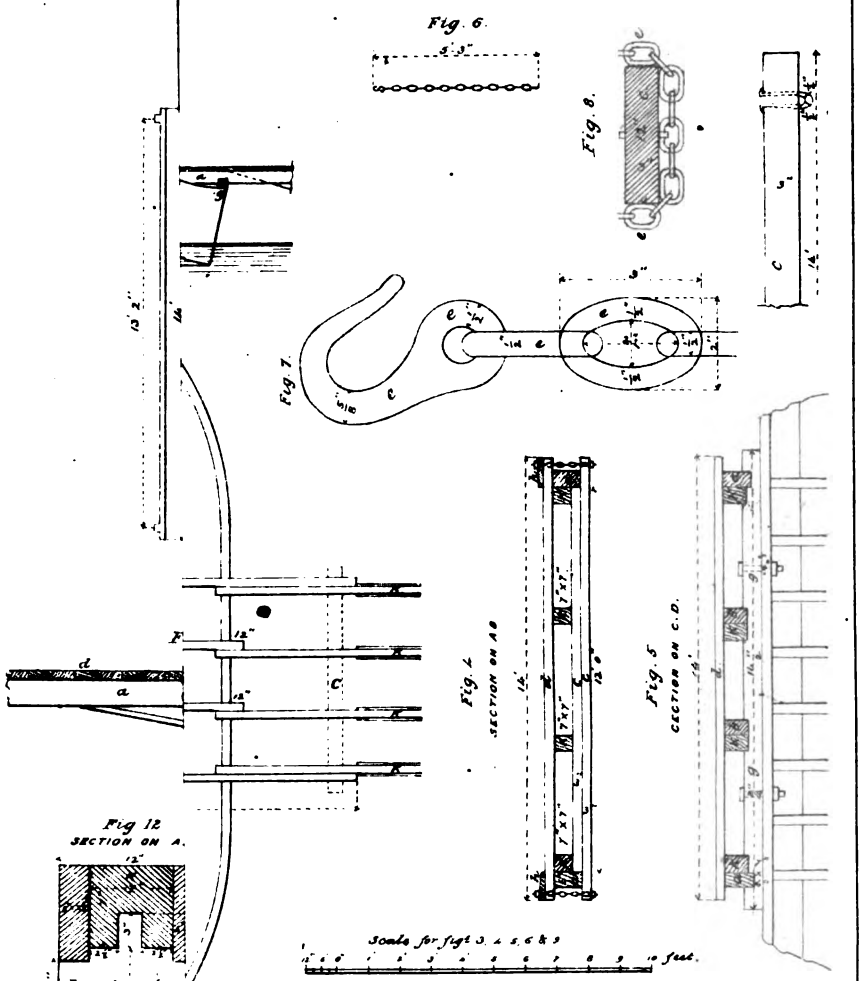

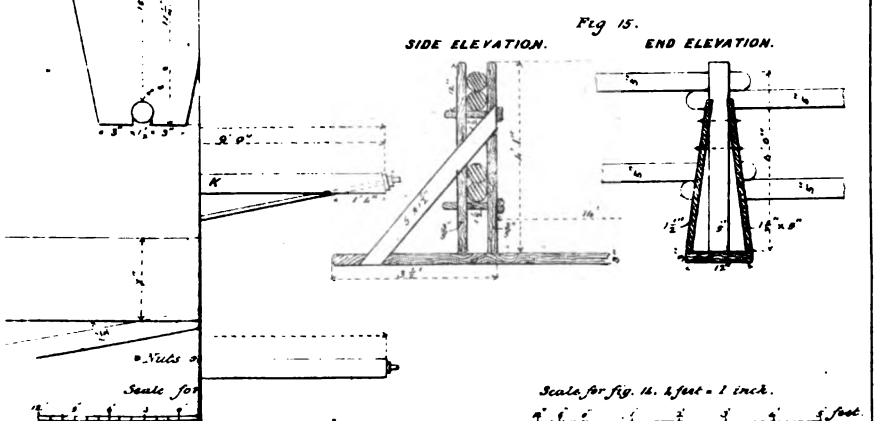

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Proposed Superstructure for Boat Bridges.

It consists of the following component parts:—

1. Gunwale pieces, *gg*—[*Figs.* 1, 2, 5.]
2. Trussed beams, *kk*—[*Figs.* 1, 2, 10, 11, 12, 13 and 14.]
3. Stiffening beams, *aa*—[*Figs.* 1, 2, 4 and 5.]
4. Cross beams, *bb*—[*Figs.* 2 and 5.]
5. Stiffening planks, *cc*—[*Figs.* 2, 4 and 8.]
6. Stiffening chains, *ee*—[*Figs.* 1, 3, 4, 6, 7 and 8.]
7. Rough wedges, *hh*—[*Figs.* 1, 3 and 4.]
8. Ordinary roadway planks, *dd*—[*Figs.* 1, 4, 5 and 9.]
9. Railing planks, *ff*—[*Fig.* 15.]

1.—*Gunwale pieces.* See *gg*—[*Figs.* Nos. 1, 2 and 5].

Each is a single piece of timber 14½ feet long and 8 × 8 inches scantling, secured to the gunwale by two bolts of round iron of ¾-inch diameter.

It has four notches of 1 inch in depth, to receive both the trussed and the cross beams, and two deep notches, to receive the stiffening beams, of such dimensions as to bring the top surface of the trussed and of the stiffening beams to a level. *Fig.* 5 shows all details.

2.—*Trussed beams.* See *kk*—[*Figs.* 1, 2, 10, 11, 12, 13 and 14].

They may be each of a single beam 30 feet long and 7 × 7 inches scantling, or each may be built of four pieces bolted together by round bolts of 1 inch diameter, as shown in the drawings. Each beam runs in over the boat 1 foot, and rests on the gunwale piece in a notch 1 inch deep.

3.—*Stiffening beams.* See *aa*—[*Figs.* 1, 2, 4 and 5].

These are stout beams of 10 × 6 inches scantling, placed, as shown in the *Plate*, two to each boat. Each should, if possible, be a single piece of timber 26 feet 8 inches long, but may be in two pieces scarfed together. They are let into the gunwale pieces to such a depth as to bring their upper edges and those of the trussed beams to a true even surface.

4.—*Cross beams.* See *bb*—[*Figs.* 2, 4 and 5].

Are 7 × 7 inches scantling and 13 feet 2 inches long, and rest on the gunwale pieces in notches 1 inch deep. They merely rest on the gunwale pieces, and are not fastened to them.

5.—*Stiffening planks.* See *cc*—[*Figs.* 2, 4 and 8.]

Each plank consists of two pieces. One main piece 14 feet long and 12 × 3 inches scantling, and a minor piece (spiked to it as shown in *Fig.*

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4) 12 feet long 8 inches wide, and of such depth as to compensate for the difference in thickness between the trussed beams and the stiffening beams (*kk* and *aa*) which in the *Plate* is 3 inches. They are placed, as shown in the *Plate* near the ends of the stiffening beams, and in every case immediately under a roadway plank.

Each stiffening plank is tightly lashed at each end to the roadway plank immediately above it, so as to allow no play whatever, by means of a chain here designated

6.—*A Stiffening chain.*—Which is shown in detail in *Figs.* 6, 7 and 8, and as regards its general application, in *Figs.* 1, 2 and 3.

Such a chain is passed round each projecting end of every stiffening plank, and of the roadway plank immediately over it; the hook with which it is provided at one end is passed into the nearest link, and everything is then brought home by the use of a rough wedge, *hh*.

The centre of each chain is secured to the under part of the stiffening plank by a stout staple [*Fig.* 8], which passes entirely through the plank, and is clenched on the upper side. The object is to prevent the chain from being lost in the confusion which often attends the dismantling of a bridge in a hurry, and often in the dark and in heavy weather.

7.—*Rough wedges.* See *hh*—[*Figs.* 1, 3 and 4.]

May be about 18 inches long. Their use is obvious.

8.—*Ordinary roadway planks.* See *dd*—[*Figs.* 1, 4, 5 and 9.]

Are 14 feet long, 3 inches thick, and as nearly 12 inches wide, as may be practicable.

The width for 6 inches at each end is to be reduced by 3 inches, as shown in *Fig.* 9.

Each plank is to be furnished with two hard wood cleats 3 × 2 inches, securely spiked on—see same figures.

9.—*Railing planks.* See *Fig.* 15.

Each plank is from 17 to 17½ feet long, and they may be placed at any convenient distance apart. The railing bars may be bullies of about 5 inches diameter, supported on treenails of 1½-inch diameter of hard dry wood.

A. T.

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No. CLXIX.

NOTE ON RESERVOIR MASONRY DAMS.

By Lieut.-Col. Fife, R.E.

In the "Professional Papers" for August, Vol. IV., a section of the proposed Dam in the Moota valley is given in *Plate* XLVI., and as the subject of the best section for works of this nature is peculiarly interesting at the present moment, when it is contemplated to carry on works of irrigation over a great part of our Indian possessions, the drawings attached to this paper will probably be considered valuable.

The Barrage d' Almanza was constructed in the 16th century, and is in excellent condition, which proves the general soundness of the design.

The Barrage de Gros Bois is also an old work. It has shown signs of failure and has been buttressed. The batter in this case is on the water side, and the section is recommended in the "Aide Memoire." It may be well adapted for an ordinary foundation, as its tendency to oscillate on a yielding foundation when the reservoir is alternately full and empty, may be less than when the batter is outside, but it is not well suited when a hard foundation is attainable and where a great height of Dam is necessary.

The Barrage du Furens is a recent work. Its height is 164 feet. The great pressure induced by such an immense column of masonry and water led the very ingenious Engineer, M. Delocre, who designed the Dam, to adopt the principle of equal pressure, and hence the curved faces and comparative lightness of the superior part of the section, which, at first sight, would appear almost too weak to retain the great head of water to which it is exposed. The thickness at top would no doubt have been still lighter,

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but that it was necessary to guard against the effect of the ice, which in that latitude attains a thickness of about 2 feet, and when broken up by a sudden thaw is driven by the prevailing wind with great violence against the masonry, which has thus to bear the most severe shocks, in addition to the ordinary action of the waves.

The Barrage du Ban is another, and more recent, design, on the equal pressure principle. It differs from the Barrage du Furens in having a higher pressure limit. The lower part of this profile is intended to show what the form would have been, had the height of the Dam been exactly equal to that on the Furens.

The information respecting these works has been extracted from a Memoire by M. Delocre, a translation of which for the use of the irrigation Department in the Dekkan is now under preparation, and will shortly be published.

J. G. F.

POONA,
19*th October*, 1867.

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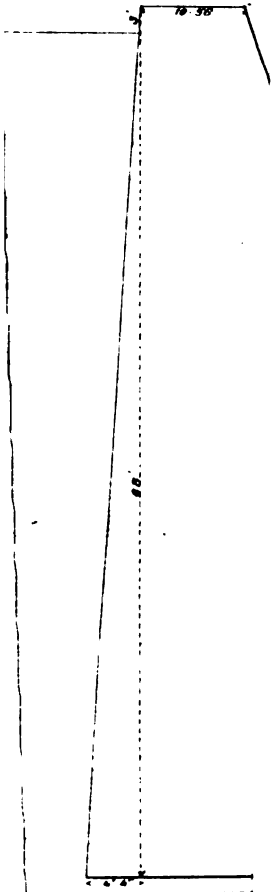
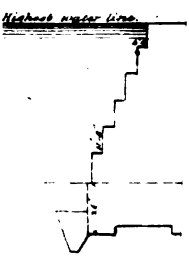
Moota Dam.



Barrage de Gros B



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No. CLXX.

DETAIL OF WORKING ON THE GREAT TRIGONOMETRICAL SURVEY.

(*2nd Paper*).

Recording observations.—It is not however sufficient to be skilful and scrupulous in the manual and optical processes of observing; equal care and attention must be bestowed on the registry of the data in the angle books, otherwise the care and skill bestowed on the observations will be entirely wasted.

An error in reading off a micrometer, or in writing down the reading, will produce just as great a discrepancy in the work as if the eye had made an error of the same extent in observing.

The observer should therefore give out the degrees and minutes in an audible voice, and the writer should repeat them while he is writing down. Unless this precaution be taken, errors may arise from peculiar pronunciation or defective hearing. Similarly, the readings of the micrometer heads should be given out distinctly to the nearest tenth of a second, and duly repeated by the writer. The figuring on the micrometer heads is seldom neatly executed, and a liability sometimes exists to mistake 30″ for 50″, and *vice versâ*, which, if it occur in the microscope, would affect an angle by nearly 7″, or the mean of the whole twenty-four angles by four-fifths of a second. Mistakes of this and similar kind can only be avoided by strict attention. The writer should examine when the observations are repeated, whether any reading is discrepant, and should give due notice to the observer of such an occurrence.

The book in which observations are recorded is called an *angle book*, and

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two of these books are kept on each series, one of which is used in the observatory, and called the "Original Angle Book," the other is a transcript of the former, and is termed the "Duplicate Angle Book." Of these, the former, when completed, will be transmitted to the India House, and the latter retained, as a record, in the Surveyor General's Office. The headings of the columns in the angle book are so explicit that no farther explanation seems necessary.

The angle book should on no account ever be suffered to fall in arrears. The original should be examined by two computers, and attested by their signatures, and the name of the observer should be recorded. The duplicate should be compared with the original by two persons, and attested by their signatures. It is a standing rule, in order to exclude errors, that all computations and comparisons should be performed independently by two persons, and attested by their signatures; and, unless such precautions have been observed, the results are considered untrustworthy as final work.

Observations should never be recorded on loose scraps of paper, or in pencil in rough books. The original record is always the most valuable document, and the labor of copying, besides being expensive, causes delay.

It is usual to add up all the angles observed at any one zero together, and divide them by the number, by which means you get as many sets of means as there are zeros, each mean being considered as an integral observation.

It is a fixed rule never to reject an observation, unless there be some obvious error in it. The circumstance of its differing, however widely, from the mean, is not a sufficient cause for its expunction.

Notwithstanding all the precautions which may be taken in making the observations, and recording them with fidelity and precision, it will be found that every mean angle is nevertheless burthened with small residual errors, which it is impossible entirely to eliminate, and which must therefore be dispersed in the subsequent office computations, agreeably to certain rules. These errors arise partly from imperfections in the instrument, and in the observer, and some part of them may also be attributed to other circumstances beyond our control. For instance, the image of an observed object is subject to distortion, on account of the rays of light passing through a medium of very variable density and temperature.

There is no reason to conclude that the vertical refraction is all in the normal of either extremity of the trajectory; but supposing this to be a

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rejectaneous consideration, still smoke and various vapours perpetually rising from the earth, have probably not an uniform density at a given height above the surface, and the ray, in its passage through these, must unquestionably be liable to lateral as well as vertical refraction. We see, in fact, both by night and day that this cause is perpetually in operation; for the small disk of an Argand lamp, which is only twelve inches in diameter, and in a clear, settled atmosphere is reduced to a luminous point, swells out sometimes for several nights in succession into a broad ill-defined blaze, subtending occasionally two minutes of the horizon, and vibrating more like a sheet of fire than an object intended for accurate intersections, whilst the visible disk of the heliotrope, formed by limiting the rays to an aperture of two inches diameter, is even wilder and more straggling.

The only method of overcoming these sources of irregularity is to await a favorable state of the atmosphere, and be prepared to profit by it when it offers itself. Such occasions occur for day observation almost every sunny day for a shorter or longer period, between half-past three p.m. and sunset. The lamps are also frequently well adapted for observation from sunset to past midnight, especially in the early part of the season, but at other times they are steadiest from after midnight till about sunrise.

In hilly countries, when the stations are placed on lofty peaks, with deep intermediate valleys, objects are less disturbed by atmospheric causes than under other circumstances. Very good observations may then be obtained for an hour or two after sunrise; but, in general, however promising the apparent state of the atmosphere may be at sunrise, it can rarely be depended on. It is at this period of the day that mirage is most conspicuous. Two or three heliotropes are sometimes seen piled one above the other, or placed side by side, and then, uniting together, form columns or pillars of fire subtending several minutes, although produced by the rays of light passing through an aperture limited to two inches in diameter. This kind of lateral refraction is however too conspicuous to betray, but there is another insidious sort which ought carefully to be guarded against, because at the time it is in operation, the visible disk of the lamp or heliotrope appears at first sight small, well-defined, and steady; if, however, it be carefully bisected on the wire, and then watched, it will be found after the lapse of a few minutes, gradually to diverge to one side, and after a shorter or longer time, will again move off slowly in another direction. This

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treacherous state of the atmosphere is very frequently in operation, and the only remedy is to watch carefully, and adjust the position of the telescope so that the object may appear to diverge equally on each side of the wire. With this precaution, good observations can be made, but each intersection occupies several minutes of time, and the observations proceed very slowly.

The accordance, or otherwise, of angles taken at the same zero, enables an observer to judge of the accuracy of his intersections, and the average errors of the triangles will show how far care and precaution have succeeded in eliminating the imperfections of the instrument, and other sources of error.

As perfect freedom from error is unattainable, success can only be judged from comparative approximation to the truth, and to enable an observer to form a fair estimate of his labors, compared with previous operations of approved merit, a table is subjoined showing the errors of ten consecutive triangles, taken from the reports of the undermentioned Series.

Table exhibiting the Errors of Ten consecutive Triangles of the undermentioned Series.

No. of Triangle.	Great Arc Series.	Amua Series.	Pilabit Terai Series.	North Long. Series.	Chendwar Series.	Bombay Long. Series.
	3-foot Theod. T. and S.	18-inch Troughton.	15-inch Cary.	18-inch Inst. by Col. Everest and Said Mohsin.	18-inch Troughton.	18-inch Dolland.
1	− 0·31	+ 0·71	− 0·79	+ 1·99	+ 1·52	− 1·04
2	− 2·75	+ 3·58	+ 2·07	− 0·45	+ 0·84	− 0·39
3	+ 0·10	+ 0·07	− 2·97	− 1·12	− 2·36	+ 1·92
4	− 0·06	+ 0·23	+ 1·58	− 0·78	+ 1·64	+ 1·11
5	− 1·18	− 1·80	− 2·48	− 0·68	− 0·32	− 1·70
6	+ 2·72	− 1·21	− 3·92	− 0·39	+ 0·50	+ 0·11
7	+ 0·12	− 3·20	− 0·33	+ 4·41	+ 0·62	+ 0·24
8	+ 1·09	− 1·89	− 3·49	+ 0·02	+ 0·88	+ 0·34
9	− 3·32	+ 0·39	+ 2·19	− 0·88	− 0·36	− 0·03
10	− 0·05	− 0·42	− 1·61	+ 2·20	− 0·38	+ 2·98
	1·17	1·35	2·14	1·29	0·94	0·99

Vertical Angles.

The relative heights of the stations of a trigonometrical survey are deduced upon the following principles:—

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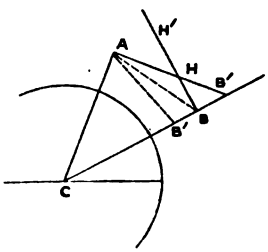

Although the lines BC and AC, which we will suppose to represent the directions of plumb lines at B and A, do not really meet at C, the centre of the earth, (or even meet each other at all, unless under the same meridian or the same parallel of latitude,) yet the variation due to the compression of the earth may, in estimating the difference of height, be omitted as rejectaneous, and consequently BAC will be a triangle, the angle at C being the angular distance between the two stations on the earth's surface. Now AH, BH' drawn prependicular to the radii will represent the planes of the horizon, consequently though B is more elevated than A, still it may stand at an angle of depression. Let A and B be the angles of depression at A and B, then it is easy to see that

$$C + (\tfrac{1}{2}\pi - A) + (\tfrac{1}{2}\pi - B = \pi,$$

or

$$A + B = C.$$

If one of these angles be an angle of elevation, the principle will remain the same; for, by writing $-$ E instead of B, the formula is still A $-$ E $=$ C.

Suppose now that both A and B appear raised by refraction, and the angles become A $-$ δA, B $-$ δB, or E $+$ δE; then calling these new values A', B', or E', the equation will be transformed to

$$C - (A' + B') = \delta A + \delta B,$$
$$\text{or } C - (A' - E') = \delta A + \delta E.$$

It is usual to suppose an equality between δA and δB, and putting each equal to ρ, the mean terrestial refraction, we get

$$\rho = \tfrac{1}{2}\left\{ C - (A' + B') \right\}$$
$$\text{or} = \tfrac{1}{2}\left\{ C - (A' - E') \right\}$$

If an isosceles triangle be made, by setting off CB' $=$ CA, then BB' will be the difference of height; also since $\angle$ B'AH $= \tfrac{1}{2}$ C $\therefore$ B'AB $= \tfrac{1}{2}$ C $-$ A $= \tfrac{1}{2}$ (B $-$ A) $= \tfrac{1}{2}$ (B' $-$ A') since δA $=$ δB.

The angle BAB' is called the subtended angle, because the difference of height is subtended thereby; call this angle S. Then if c be the length of the chord of the angle C, the difference of height will be deduced from

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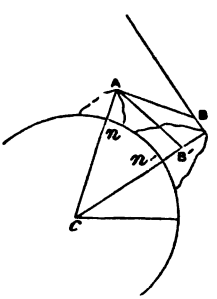
the equation $\frac{c \times \sin S}{\cos B} = c \times \sin S \times \sec B = c \times \sin \frac{1}{2}(B' - A') \times \sec B$, or $c \times \sin \frac{1}{2}(A + E) \times \sec B$. This equation is quite rigorous, and must be used when the depression is great, and consequently the difference of height considerable. For instance, when one station is on a lofty mountain, and the other in a low plain, the vertical angles may be very large, and the difference of height several thousand feet. But when A and B are small we may substitute unity for cos B, and then the ordinary formula for small differences of altitude becomes $\delta h = c \times \sin S$.

Several other considerations must now be made. The angles at both A and B are observed with an instrument which is elevated by a quantity a above the point whose height is sought. The corresponding angular value, therefore, or $\frac{a}{c \sin 1''}$, is a correction to be subtracted from all angles of depression, and added to all angles of elevation.

It sometimes happens that the vertical angles are taken to the top of an insufficient platform, which after being visited is raised; let the absolute height thus added be p, then $\frac{p}{c \times \sin 1''}$ is a correction which is to be subtracted from all angles of depression, and added to all angles of elevation, observed prior to the augmentation, in which case the new platform is treated as part of the mountain.

Daylight angles are often taken to the top of the flag-staff, or to an object raised above the station mark, in which case $\frac{f}{c \sin 1''}$ is to be applied positively to all depressions, and negatively to all elevations, f being the height of the object or staff.



Lastly, c to be accurate should be corrected for the height of the given station (A) above the sea, because c is the geodetic distance, nn', given in the triangle sheets, whereas the true distance AB′ is the element required in these computations. Therefore let h be the height of the given station (A) above the sea level, and r' the radius of curvature, then $r' : r' + h :: c : c + \delta c$, or, $r : h :: c : \delta c = \frac{c\,h}{r'}$ in which c may, as before, be taken for the measured chord, or measured arc, as given in the triangle sheets.

But it is the logarithm of $c + \delta c$, and not the natural number δc, that

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is required in the computations, and it will be more elegant, as well as expeditious, to deduce the correction to the log. of the geodetic distance. This correction is always additive, and may be found from the following formula:—

$$\text{Ar. Co. log. } r' + \text{log. M} + \text{log. } h,$$

the natural number answering to which, carried to 7 places, is the correction required for log. c. The term M of the foregoing formula is the modulus of the decimal system of logarithms.

The problem of determining the relative heights of two stations A and B rests upon the foregoing mathematical principles, and the practical part of the operation obviously consists in carefully measuring with the instrument at each station, the altitude or depression of the others.

It will be recollected that in page 5 it was assumed for granted that the refraction at both stations is the same; but, in order that this equality may become a probable occurrence, the back or reciprocal vertical angles ought, rigorously speaking, to be taken at one and the same instant.* But as that cannot always be managed, the next best method is to be careful to observe them about the same hour from noon, for then the errors caused by terrestial refraction are more likely to compensate each other. The best period of the day for observing verticals is the time of minimum refraction, which usually occurs about 2-45 to 3-45 in the afternoon. Long experience has proved that reciprocal vertical observations, taken to heliotropes at the period of the day above indicated, give the most accordant results, and may therefore be confidently relied on. If the stations are not visible at the time of minimum refraction, the precaution should be taken of observing them simultaneously, by means of two instruments and two observers.

Four sets of observations, two with the face each way, are sufficient at each station, and every occasion should be used, when the rays cross each other and form separate series, to get as many points of verification as offer themselves.

Vertical observations taken with the face each way, that is to say, with the face of the vertical circle in one instance to the left hand, and in the next to the right, are called *collimated* observations; because the mean of

* This was done on the Great Indian Arc, in crossing the plains of Hindostan, because the vertical angles were there subject to the influence of extraordinary refraction and mirage, on account of all the rays grazing along the surface of the ground.

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the two faces gives a vertical angle free from error of collimation, which is not the case with a single face.

The method of observing is as follows :—The instrument should be duly levelled and adjusted previous to the time of minimum refraction; and as soon as objects are steady, or nearly so,* direct the telescope to one of the principal stations, and having clamped the vertical circle, bisect the object with the horizontal wire, and note the hour and the minute at which the observation was made. Now read off the microscope of the vertical circle, according as the vertical angle may be an elevation or a depression, and let the readings be duly recorded in the angle book; release the clamp; turn over the telescope 180° in altitude, and the instrument round 180° in azimuth; bisect the same station again, and record the readings as before, together with the hour and minute of time at which the bisection was made. The mean of the two observations will give one collimated vertical angle. Repeat the last observation as before, and then reverse the instrument, and take another observation, which will complete the second collimated vertical angle. If these two be accordant they will suffice; otherwise a third, and even a fourth, ought to be taken. Now direct the instrument to another station, and take the vertical angles in the same manner, and in that way proceed until all the surrounding stations have been observed; but if the objects begin to rise, which will be ascertained from the depressions diminishing, or altitudes increasing, it will be necessary to desist for that day, and reject any observation which may have been made after the time of minimum.

When you arrive at a station which has been observed from one in rear, the back or reciprocal observations must be taken within a minute or two of the corresponding times. If any atmospheric change should appear to take place intermediately to the observations of the reciprocal vertical angle, the equality between the refractions, which the nature of the problem demands, is likely to be destroyed, and therefore too long a space of time ought not, if possible, to be allowed to elapse before the reciprocal observations are made.

* Heliotropes are seldom perfectly steady till 4 or 4½ p.m., but at that period they are beginning to rise at the rate of a second per minute. Although they may appear a little agitated at 3 p.m., still the refraction is then least, and the observations give the best results. In fact, any error arising from the agitated aspect of the heliotrope will be much less injurious than refraction, and indeed may be counteracted in a great measure by multiplying the observations, because the agitation of the disk does not produce a constant error in one direction, as happens in the case of uncertain refraction.

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In page 418 it has been remarked that corrections must be applied for the height of the instrument, and also for the height of the observed objects. The former should be carefully measured by the observer, and the latter by the men in charge of the heliotropes and lamps, so that on arrival at each station the heights of the objects may be duly measured, and noted in proper form.

Hitherto we have only considered the case of principal stations at which the back, or reciprocal, vertical angle can readily be observed; but it is clear that if the amount of refraction were known, the relative heights could be deduced from verticals taken at one extremity of a ray, whereby the height of intersected secondary points could be ascertained.

It is usual to estimate the terrestrial refraction in terms of the contained arc, that is to say, $\rho = n\mathrm{C}$, whence $n = \frac{\rho}{\mathrm{C}}$, and by the supposition of an equality between the refractions at the extremity of a ray, we obtain the value of n from all the observations at every principal station by the formula in page 417.

The mean of all the values of n at any station may therefore be adopted as a mean ratio of refraction to contained arc at that locality, and this mean refraction may without risk be applied to correct any single vertical angle taken to any secondary point; consequently, if D be the observed depression of that secondary point, and C the contained arc due to its distance, then $\mathrm{D} + n\mathrm{C} = \Delta$ will be the true depression cleared of refraction. Let the unobserved reciprocal vertical be D′ or $-$ E′, its corresponding value in vacuo being Δ, then as $\mathrm{C} = \Delta + \Delta'$, therefore $\Delta' = \mathrm{C} - \Delta$, and the subtended angle $\mathrm{S} = \frac{1}{2}(\mathrm{D} - \mathrm{D}') = \Delta - \frac{1}{2}\mathrm{C} = \mathrm{D} + n\mathrm{C} - \frac{1}{2}\mathrm{C}$; or, for an elevation, $\mathrm{S} = \mathrm{E} - n\mathrm{C} + \frac{1}{2}\mathrm{C}$.

Upon this principle may be deduced the relative height of a secondary point, from a vertical angle observed at one station only, without any corresponding back observation; but, in order that the factor n may be used with confidence, the vertical should be taken about the same time from noon as the other verticals from which the value of n is derived. Some observers adopt a mean refraction deduced from the whole series of triangulation, or they employ the factor deduced from other geodetical operations of known celebrity, such as the English and French trigonometrical survey operations; but the factor obtained from observations made on the spot appears preferable, as better adapted to existing circumstances

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of locality and atmosphere. It may be premised, *à priori*, that refractions observed in the climate of France or England are not likely to assimilate with others made in the torrid zone, nor is the refraction at a station little elevated above the sea, likely to be the same as the refraction on a lofty mountain, where the barometric pressure and temperature are so much smaller. Every consideration therefore seems to combine in favor of the adoption of a local value of the factor of refraction.

If a secondary station be observed from several principal stations situated at very various distances, the refraction can be inferred by another process, viz., by assuming a variety of different values for n, and finally adopting that value which furnishes the most accordant results. This method was adopted by Mr. H. Colebrooke, in determining the height of the mountain Dhawalagiri, situated to the north of Nepal.

The following extract from his paper is taken from Vol. XII. of the "Asiatic Researches":—

Station.	Distance in Miles.	Intercepted Arc in Degrees.	Altitude by Observation.	Height, allowing for Refraction.						
				$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{11}$	$\frac{1}{12}$	$\frac{1}{13}$	$\frac{1}{14}$
		° ′ ″	° ′							
A	89·35	1 17 51	2 48	24875	26663	27110	27476	27558	27626	27855
C	102·85	1 29 36·6	2 19	24348	26716	27308	27792	27900	27991	28294
D	136·35	1 58 48	1 22	21338	25494	26554	27384	27573	27773	28286
			Mean,	23520	26091	26784	27551	27677	27797	28145
			Extreme Difference,	3537	1222	774	408	342	365	439

"It is apparent from inspection, that the observations at the stations A and D agree best; and if that computation be nearest the truth, wherein the extreme differences are least, the conclusion will be, that the height is about 27,550 feet; such being the elevation deduced from the mean of observations calculated according to middle refraction."

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Correspondence.

THE Editor acknowledges with thanks the receipt of the following Papers:—Sand Pumps for Well foundations—Irrigation of Sindh—Maynee Tank Project—Bhatodee Tank Project—Completion of Mitrow Canal—Col. Rundall and Col. Anderson on the Ganges Canal—Iron Girder Bridges on the Delhi Railway—Lahore Central Jail—Brick making by Machinery—Reports on the Hurdwar Stone Quarries—Screw-Pile Lighthouses for India—Irrigation in Gujerat, Candeish and the Deccan—Embankments and Spurs on the Markunda River—Embankments in Bengal 1866—Preparation of Timber on the Boucherie system—Experimental Metalling on the Agra and Bombay Road—Work Rates on the Ganges Canal—The Alignment of Rajbuhas—Distribution of Canal Water—Upper Indus River Works—Regulation of Selye and Damooda Rivers—Reservoirs for the Damooda River.

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Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following Papers :—Wedge-bricks for Arches—Traffic on Roads, Railways and Canals—New Canal Module—Artificial Hydraulic Lime—Iron Mile Posts—Berar Specifications—Rewaree Slate Quarries—Irrigation in Ceylon—Analysis of Mysore Limes—Trials of De Lisle's Clinometer—Irrigation in Spain—Milroy's Excavating Apparatus—Tree Spurs on the Ravee.

To the Editor.

MY DEAR SIR,—I think it would be useful to the Profession generally, if room could be found, in some of the future series, for the late Government Reports on the Godavery and the Ganges works. The outer world has not the opportunity of obtaining copies of these interesting reports, and in these days when so many are turning their thoughts to the subject of Irrigation and Water Conservancy, and so much money is being spent on them, these and kindred reports cannot fail to prove acceptable.

One would like to know more of the Madras system of Irrigation, of the many tanks and anicuts, and system of sluices.

Sheets No. 74 and 75 of the Trigonometrical Survey Maps of India, exhibit the most extraordinary system of Tank creation that can be seen in any part of the world, showing that, during the dynasty of the Kings of Wurungal, the Telinganas were giants at water conservancy. We see every nullah, great and small, bunded up, and tank below tank created till the whole country looks gemmed. This is what we want done throughout India, but Government alone could not do it; no, nor if it was backed by all the surplus wealth and energy of England, could it do more than make all the Main Canals and large storage works. The people must assist in this work of regeneration: every village and town community must be induced to lend a willing help in making the minor channels and subsidiary tanks; and for this we must have something more attractive than a 30 years' settlement, or even a permanent one.

We sadly want Commissioners of Irrigation in the several Provinces; men gifted in several ways, capable of not only guiding the efforts of the people, but also of persuading them into assisting in such noble works. I can't believe it possible that such an extraordinary system of Irrigation and Tank formation as surrounds Hyderabad and Wurungal can have been the result of ought than rulers and people working harmoniously.

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For our great storage tanks, which must be made, we have yet to hit upon the best arrangement of sluices, capable of drawing off immense bodies of water under heads varying from 30 to 150 feet. For these works no precedents exist in Europe or Asia, and yet who can doubt the necessity for such great storage lakes, if we are ever to prevent the annual mighty floods, and economise the rain-fall for useful purposes?

Another great question is that of Waste Weirs. There are many immense tanks in Southern India which have failed from these being made too small. Once in a hundred years comes a mighty fall of rain, and the Waste Weir is found wanting; or again, there is an annual silting up going on in the bed of the tanks, and the people fail to keep the bunds up in due proportion, so that the calingulas which were formerly sufficient, become no longer capable of discharging the flood water. One sees many magnificient sites for tanks, but when a site for the necessary Waste Weir is sought for, it is not to be got, except at a vast outlay in cutting away the crest of a hill. In such cases, it strikes one that it would be advisable to erect a masonry bund, and allow the flood water to discharge itself over the same. The question here would be, How about the fall of large bodies of water for heights varying from 30 to say 100 feet? Could not a cushion of water, made of varying depths, according to the height of fall and quantity of falling water, be designed, so as secure the foundations of the bund from injury?

Excuse my addressing you on these points, as they seem to me to be such as require a multitude of councillors.

Yours faithfully,

R. M. B.

To print such Reports, as R. M. B. asks for, "*in extenso*," would simply be to exclude every other subject from these Papers. Interesting, doubtless, as Irrigation Works are to most Engineers in India, it is necessary to consult the tastes of all. Meanwhile, these Reports are not so inaccessible as R. M. B. supposes, and copies can generally be procured on application to the Press of this College, or to the Public Works Secretariat, by any one really interested in obtaining them.

In the present number R. M. B. will find much information on the subject (Tank Irrigation) which he names, and the remainder of Major Sankey's Report, which will be given next time, will be found equally interesting.

The method of building Waste Weirs proposed by R. M. B. is very common, especially in Mairwara and Ajmere (*see* Colonel Dixon's work on the subject), and is generally resorted to when a separate escape for flood water cannot be conveniently provided. When it *can*, however, the latter method is evidently preferable.

In contrasting the Public Works made by the ancient and modern rulers of India, as is so often done to the disadvantage of the latter, the system of forced labor, by which such great results were achieved must not be lost

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sight of. Such a system is a great power, where, as is always the case in a despotic Government, the intelligence of the rulers is in advance of that of the people; and there is no doubt that to this system, India was mainly indebted for her public works in former times. But whatever the capabilities of such a system, or the hardships inflicted by it, we have deliberately abandoned it, and it is impossible to recur to it now. We must perforce wait until education brings the people up to the level of the Government, before we can hope to see them work with us in constructing Public Works.—[ED.]

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Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following Papers:—Launching Girders on the Jubbulpore Railway—Notes on the Slide Rule—The Hindostan and Thibet Road—Colonel Fraser on Light-houses—Superstructure of Boat Bridges—Laws of Water in Motion—Notes on Retaining Walls, Part III.—Tracing Hill Roads.

To the Editor.

DEAR SIR,—I have read, with much interest, the Clinometer Reports printed in your number of Professional Papers for August, and should be glad if you would allow me space for a few observations on them.

Colonel Bell of the Bombay Engineers was the first to use the reflecting level for tracing roads. His instrument was heavy, having a large pear-shaped bulb of gun metal. A long screw, with large heads and a clamping nut passed through the bulb, and served to adjust the instrument to the required slope, with the assistance of pegs set out with a spirit level. The defects appeared to be its weight, and its want of self-adjustment.

I proposed to remedy these defects by diminishing the size of the bulb, and substituting a square sliding bar with a clamping screw, for Colonel Bell's long screw. Messrs. Cooke and Sons made up one on this pattern, but it was found to have this inconvenience, that the high slopes 1 in 5 to 1 in 20 had very open divisions, while in the flatter gradients, the divisions were too close together to be read by the naked eye.

Mr. Alfred Cooke then devised the instrument in its present form. The object of the double bar is to equalize the divisions.

The instrument is first adjusted to level, with both bars home against the stop, *g*. The light bar is then set back until the mirror is inclined at 1 in 50, and a stop is screwed in. After that the principal divisions are marked experimentally, and the remainder are filled in by interpolation. In every case, except where levels are required, the light bar must be set to the stop, *h*, before the heavy bar is set to the required division on the limb.

It seems to me that there must be some error in the drawing of your *Plate* XXXII.; the stops *g* and *h* in *Fig.* 1 are shown at the same end of the arc, where they cannot possibly both be; and unless the position of the stop *h* in the other figures differs very widely from my instrument, there would seem to be some error in them also. I

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enclose a correct tracing from a drawing prepared for the "Bombay Builder," showing the correct setting for 1 in 20.

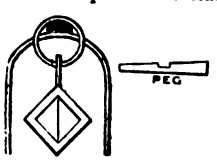
You will now see that I have very little claim to have the instrument called by my name, and that Colonel Bell or Mr. Cooke ought to have the credit of the invention.

Now, as to the objections: *The action of the wind* is considered a serious one. Lieut. Osborn, R.E., who used it with great success, got over this difficulty by giving his hand a very slight vibration, which sufficiently neutralised the oscillations caused by the wind to enable him to take good observations. A little practice will enable any observer to do the same.

Increase of size.—This would be sacrificing the advantage of handiness and portability; and, besides, cause greater fatigue to the hand and more unsteadiness in use.

Wire across mirror.—My instrument was provided with one at first, but was soon rejected, as it caused great fatigue to the eye in the attempt to bring three points together, viz., the reflected image of the eye, the direct image of the vane, and the cross wire. The latter is really unnecessary, as the centre of the pupil and the centre line of the vane are the proper objects to determine the observation and the small size of the mirror renders it easy to bring the reflected image of the eye nearly in the line of the diagonal. A slight error in this respect is of no consequence in road making.

I do not quite understand the objections made by Mr. Stanley Alexander to the suspension of the instrument. A chain an inch long would allow the mirror to turn and twist about, and the knife edge and link gives as delicate an adjustment as that of an ordinary balance. When placed in a wind-guard, as Colonel Bell's was, the ring should be passed through a slit in the lever, and secured by a peg with a notch to prevent slipping. This would always keep the face in the proper direction.



The instrument must of course be held at the proper distance from the eye, but this is soon learnt by practice.

The trouble of verifying the setting at each observation is very slight, compared to that of adjusting a theodolite.

Some gentlemen have suggested tripod stands, but in many cases these could not be used for want of slope to set them up. No provision was made for any stand at all; what is really required is a long stick with a crutch, which any carpenter can make in five minutes, of bamboo. It should be long enough to bring the mirror to the level of the eye when the hand rests on the crutch. Lieut. Osborn preferred a long rest, 3 feet long, to support both hands. In fact every observer would soon find out what sort of rest would suit him best.

I now come to Lieut. Browne's report, which is the most unfavorable of all. It occurred to me that he may have omitted to set the small bar to its proper stop when laying out his gradient of 1 in 20; I therefore, with the assistance of Captain White, R.E., marked off a distance of 26·4 feet from a wall, and took the difference of level between a mark made with the two bars of the instrument in their proper positions, and again with the two bars together. The difference was exactly 0·32, which multiplied by 100, would give the exact error he found in half a mile.

Perhaps Lieut Browne will be kind enough to verify this, and ascertain whether

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this supposition is correct. Otherwise either his instrument must have been a bad one, or his "personal equation," as astronomers call it, must be very large.

Lieut. Osborn's report, which is perfectly reliable, shows that a considerable amount of accuracy can be obtained with the instrument.

A clinometer seems to be in common use on your side for tracing roads. A short description of it would be interesting to us. We generally use the theodolite here.

Believe me, yours truly,

A. DE LISLE.

BOMBAY,
10*th September*, 1867.

QUERY.

To the Editor.

DEAR SIR,—The objection to the employment of steamers on canals is, that the waves or swell caused by the paddles are injurious to the banks. Might not this be practically avoided by having a series of paddles, individually of small width, on a long narrow framework carrying merely the machinery, the cargo being stowed away in a train of barges? On an irrigation canal, where the supply may be considered unlimited, the lockage would not be more expensive even if the whole train, without being disconnected, were transferred to the different levels.

In canals solely designed for navigation, as is the case in England, the supply is limited, and every cubic foot of water that is saved in lockage is so much gained; but on Indian canals there is always an enormous surplus going over the falls, so that chambers of the smallest possible dimensions are really not wanted. Instead of the usual chamber, about 16 feet in width and 100 feet long, large reservoirs might be constructed capable of containing a whole fleet of boats. Provided the gates were well protected by long spreading wing walls, the rest of the work would not need revetment, and most likely the reservoir might be built for less than the massive masonry chamber. The former might be filled and emptied as quickly by carefully distributed inlets and outlets as the latter; the boats only would feel the fluctuation in level whatever the quantity withdrawn or supplied, and the working of the gates depends only on the depth, and not the superficial extent of the chamber or reservoir. Fuel for the steamers could be easily grown on the canal spoil; besides, a large supply could be obtained from trees growing spontaneously on the water's edge, if these were allowed to grow to any size, and thus an annual expenditure for cutting jungle not needed. Still water canals connecting the principal places of commerce with the main or irrigation canal, would give a prefect system of water communication. In a mutiny a railway is more easily damaged than a canal.

Yours faithfully,

S.

Punjab, 4*th Oct.*, 1867.

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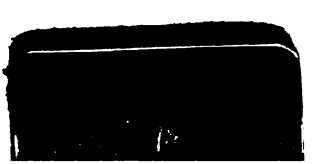

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