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THE COMPLETION OF KALABAGH BRIDGE.

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Introduction.

A paper (No. 145) was presented to last year's Congress describing the construction of the railway bridge at Kalabagh up to the close of the working season of 1929-30. The present paper is written to complete the narrative up to the opening of the bridge in August 1931, and to amplify certain points of which a full description could not be given in the previous paper for lack of space.

Modification in design.

The original design for the bridge provided nine spans each of 250 ft. clear (263 ft. centre to centre of piers) approached from the Mari side by a bank about 700 ft. long. This bank was washed away in the record flood of August 1929 and three of the partially sunk wells were badly tilted.

During the winter of 1929-30 the question of what modification was necessary was carefully considered. Although the existing design afforded ample waterway for normal floods, it was felt that extraordinary floods such as occurred in 1929 and 1878 must be provided for by an increase in waterway, and it was accordingly decided to bridge the river from bank to bank. Thus there would be no approach bank or protection bund to be maintained against the attacks of the river, and it was also felt that the increase in waterway would have the effect of lessening the severity of the scour around the mid-stream wells.

The length of the spans to be used in the additional 700 ft. of waterway had next to be decided. From experience with the existing wells in the great flood, it was possible to fix the safe depth of foundation for the extension wells at forty to forty-five feet, and with such foundations the economic span worked out somewhat under 200 ft. These economies, however, would be upset if, through failure to right one or more of the tilted wells, special spans had to be employed in the original bridge thereby rendering two or more of the 250 ft. spans surplus. These spans had been delivered at site, and it would therefore pay to use them rather than keep them in stock for an indefinite period. In this case the 700 ft. extension would be bridged by using two of these spans with the addition of a new span of about 175 ft. On the other hand, if all the tilted wells were successfully righted, the extension would be economically bridged by four spans of 175 ft. The exact length of the spans was fixed to suit piers at 174 ft. 4 in. centres thus three such spans bridged exactly the same length as two of the 250 ft. spans (263 ft. centres of piers).

The advantages of this were twofold. Firstly, the construction of the new Mari abutment and first pier could safely be started without being certain that the tilted wells would be righted, as the space between the first and the original abutment of the bridge (well A) was equally suitable for two of the 250 ft. spans or three of the 175 ft. spans. Secondly, the Consulting Engineers could be instructed without delay to get out the design for the 175 ft. span, as one would certainly be needed. In the meantime the result of the efforts to right the tilted wells would show whether one or four would have to be ordered.

Designs of wells for extension piers.

The experience gained in the sinking of the original wells was made full use of in the design of the wells for the extension piers. The original wells had been sunk by open dredging to a depth of about forty feet, but from thirty feet onwards the difficulties had been great and the progress slow. For depths beyond forty feet the pneumatic process had been found necessary.

It was therefore essential to design the wells so that the pneumatic process could be employed on them if required. Consequently, they were designed as caissons, twelve feet high, so as to provide a working chamber of adequate height and volume, (See fig. 1.)

In the original wells the junction of the curb and cant plates was formed by an 8″×6″ angle with the 6″ leg horizontal. Thus there was no cutting edge, but the caisson while sinking was supported by a comparatively broad base all round. A cutting edge has been improvised and fitted to six of the wells, which produced a 50 % improvement in performance over the wells not so fitted. It was therefore decided to incorporate a cutting edge in the new design.

The original caissons were designed so that during sinking a dome could be lowered to the bottom of the shaft and clamped to a seating ring when it was desired to close in the top of the working chamber in order to employ the pneumatic process. When the well was fully sunk the dome was removed and used again on another well.

In the original wells the dredging hole had been inconveniently small (8′-2″ diam.) as its side had been governed by the limits to which a removable dome of cast steel could be made without undue weight and cost. As it was essential to provide a much larger dredging hole to give the open dredging process a fair chance, and as large steel castings are not easily procured in India, a cheap dome was designed instructural steel which could be concreted in place and left in permanently. Referring to fig. 2 it will be seen that the mouth of the working chamber is 9′-6″ by 9′-6″, while the diemensions of the shaft are 10′-6″ by 10′-6″ Thus a ledge six inches wide is formed all round on which the dome can rest. The dome itself was 10′-0″ by 10′-0″ to allow adequate clearance while lowering it down the shaft, and was made in three pieces of three quarter inch plate, stiffened on the upper side by a half inch plate seven feet diameter, and by channels arranged radially. The stiffening on the lower side consisted of similar channels, parallel to each other, and at right angles to the joints in the three quarter inch plate. The ends of these channels were bevelled, to guide the dome into the mouth of the working chamber when being lowered into position, while to centre it finally, angle cleats were fixed round the edges to bring it exactly into place with a three inch bearing on the ledge all round. The centring of the dome would be done by a diver, who would also make the joint between the first section of air shaft (which was attached to the dome) and the remainder of the air shaft reaching to above water level, the sections of which would be bolted together in the open air and lowered down until the bottom end rested on the section attached to the dome. After this joint was made, the space between the air shaft and the wall of the dredging hole would be concreted in.

The height of concrete required to resist the upward pressure of the air on the dome was calculated as follows :—

The area of the dredging hole is 98·4 sq. ft. and the area of the mouth of the working chamber is 80·6 sq. ft. The area of the space between the air shaft and the dredgin hole is therefore 98·48—80·6=17·8 sq. ft. If the depth of the cutting edge below the surface of the water be *d* ft. the pressure in the working chamber would be that due at head of water *d* ft. height, or *d*-2·3 lbs. per sq. in., and this would be the upward pressure on the dome. As the dome is approximately 12 ft. above the cutting edge, the corresponding downward pressure on the dome would be (*d*—12) 2·3 lbs per sq. in. Thus there would be a nett upward pressure tending to lift the dome off its seat of 12-2·3=5·22 lbs. per sq. in giving a total lift of 5·22×80·6×144=60585 lbs, or 26 tons say. The weight of the air lock and 32 ft. of shaft being about 6½ tons, there would be a nett upward lift of 19½ ton. This lift would have to be balanced by filling the space between the dredging hole and the air shaft with concrete to a height of *h* ft., *i.e.*, by substituting concrete at 146 to 148 lbs. per c. ft. for water at 62·5 lbs. per c. ft. The height *h* would then be found from

$$h \times 17{\cdot}8 \times (147 - 62{\cdot}5) = 19\tfrac{1}{2} \times 2240$$

to be 30 feet.

The grip of the concrete on the sides of the dredging hole, and its keying into the inequalities of the steining would offer enormous resistance to any lifting of the dome, and constitutes a more than adequate safety factor.

Owing to the excellent performance of the new caissons in sinking to their full depth without any trouble, the need for these domes never arose, but one was completed and others partially made and kept ready for use if required.

Working season 1930-31.

The work programme for the season 1930-31 was :—

(*a*) Original Bridge.

(*i*) To complete the sinking of well E. This well had been straightened in the previous season, but 26 feet of sinking was left.

(*ii*) To complete the straightening of well F, and sink it to its full depth. (This well had been tilted to about 1 in 3 in the flood of 1929, and at the end of the 1929-30 season the tilt had been reduced to about 1 in 4).

(*iii*) To float out, pitch and sink well G.

(*iv*) To build 5½ feet of pier masonry on all the wells (except A, B and C, on which this work had already been done).

(*b*) Extension.

(*i*) To pitch and sink the three new wells.

(*ii*) To build the new abutment (on open founds).

(*iii*) To build the superstructure of piers and abutments to their full height.

(*c*) Girder Erection.

(*i*) To erect the first four 250 ft. spans from the Mari bank leaving five spans for the following season.

(*ii*) To erect the four extension spans after the four main spans, as they lie over a part of the river bed which is not usually covered with water till the latter part of June.

There was an early fall in the river, and in the first week of September it was possible to get the concreting boats out to well E and build on four courses (11 feet) of steining by the middle of the month.

The air locks were refitted and pneumatic sinking started on the 19th. The well still had a cross tilt of 1 in 38 remaining from the tilt given it by the floods of 1929, and to rectify this, four 44 ft. girders were placed transversely on the well, and kentledge loaded on the overhanging ends, the other ends being held down by cross pieces secured to the 2" diameter bond rods and to special large Lewis bolts extending some 4'-6" into the steining. These measures righted the well during the sinking of the newly cast length of steining, and after that, sinking and building progressed uneventfully until the well reached its designed depth (on November 11th.) and was plugged.

The river continued to fall during September, and by October 5th. the current became slack enough to float out the caisson for well G to its approximate position. The depth of water in which it had to be pitched was expected to be about 20 or 22 ft., and as the height of the caisson and first strake was 16 ft., two extra strakes each of 4 ft. had been provided, giving a total height of 24 ft., thus allowing a freeboard of 2 ft. over the deepest water expected. The caisson and first strake were launched without the additional strakes, partly to avoid top heaviness in launching and towing, and partly to keep the top of the floating caisson reasonably level with the decks of the barges between which it was floating. If the two strakes had been added, the empty caisson would have had insufficient headroom under the gantry erected on the barges to allow for the suspending tackles, and all concrete would have had to have been lifted up from the mixers on the deck of the barges before it could be placed in the caisson.

Accordingly only the caisson and first strake were launched and towed to approximate position. Concrete filling was started, and as the caisson sank in the water another strake was added while its horizontal joint was at a convenient height for riveting, and then concreting continued. The river bed at the position of the well was levelled up by divers, and when the cutting edge reached a depth about one foot above the proposed level, it was prevented by the suspending tackles from sinking further, and about 30 tons more concrete put in. It was then brought into position and the tackles lowered off. This was done on October 12th., and after final adjustment the caisson was within one and a half inches of correct position. Concreting of the caisson was resumed at once, so that the cutting edge should get a good grip of the bed without the slightest delay. Sinking by open dredging was started on the 22nd. and continued till the end of November, when, after striking several times the well refused to go further by open sinking. The well was 19 ft. embedded, and had reached a depth of R. L. 651. From experience with other wells it was known that the pneumatic process was required from now onwards, and accordingly preparations to make the change over were put in hand. There was some delay here, as at the time open sinking was finished, the divers were fully occupied on well F and the removal of the shafts and domes from well E had to wait for about a week. When the work was started, it was found that the removal was very difficult, as the domes had been in place some nine months. Spoil from the shoots which had fallen down the shafts had consolidated on top of the domes, and it was a long and laborious task to clear the clamps, which secure the dome, sufficiently to open them.

Consequently, it was December 13th. before fitting up the domes, shafts and locks on well G began, and sinking under air was started after the Christmas holiday. Sinking and building went on uninterruptedly until the middle of February, when a slight but obstinate tilt towards Kalabagh side gradually increased to 1 in $37\frac{1}{2}$. As this was above the allowance of 1 in 50 laid down in the specification for the bridge, steps had to be taken to correct it. It was decided to remove the material on the Mari side, particularly a heap of spoil which had accumulated there and so release the pressure on that side and give the well room to move over. To assist the movement a load of rails would be cantilevered out from the Mari side. A barge was rigged up with two Scotch derricks for dredging and brought alongside, and grabbing started on the night of the 22nd—23rd. Grabbing was done until the side of the well was exposed for a depth of about 15 ft., and as after that no further progress in depth was being made, owing to the sides fallinginto the hole, it was stopped there. While grabbing was going on large Lewis bolts had been let into top of the well and grouted in with Swasticrete. The girders were fitted up and loaded with 30 tons of rails by March 5th, a righting moment of 600 ton-feet being obtained. On the 6th an improvement in the tilt was made to 1 in 46, and the next day of about 1 in 60, *i.e.*, to within specified limits. There was little improvement after this, as the well was embedded nearly 50 feet the best reached being about 1 in 70. Thereafter the tilt gradually worsened again, and was 1 in 63 when the well was finished.

The last few feet of sinking on D took rather longer than the average. As wells F and G were at about the same level and both approaching their full depths, it would have been inconvenient to have had the plugging and pier building going on simultaneously on both, and it was therefore decided to push on with F and get it finished well before G. The usual daily shifts worked on all wells were three of six hours each, which with the times taken at the change of the shifts for the supervisors to communicate special instructions to one another and for changing tools, etc., occupied nearly 21 hours out of the 24, leaving about three hours for blowing down the boiler and cleaning the fire. When the wells were nearly down, the pressure under which the men worked was about 30 lbs. per sq. in. and the length of shift was reduced to five hours and the number of shifts per day increased to four. The shifts on G were reduced from three to two by transferring one shift to make up four on F. This arrangement continued until F was finished on March 13th., after which four shifts were put on G, resulting in greatly improved progress. Well G was sunk to R. L. 615·5, which depth it reached on March 24th.

Owing to well F having been straightened in the first half of December, or about one month earlier than had been expected, and also owing to the good progress which had been made on the other works, it had been decided to make a push to get all 250 ft. spans erected before the close of the working season, and well G was therefore stopped two and one half feet short of its designed depth so that the plugging could be done and the pier courses cast in time to fit in with the accelerated programme.

Of all the work to be done during the working season of 1930-31 the job which provoked most anxiety was the straightening of well F.

The scheme had been worked out during the previous season, and had been put into operation at the very end of it. In the short time available (some five weeks) before the rise of the river covered the well top, and the swiftness of the current made approach to the well a distinctly dangerous business, the longitudinal tilt had been reduced from 1 in 3·3 to 1 in 4·1, and the cross tilt from 1 in 8 to 1 in 10.

It is evident that in righting a tilted well the initial movement is the most difficult to attain, as the centre of gravity is away from the centre of the base of the well, and the moment to be overcome is at its maximum. Every movement in the right direction brings a corresponding lessening of the moment as the centre of gravity approaches the centre of the base of the well, and in the last stages of straightening, progress is easy and rapid. Moreover, once the initial movement has taken place, the grip of the earth on the skin of the well is lessened, leaving it freer to move.

The progress secured had made it almost certain that the well could be righted in the next low-water season, but the difficulties which were being experienced at the time work was suspended had been sufficiently serious to make the progress of the last few days almost negligible, and more than sufficient to make those responsible for the righting operations to feel that they were by no means "out of the wood."

As the special methods adopted to right this well were only lightly touched on in the paper presented at the last session a full description will be given here.

At the end of the working season of 1928-29, well F had been sunk about 22 ft. into the bed, and had 10 courses (each 2 ft. 9 in. thick) of concrete steining cast on top of the 16 ft. caisson, giving it a total height of 43½ ft. The cutting edge had reached R. L. 650, and the progress during the last two feet of sinking had been only two inches per day. As it was past the middle of May and the river had risen, work could not be continued on the well and it had to be left till the pneumatic plant could be used on it in the next season. The toughness of the material in which the well was embedded made it appear safe to do so. The floods of 1929, however, were exceptional ones, one of them beating all records. The local scour around the well caused by these floods was considerably more than the depth the well had been sunk, and it was underscoured to such an extent that it acquired a tilt of 1 in 3·3 upstream, and of 1 in 8 crosswise. In other words, a point on the top of the well on the upstream face 11½ feet was lower than the corresponding point on the downstream face, and similarly there was a difference of 2·8 ft. between points on the Mari and Kalabagh sides of the well. The maximum tilt measured diagonally was 12 ft. 3 in. The sinking of the upstream end of the well had taken the top of the well below water level at all seasons of the year ; it was therefore determined to attempt to right the well by pivoting on the centre bar, as the movement would bring the upstream end of the well out of the water.

The weight of the well in water was 980 tons, and the centre of gravity was estimated to be about 7 feet upstream of the centre bar. Thus a moment of 6,860 ton-feet was required to overcome the adverse moment due to the weight of the well. As in addition to this there would be other resistances due to the frictional grip of the earth on the sides of the well, and some direct crushing of material under the cutting edge, it was determined to try to get a moment about 50°/₀ more than he adverse moment due to the weight of the well. The first method considered was the cantilevering of a load over the downstream end of the well. Four old girders, 65 ft. over all were fortunately available with the North-Western Railway Bridge Department at Jhelum, which made excellent cantilevers after flange angles had been added and stiffeners fitted at the middle of each girder where the reaction from the well top occurred. These girders were laid diagonally, across the well top, in the line of the maximum tilt, and their inner ends were held down by every available bond rod and by a number of large Lewis bolts let into the well top some 3 ft. and strongly grouted with 1 : 1 : 3 concrete. Each of these bolts was calculated to be good for 20 tons, with a factor of safety of 2·15, and their combined strength, sufficient to withstand the upward lift due to a load of 150 tons of rails distributed over the cantilevered portion of the girders. This load of 150 tons generated a moment of approximately 2,000 ft. tons about the centre bar.

As this cantilevered kentledge provided only about one-fifth of the moment required, other expedients were looked for. An article in the "Engineering News Record" describing the righting of a tilted caisson in New York harbour by hanging heavy weights from the higher side gave the hint for combining this method with the cantilevered load. Accordingly, a crate was designed to hang on the downstream face of the well, big and strong enough to hold about 90 tons of pig iron (weighed in water). It was made of old double-headed rails, and weighed about 8 tons, thus giving a total load of nearly 100 tons. As the well had a side tilt, the connection by which the crate was hung had to be self-adjusting as the well straightened up. This object was attained, and the 100 ton pull divided into manageable units by the arrangement of pulleys shown in plate XVII accompanying paper No. 145.

The moment obtained from the crate on the downstream face was 1,900 ton-feet, and a second crate was provided on the adjacent inclined face on the Mari side, from which a moment of 1,600 ton-feet was obtained.

An additional moment could be applied by realising the air from the downstream working chamber, and keeping the pressure on in the upstream chamber. The upward pressure of the air on the roof of the working chamber gave a lift of about 400 tons, and a moment of some 1,200 ton-feet about the centre bar. The sum of the moments obtained from these three expedients totalled 6,700 ton-feet almost exactly the same as the adverse moment of the well, *viz.*, 6,860 ton-feet. It was intended to provide the balance of 160 ton-feet and the additional moment necessary to overcome the skin friction by jacking up against the roof of the upstream working chamber with four hydraulic jacks, from which a moment of 4,800 ton-feet was expected. Thus the scheme provided a total moment of 11,500 ton-feet, or some 65% more than the well's adverse moment.

In carrying out the scheme, the first step was to dredge away the earth at the downstream end of the well to make a pit in which the crates could hang, and also to make a space into which the well could move over as it approached the vertical. Dredging was started in the latter part of January 1930 and continued until the middle of March, when an excavation in front of the downstream end of the well had been made to about $3\frac{1}{2}$ ft. below the cutting edge, which extended on both sides of the well nearly to the centre. Simultaneously with the outside dredging air-lifts had been put to work down both shafts to clear them and the working chambers. Soundings down the shafts had shown that the chambers and the shaft were completely filled with silt to within a dozen feet of the top. While the dredging was going on, the crates and the special pulleys for suspending them were being manufactured, the Lewis bolts which were provided in addition to the bond rods for holding down the inner ends of the cantilever girders were grouted in, and the concrete allowed to set, and the catheads for suspending the crates fitted in position. The domes closing the tops of the working chambers were also fitted, and the air-shafts erected up to the level of the top of the well.

Between the 17th and 26th March, the crates were hung on the catheads, the 4 girders erected in position, the air-locks fitted, and the crates and cantilever girders partially loaded. On the evening of the 26th March the air was put on, and on the 28th morning a first inspection of the downstream working chamber was made. Only a small part of the floor could be seen, the rest of it being covered with water of varying depth. However, by wading in the water and silt it was ascertained that the earth was clear of the sides and downstream face of the chamber. On the next day the upstream chamber was inspected. Here no ground at all was visible, but only an expanse of water agitated by the air gurgling through to the downstream chamber at the top of the manhole. As it appeared that the downstream half of the well was free to move, it was decided to concentrate on the work to be done in the upstream chamber, and accordingly ashes and bags filled with cinders were dumped down the shaft to get a dry platform in the chamber. On April 2nd two hydraulic jacks of 100 tons capacity each were taken down and put into operation, but before they had exerted their full power, they had pushed down the timbers on which they were set nearly 20 inches into the soft "made ground" of ashes and silt. As it appeared that jacking from the waterlogged ground was ineffective, it was decided to lower the water level in the upstream chamber so that the ashes and silt could be removed, and the jacks based on the *pucca* ground. A digression to explain how this was to be done is necessary here.

On referring to Fig. 3 it will be seen that air, if let into the downstream chamber under sufficient pressure, will drive the water down to the level of the highest point of the cutting edge, and will then escape. Thus, however much air is pumped in, the water level cannot be lowered further, and at the centre of the well there will remain a depth of half the tilt, *viz.*, nearly six feet. Similarly, air pumped into the upstream chamber will drive the water down no further than to the top of the communicating manhole, and will then pass into the downstream chamber, leaving the centre bar submerged about 5 ft. If the manhole were closed by a tightly-fitting door, and the air pressure in the upstream chamber raised a little more than 2 lbs. per sq. in. above that in the downstream chamber, the water in th upstream chamber would have to be driven down to the highest point of the centre bar before the air could get out, thus drying out the upstream chamber.

The first step in fitting the door was to make an excavation in both chambers in which to work, and this was not accomplished without great difficulty, as all digging had to be done under water, and the space dug out was continually being refilled by fresh silt and ashes slipping in. It was, however, done, and the earth revetted as shown in Fig. 3. After making several unsuccessful efforts to fit a door made in one piece, a new door was made, designed in three pieces with horizontal joints. Thus when the top piece was fitted, the water was lowered by approximately one-third of the diameter of the manhole, say a foot. The middle piece was next fitted, which lowered the water a second foot, and, finally, the last piece was fitted which drove the water down to the bottom of the manhole, and after the joint had been caulked, the water was pushed down to the centre bar. This job took till April 11th. The fitting of the door under water was one of the toughest jobs imaginable, and by the time it was done, all hands were at their last gasp through working for hours on end in water, and suffering more or less from "bends" through being decompressed while soaked through and with lowered vitality.

The centre bar having been exposed, some undercutting of it was done to help the well to make its initial movement, and the first foot of the tilt was removed by April 15th. This promising movement came to an end on the following day, as the cutting edge on the Mari side of the downstream chamber was being held up by a large boulder, the removal of which took three days. By the 18th sufficient spoil had been removed from the upstream chamber to allow of a proper jacking platform being made, and three hydraulic jacks were put in and made ready for lifting. The river, however, had risen and the increased velocity had set the sand on the river-bed moving, so that the dredged out excavation around the downstream end of the well had filled up, and silt was coming into the downstream chamber as fast as it could be removed. A good deal of silt was removed with a blow-out pipe on the 20th and 21st and the jacks were operated in the upstream chamber, resulting in a slight movement which brought the tilt down to 10·1 ft. A second attempt on the 22nd to move the well by jacking was unsuccessful. Further undercutting of the centre bar was carried out, and by the 26th morning the tilt had been reduced to 9·35 ft., *i.e.*, a correction of 2·2 ft., after which progress was held up. The cutting edge on the Kalabagh side in the downstream chamber was found to be resting on a nest of boulders. Owing to the cross tilt of the well, the depth of water was always more on the Kalabagh side than on the Mari side, and the tops of these boulders were fully three feet under water. While unsuccessful efforts to remove them were being made, another freshet came down the river which brought down more silt, so that the excavation around the downstream end of the well, which had been dredged down to R.L. 646 was silted up to R. L. 660, and on the morning of April 30 the downstream working chamber was found filled with silt to with in two or three feet of the roof.

Efforts to clear it proved of no avail, as fresh silt came in to take the place of what was removed. Straightening work was therefore stopped for the season on May 3rd, and the removal of the air locks, kentledge, etc., started, not before time as the current was now so strong that approach to the well in boats or even in a motor launch was becoming a dangerous matter. Under these conditions, the removal of the 65 ft. girders and the crates was not feasible and they were left in position through the flood season.

During the recess from May to September the experience gained was pondered over, and two principles clearly emerged. The first was that ample dredging was essential for success, and that time spent on dredging would be more than repaid during the righting of the well. The second was that stones and boulders under those parts of the cutting edge where there was any appreciable depth of water could not be brought into the working chamber, but that trenches must be made outside into which they could be pushed from inside the chamber as shown in Fig. 3 (*c*).

In the first week of October 1930, which was as soon as river conditions permitted work to be started on the well, dredging was commenced with two Scotch derricks mounted on a 150-ton barge. This set worked at the sides of the well, dredging out the trenches mentioned above. In the last week of October, a third grab was put into service. This was worked from an A-frame mounted in the bows of an 85-ton barge, and dredged around and between the crates. By November 12th the trench on the Kalabagh side had been dredged out, and divers were busy removing the material close to the well which the grabs had been unable to reach. Dredging was started on the Mari side and the erection of the air locks was begun on the following day. On the twenty-first a large boulder under the Kalabagh side cutting edge was discovered by the divers and pulled out into the trench. This was probably what had held up the movement of the well in April.

A sand-pit had been made in one of the offices, with a model of the well (scale 1″ to 1 ft.) set in the sand at the exact longitudinal and cross tilts. Every time the contractors' engineer or the resident engineer made an inspection in a diving dress he altered the sand with a trowel to what he had found. This model was of great use for moving about the grubs to the positions where they were most wanted, and for demonstrating to the divers the work which was required to be done.

By the 28th November, the trenches on both sides had been completed and only the single dredger was working between the crates, removing the last of the earth from the excavation. On that day, the air was put on, and the first shift of the season sent down. The conditions inside were much the same as when work was stopped in May. The heap of silt in the chamber was soon removed, as of course this time no more was coming in. The load was replaced on the cantilever girders and movement was anxiously looked for. This time there was no disappointment, and by December 4th the well had moved some five inches, and thereafter the progress increased day by day. On the 10th is than 3 ft. of tilt remained, and this was reduced to ·54 ft. (or 1 in 71) at midnight on the night of the 10th—11th thus bringing it within the limit of 1 in 50 allowed by the specification.

Building and sinking then proceeded without further incident, and the well reached its designed depth on March 13th, 1931.

Girder erection.

The erection of all the girders was carried out by the staff of the Deputy Chief Engineer, Bridges, North Western Railway, by whom the erection scheme and the method of floating out the main girders had been devised. No attempt will be made here to give a full description of the girder erection but only a short resume will be given.

The principle adopted was to erect the girders at ground level near the water's edge and roll them out on to two 200-ton barges which had been specially fitted up to receive them. The barges then carried the complete span to the pair of piers on which it was intended that it should rest, these piers having been built to a height just below the level of the span when supported on the barges. The jacks carrying the span on the barges were then released, thus allowing the girder to come down on to blocking placed on the pier tops ready for receiving the girders. Further lowering of the jacks allowed the barges to rise in the water, until eventually they were free and could be moved away. Steel trestles were erected on the pier tops, and the girders raised by jacking up to their final level. The trestles were afterwards surrounded by mass concrete cast to the form of the pier.

The four spans of 175 ft. next to the Mari bank were erected on standard steel staging. A 25-ton steam-crane with a special long jib was used for their erection.

Girder erection was started at the beginning of December 1930 and was completed at the end of July 1931.

Conclusion.

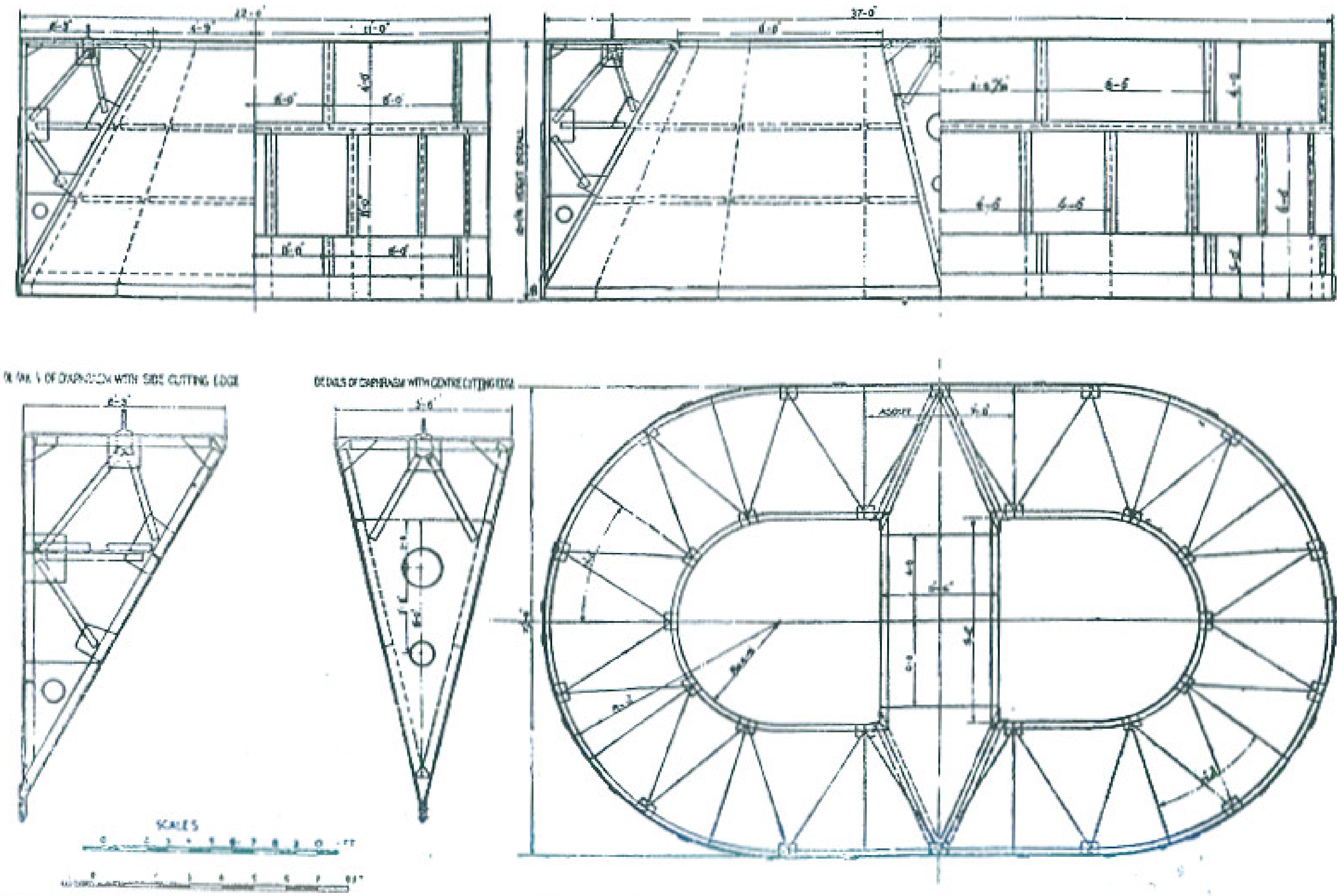
The cost of the bridge including the damage done by the flood of 1929 and the extension of 700 ft. provided for future extraordinary floods is almost exactly Rs. 50 lakhs, and the time taken to complete it, $4\frac{3}{4}$ years.

The narrow-gauge line from Bannu has been extended over the river to Mari Indus station, as the scheme for converting the Kalabagh-Bannu Railway to broad-gauge is in abeyance. The bridge however is built to broad-gauge main line standard.

It was opened to traffic on August 9th, 1931, when the evening train from Bannu was the first to cross over it.

KALABAGH BRIDGE CONSTRUCTION
MILD STEEL OVAL W 'LL CURB 37'-0"×22'-0"

FIG I



KALABAGH BRIDGE CONSTRUCTION
DETAIL OF PLATE DOMES FOR EXTENSION WELLS

FIG 2

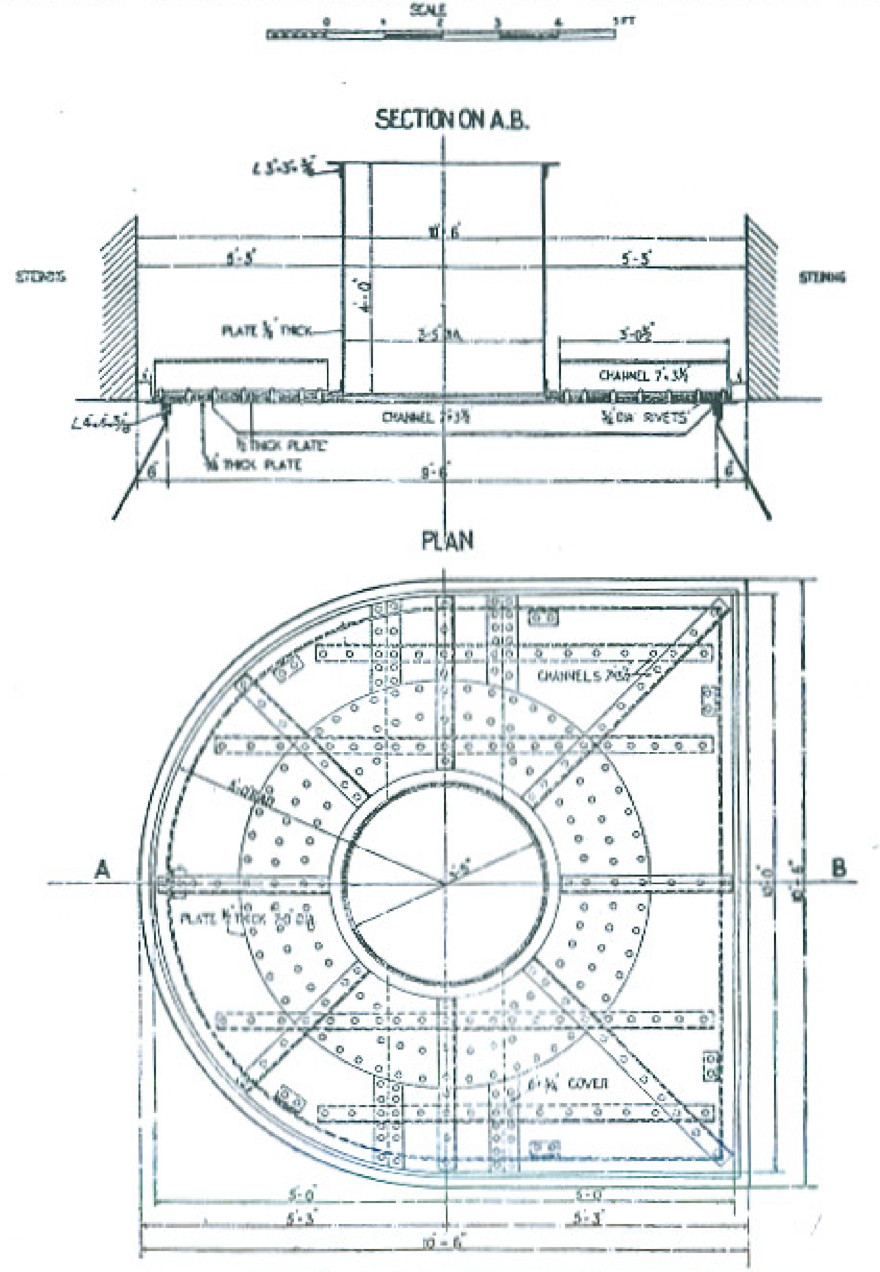


FIG3(a)

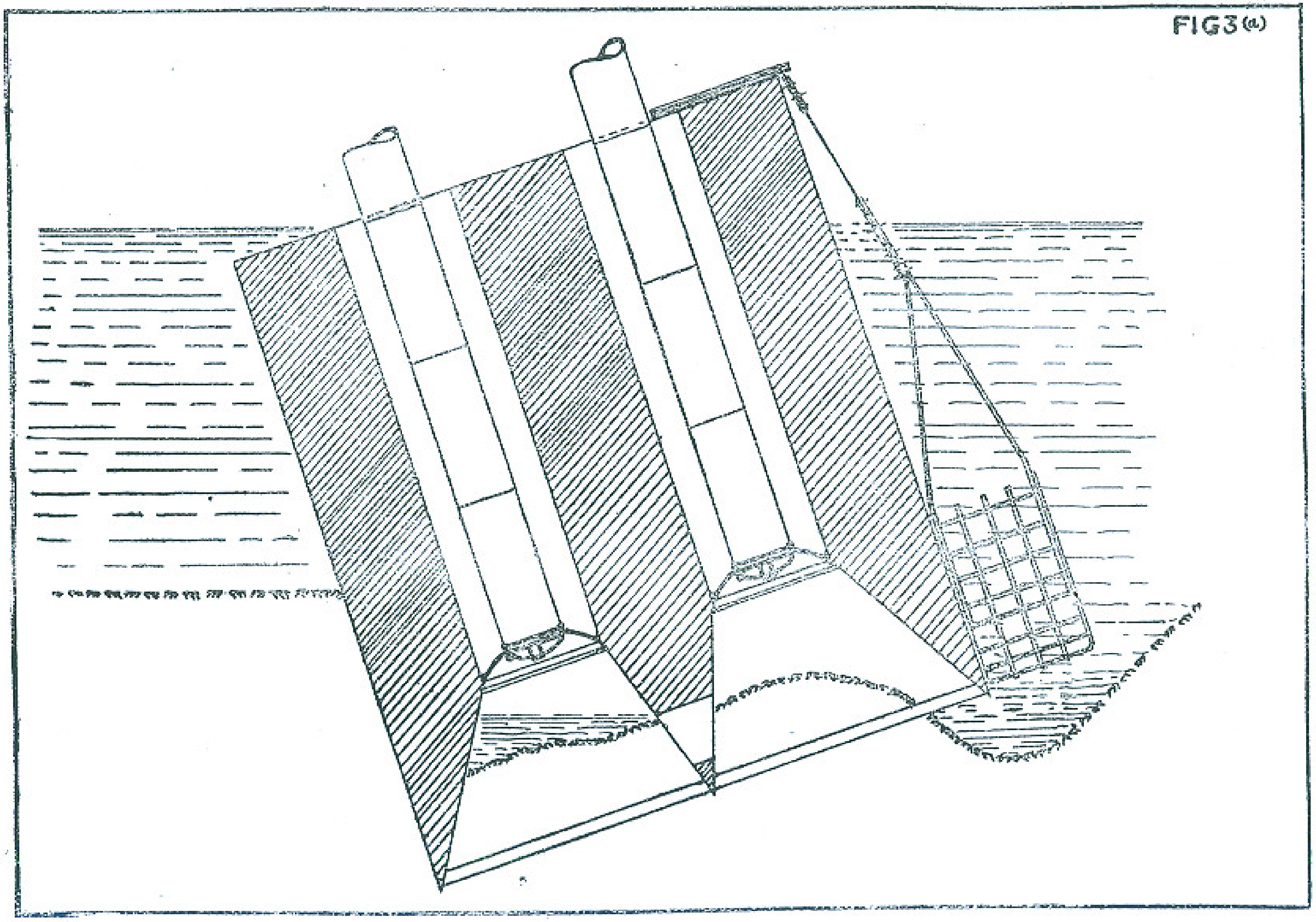


FIG:3(b).

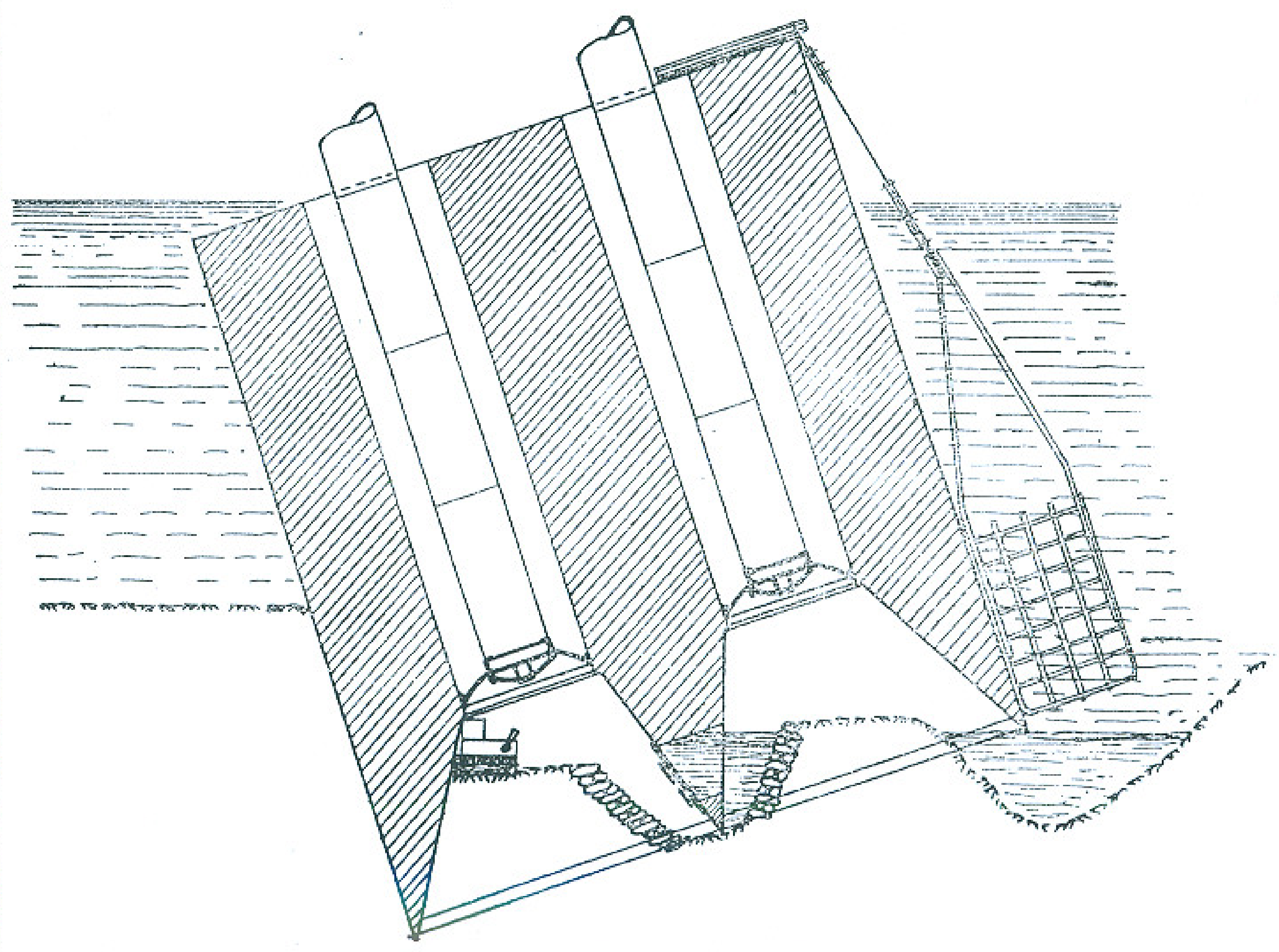
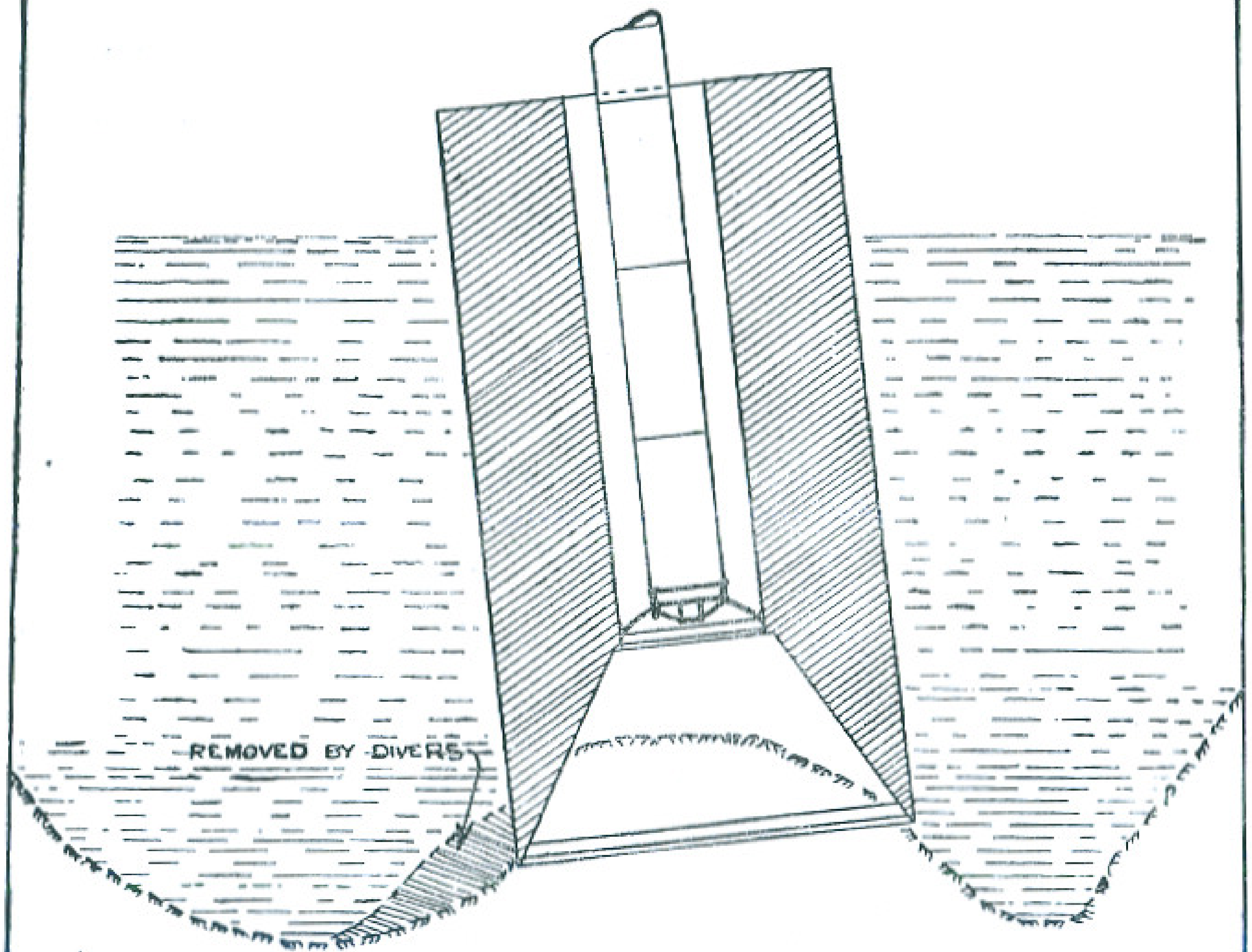


FIG:3(C)



SECTION AT CENTRE OF DOWNSTREAM WORKING CHAMBERS.

MR. JUDGES, introducing his paper remarked that the paper on Kalabagh Bridge read at the last session of the Congress was necessarily an incomplete account of the construction, as it was prepared nearly a year before the bridge was finished. The paper now before the Congress had been offered so that a full account of the construction of this bridge should be on record in the transactions of the Congress. The Author said that it was of course necessary to have both papers before one to get a collected account of the work. He admitted the omission of the account of girder erection in last year's paper because it was not within his province, as the work was done by Mr. Everall and his staff. Now that Mr. Everall had kindly given a full description of the girder erection that omission was made up.

Since the opening of the bridge the ferry service at Kalabagh had been dispensed with, and the Ghat stations at Mari and Kalabagh with their transhipping arrangements had been closed down. Passengers to and from Bannu and other trans-Indus stations were now spared the inconvenience of double transhipment from broad-gauge train to ferry steamer and from ferry steamer to narrow-gauge train. They now crossed the platform at Mari-Indus station from the broad-gauge train and take their seats in the narrow-gauge train which would take them straight through to their destination.

Besides the benefit to the public of that improved service, the opening of the bridge brought a substantial saving every year to the Railway Administration after maintenance and sinking fund charges had been defrayed.

The Kalabagh Bridge formed a great improvement in the communications between the Punjab and the Bannu and Dera Ismail Khan districts of the N.-W. F. P. and Waziristan. The de Montmorency Brdige over the Jhelum, which was the subject of another paper before this year's Congress, had linked up the Mianwali and Shahpur districts and the bridge over the Chenab, which was expected to be opened before the middle of next month would then complete the chain of the three large bridges recently built by the North Western Railway Administration to improve the railway communications between Lahore and the western districts of the Punjab and Waziristan.

MR. W. T. EVERALL congratulated Mr. Judges on his interesting paper and expressed, as one who saw something of the many interesting stages of the construction, his admiration of Mr. Judges' engineering skill especially in the way in which he and the Contractors' bridge staff rectified and completed the sinking of the displaced wells in the main stream.

The straightening of these pier wells was an undertaking which called for great initiative and bold methods and their successful adoption, some of which are described in this paper, was in a large measure due to Mr. Judges. It was necessary for Mr. Judges to spend a great deal of his time inside the caissons, working under compressed air 50′ below water level. He was present in the caissons, during all the critical stages, when the retilting of the piers was done, and his position at such times might well have been very unpleasent as there was the possibility of blowing in taking place due to the caving in of soil below the well curb.

Reference was made by Mr. Everall to the modified design of the lower edge of the well curbs referred to on page 2, and he said that it is possible that the shape finally adopted was suitable in this particular instance, as the sinking was done partly by open dredging and partly by pneumatic methods.

There are, however, advantages when sinking entirely by compressed air, in adopting a curb with the lower edge constructed in the form of a horizontal ledge 5″ to 6″ wide. Such an arrangement assists in controlling the well, especially when part of it is bearing on boulders and part of it on sand or other easily displaced material, as under these conditions it is possible for caving in to take place and the well to become tilted.

The ledge arrangement also provides a suitable place from which to operate hydraulic or mechanical jacks ; a very helpful feature when working through irregular and variable strata.

The preliminary borings made in the main river bed gave very clear indications that the strata for a considerable depth consists of compacted boulders, and under these conditions Mr. Everall suggested that it would have been more economical and quicker if the pneumatic method of sinking had been used throughout for these piers, and a curb adopted, constructed on the lines he had just described.

Mr. Everall remarked that the Author briefly mentions the erection of the steel superstructure, and that it may interest the members while the subject of this bridge is before them, if he (Mr. Everall) described several of the interesting features of that part of the work, which came under his control and was carried out departmentally by the Bridge staff of the Railway.

The girder erection was commenced in December 1930 and at that time it was programmed to erect by the end of the working season in June, four of the large 250 feet spans Nos. 1, 2, 8 and 9, and the four smaller 175 feet ones on the Mari-Indus approach, if the latter were delivered at site in time, and to complete the remaining five large spans over the main stream, during the following working season of 1932.

The speed of the girder erection was largely governed by the time in which the completed well piers could be handed over to the erecting gangs.

About the middle of February the position was again reviewed by Mr. Edwards, Chief Engineer of the Construction Branch, and the speaker and it was decided then, that in view of the excellent progress made up to that time with the well sinking and the likelihood of all the wells being down to their final levels by the beginning of April, to attempt the completion of the whole of the girder erection before the heavy floods came down in June.

Up to the end of February, during a period of nearly three months approximately 15% of the girder work had been erected and this was well up to the schedule of the original programme, but it was realized that if the bridge were to be completed before the flood-season, the work would have to be speeded up considerably.

A revised programme of operation was drawn up and arrangements made for extra plant and tools, and duplicating the staff and labour, so that the work could proceed continuously day and night.

To ensure satisfactory work at night time, powerful electric flood-lighting was installed over the area, and this proved a successful measure.

The diagrams on plates 1 and 2, show the general scheme for the erection.

All the large spans with the exception of Nos. 1, 8 and 9 were erected in rotation on the dry bank at the site of No. 2 span.

The assembly of the girders was conveniently done by means of steam-cranes provided with very long jibs, 60 feet in length (see fig. 7, plate I).

These cranes were operated from broad-gauge tracks placed on the upstream side of the spans and along which the steelwork for the girders was also conveyed in low-sided trucks from the girder dump to the erection bay.

The piers had only been built up to the 692·25 level on which the lower base frames of the steel trestles sat. See Fig. (1), Plate I. This permitted a completely rivetted span, weighing 330 tons being launched on a roller runway from the erection bay to the water channel from which the floating out was done on the pontoons. Eight roller sets were used for rolling out a span ; each set consisted of four rollers 4½" dia. × 2′-2″ long mounted on a frame ; the ends of the rollers were lipped and this proved of great assistance in guiding the rollers along the runway path. The rollers travelled between the top flanges of the twinned joists which formed the runway and four rows of 75 lbs. flat-footed rails which were clamped to the underside of the bottom boom of the girders to clear the rivet heads. Figure 3, Plate I illustrates these features.

It was necessary to pile the whole of the distance between piers C and D, as owing to part of the space between piers C and D being in the dry and part in very shallow water, it was not possible to navigate the pontoons closer to the erection bay.

This piling carried the girder system on which the spans were rolled out.

The level of the underside of the main girders during the assembly and launching was kept sufficiently high to permit of variations up to 2′-0″ in the water levels and also for lowering the span on the pontoons by means of four 100-ton mechanical jacks, the latter worked from pier D and had a vertical travel of nearly 12″.

The span was then boomed out until its nose projected some 90 feet beyond pier D ; the centre line of the span following the main axis of the bridge (Fig. 8, Plate I).

The first pontoon was then floated under the girders and located between the 1st and 2nd, vertical posts ; the span being lowered by means of jacks from pier D, until the load was transferred to the pontoon. See (Fig. 6, Plate I.)

The span was next traversed across the opening by hauling from two ten-ton wire rope winches operated by hand, and located on pier F, the span itself being partly supported on the pontoon and partly on the piled launchway ; the control of the pontoon was obtained from steel ropes attached to the up and down stream anchors and to the winches on the pontoon, and by tail ropes to the piers.

After traversing the end of the span over to pier ' E ', the second pontoon was floated into position and the jacks lowered from the pier until the whole of the load was taken by the pontoons.

The methods used for floating and warping the spans into their final position was explained by studying the diagrams on plates I and II.

Substantial anchors were placed in front of each pier 250 feet upstream, and 500 feet downstream ; to these were attached steel wire ropes leading to capstans and winches fixed on the two pontoons and by separate ropes to the piers.

The movements and control of the pontoons were obtained by letting out the ropes and warping in as required and these operations were successfully carried out by skilled Indus boatmen from the Mari-Attock District, who man-handled all the equipment and plant.

The whole process of floating out and locating a span on the pier did not ordinarily take more than two hours.

The span after being floated to its location, was transferred from the pontoons to the piers and located on the seats provided on the trestle base frames ; this operation was performed by mechanical jacks worked from the piers ; the trestle legs and bracings were next erected and the lifting equipment installed. The complete span was then lifted to its final position in steps of 12" with the side of the mechanical jacks working in pairs under each end of the girders, and the link suspenders attached to the girders. The suspenders were carried on the service work bolted to the trestles.

After each step of 12 inches, the weight of the span, (330 tons) was transferred to the trestles through the jacks and jacking beam, and a link removed from each of the suspenders. The load was then transferred from the jacks to the suspenders. The mechanical jacks together with the jacking beams were then lifted, the beams then being re-bolted to the trestle legs for the next operation.

Fig. 4, Plate II illustrates these features.

After lifting the span to a height of 20 feet, which is a few inches higher than its final level, the load was transferred from the service struts marked " BB " to the outer strut " AA, " the inner ones being then removed.

Fig. 9, Plate II illustrates the method of suspending the load from the top horizontal girders by means of the links, prior to fixing the joist grillage and cast steel bearings in their final position on the top of the trestle.

Jacking beams are shown bolted to the faces of the service struts and from these beams four mechanical Duff Jacks were operated for lowering, from the ends of each main girder, the span to its final position on the bearings and for releasing the loads from the suspension link gear.

After the removal of the service gear from the permanent trestle, the latter was embedded in the concrete pier, after removing the cross bracings as shown in the right half of Fig. 4, Plate II.

In connection with the erection of spans Nos. 6 and 7 in the main stream, an interesting state of the work was reached when the floating out and lifting of these spans was undertaken.

The wells of piers F and G were at the time not sunk to their final depths, and the pneumatic sinking plant and the Contractor's labour were still working on them ; it was realised that after sinking the wells it would take practically three weeks to complete the plugging of the wells and building up the piers to the 692·25 level on which the steel trestles were to sit.

This would have involved a three weeks' delay in floating out the girders and owing to the lateness of the season would have meant the bridge not being completed before the floods ; and its opening to traffic delayed until late in the next season. It was therefore decided to build special steel stools to straddle the wells and to form the supports on which the erection trestles could sit and so enable the girder work to proceed with the minimum amount of delay.

These special stools were made up in the Bridge Workshops at Jhelum and despatched to site within 48 hours a fine piece of work for which Mr. Joseph, the Workshop Foreman, was largely responsible.

Fig. 5, Plate II gives some idea of the arrangement.

The stools were installed before the concrete plugging of the wells was completed, and this enabled the erection staff to float out and seat the spans in position immediately after the last batch of concrete had been placed in the wells and so was saved what might have been a very serious delay.

The four smaller spans of 175 feet at the Mari-Indus end of the bridge were erected on standard bridge staging units of the type which is used for all the heavy bridge constructions carried out on the railway. For this work units 24 feet in height were used and distributed in blocks as illustrated in Fig. I, Plate I.

It was anticipated that the final erection of those spans might not be completed before the floods, so provision was made for the staging to be carried on piles for spans "C" and "D" (vide Fig. I, Plate I).

The assembly of the members in their final position on the staging was done by means of a steam-crane provided with a 60′ jib operating from the service track laid on the bed alongside the bridge; this method was speedy and efficient so much so that a complete span could ordinarily be assembled within 48 hours.

A special train was chartered to run at high speed from Calcutta to Mari-Indus loaded with the steelwork.

It arrived on the morning of the 20th June, and 30 hours later the last member was erected on bolts and drifts.

The river had been slowly rising for some days and things were cut so fine that 5 hours after the withdrawal of the cranes, the serivce line was washed out. This washout would have seriously embarrassed the work had the erection of the girders been delayed any further.

The erection included the assembly and rivetting of 4,300 tons of steelwork and most of this weight in the form of completed spans was again handled in the operations of rolling out, floating into position, and lifting to their final heights on the trestles.

The pontoons used for floating out were ordinarily used as wagon flats for the ferry service. In order to adapt them for the bridge work staging in the form of plate girders were laid across the deck, and supported at intervals so as to provide an equal distribution of the loads over the pontoons. Regarding the strengthening of the pontoons, it was only necessary to reinforce, with light timber battens, the frame-work between the floor decking and the hull at places where the cross girders supporting the staging came. The staging was simple and easy to erect and remove and this made it possible to hand over the pontoons when required for their ordinary ferry work within 12 hours.

Some of the advantages of this method of erection are :—

(1) The low level at which the spans were floated out enabled the work to be done safely, even when fairly high winds prevailed ; conditions which exist more or less all the time at Kalabagh. Floating out the spans at their full height would have been dangerous and probably have caused the loaded pontoons to capsize under a sudden gust of wind.

(2) It avoided the use of a special assembly dock, which would have entailed considerable piling, and the use of a gantry crane, and would have been largely dependent on a constant water level.

(3) Ordinary steam bridge cranes were used for the erection of the girders working from the track laid on the bank along side the span.

(4) The erection was carried out expeditiously and economically. The spans were assembled and main connections rivetted up at the average rate of one span every seven days.

As this scheme provided for erection of superstructure on the steel trestles before commencing the concrete work above the level of well caps, pier work and steel work proceeded simultaneously.

(5) All the steel trestles, service gear and erection equipment were made in the bridge workshops at Jhelum partly from new and partly from second-hand materials and with the additional advantage that the various expedients were tried out in the Bridge Yard before despatching to Kalabagh.

The girder erection work of this bridge constitutes, it is thought, a record in India for this class of work, as practically 85% of the total steelwork was erected in less than 4½ months.

It enabled the Railway Administration to open the bridge to traffic on the 10th August, nine months earlier than was originally anticipated and to dispense with the existing ferry system.

Lt.-Col. Macrae said that there were one or two points to which he would like to refer.

In regard to Mr. Everall's statement relating to the design of the curbs for sinking, he would like to say that the contract was a lump-sum contract for the construction of the bridge. The design was for pneumatic sinking, provision for which, as well as for preliminary sinking by open dredging, was included in the contract. The Engineering Officer had therefore very little control over the contractor, who used the methods he chose and took the risk of partial sinking which resulted in tilting of wells by the record flood, for the Railway Engineer could only advise, not give directions. The lump-sum contract was awarded by the orders of the Railway Board contrary to the advice of the North Western Railway. This method had not proved successful where the exact nature of work is unknown, such as strata through which bridge piers have to be sunk.

The next point was that the ferry steamers would be held up by the Sukkur Barrage and could only be brought down the Indus, a distance of 400 to 500 miles, before the seasonal fall of river levels. This was the main reason for expediting work ; the Sukkur Barrage authorities kindly held open the completion of one span till the released ferry fleet was brought down and warped through it.

There is also a point referred to in the discussion on Mr. Cruickshank's paper, of which Mr. Judges' is a continuation, which was not cleared up in the written answer, in connection with the Bell bund which was destroyed by the record flood. Both from the solid nose and from the apron the pitching stone, one-man rock, each piece weighing 60 to 120 lbs., was lifted by the water and taken downsteam ; in fact lumps of the largest size were found deposited on top of remaining portions of the apron and holes in the apron were to be seen where rock had been lifted out vertically. This proved that the Indus where it issues from the Kalabagh gorge acts more like a mountain torrent than a plains river and that this site is quite unsuitable for a Bell bund which depends essentially on pitching stone subsiding as strata are washed out.

The bridge girders were designed for broad-gauge (5′-6″) the stringers to carry the cross sleepers, being spaced accordingly, with the intention of making broad-gauge rail-head at Kalabagh, and the probability of converting the narrow-gauge (2′-6″) to broad-gauge from Kalabagh to Bannu.

Partly for financial reasons and partly for reasons put forward by other than railway authorities it was decided that Mari-Indus should be the broad-gauge rail-head for the present and that the bridge must, therefore carry 2′-6″ track. Had this possibility been foreseen the girders would undoubtedly have been designed to carry deck and ordinary ballasted track, but the date of the decision left no time for this change of design, nor for re-spacing the stringers before girder erection.

The Bridge Engineer found that it would save time to erect the girders with the stringers spaced for 5′-6″ track and to re-space them after erection and this extra work has to be borne in mind in connection with the rapid rate of erection and completion.

Before this was agreed to Mr. Everall got out a scheme showing that it would be possible to open out the stringers again to broad-gauge spacing without undue interruption to traffic.

The open line staff of the Rawalpindi Division got out plans and estimates for the junction and transhipping arrangements (BG & NG) at Mari-Indus with some alterations at Kalabagh and carried out this work at very short notice, creditably succeeding in completing it simultaneously with the completion of the bridge for opening, the S. D.O. Construction having successfully rushed through the track laying on the bridge, taking in hand each span as soon as the stringers were respaced by the Assistant Bridge Engineer.

The President, MR. SMITH, remarked that the organization of the North Western Railway was to be complimented, on a very fine achievement.

As regards the methods adopted, the President did not follow exactly what the details were, but one thing which struck him was that this work was executed by Mr. Judges under grave personal risk.

He mentioned that Col. Macrae had taken his place in summing up and had brought out one or two salient points which were omitted from the paper under discussion. He would ask the members to thank Mr. Judges, Mr. Everall and the whole staff for an excellent paper which they had contributed. They would all endorse his opening words in summing up this paper as to the manner in which the N. W. R. officers executed this work and for which they deserved congratulations.