PAPER No. 93.

THE CONSTRUCTION OF THE ROAD BRIDGES OVER THE CHENAB AND PALKHU AT WAZIRABAD.

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Introduction—Type of bridge—Cost—Time taken to complete work—Curbs—Wells—Gantries—Methods of sinking—Cost of sinking—Rate of progress—Difficulties encountered—Filling wells—Construction of piers—Bed plates—Cost of girders—Methods of erection—Reinforced concrete decking—Expansion joints—Damage from floods—Appendices.

Introduction.

This paper has been compiled from the official report on the construction of the road bridges over the River Chenab and the Palkhu Nallah at Wazirabad, and is intended to supplement the information contained in the note which was written by Messrs. Macfarlane and Everall for the information of the members of the Congress who visited the work when it was approaching completion in 1921, and which was subsequently published in the 1921 Proceedings.

The Chenab, as is well known, is one of the five tributaries of the Indus from which the Punjab derives its name, while the Palkhu is in itself but an insignificant stream, draining the country to the north of Sialkot, and could have been bridged by a single span were it not for the fact that the Chenab periodically overflows its banks and discharges large quantities of spill water into it, consequently adequate provision had to be made to guard against any heading up of flood water, which might have damaged the town of Wazirabad just upstream of the railway bridge over the nallah.

The railway bridge over the Chenab—known as the Alexandra Bridge—consisted of sixty-four spans when it was opened by the late King Edward, when he visited India, as Prince of Wales, in 1876, but the length was subsequently twice reduced prior to 1920, when it was still further reduced from twenty-eight to seventeen spans, as described in Mr. Pavry's paper presented to the Congress that year. The eleven spans thus released supplied forty-four meter gauge girders, 142′-1″ long between bearings, which were sufficient to provide seventeen spans over the Chenab and three spans over the Palkhu, with two girders to spare.

Type of Bridge.

Both bridges are of deck type, with a reinforced concrete roadway, 19′-6″ wide between wheel guards, carried on cross girders spaced 5′-3″ apart and resting on the top booms of a pair of the main girders spaced 12 feet apart. They have been designed to carry a live load equivalent to 90 lbs. per square foot over the whole surface, or a maximum unit loading of a 15-ton steam roller. The bridge over the Chenab is 400 feet downstream of the railway bridge, while that over the Palkhu is only 250 feet below the railway bridge.

Cost.

The work, including the approaches and raising the road from Wazirabad to Kathala, on the right bank of the Chenab, above flood level, was originally estimated to cost Rs. 18,69,729, but the revised estimate, prepared in August 1920, amounted to Rs. 25,35,649, while the ultimate cost has worked out to Rs. 27,10,240 after allowing for a credit of $2\frac{3}{4}$ lacs realised from the sale of the tools and plant arranged for the construction of the work at a cost of approximately four lacs.

Time taken to complete work.

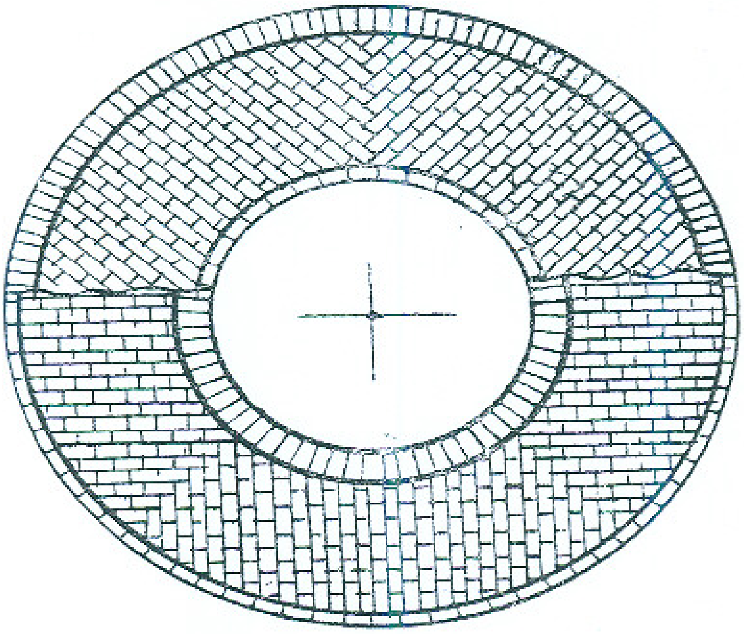
Although work was started in October 1918, it was only with extreme difficulty that the necessary plant was collected, owing to the war demands for Mesopotamia, so that the first well curb was only laid late in February 1919. Four wells were started that working season on the Chenab Bridge, whereas eleven were started in the season 1919-20, and the remaining three in 1920-21. The bridges were opened for traffic, on the 8th February 1922, by Sir Edward Maclagan, Governor of the Punjab, thereby closing the last gap in the Grand Trunk Road between Delhi and Peshawar.

Curbs.

When work was started, steel plates were practically unobtainable, and consequently reinforced concrete curbs, as described by Mr. Armstrong in his paper published in the 1920 Proceedings, were used. These, however, required time to set, and in one case, after ten feet of brickwork had been built on one of these curbs, and sinking was about to be started, a two foot flood tilted the well over to an angle of 1 in 4. The remaining curbs were therefore made of steel as soon as it became available.

Wells.

The pier wells were 19′-1″ external diameter, with 5′-3″ thickness of steining, and the alternate courses bonded as sketched in the margin.



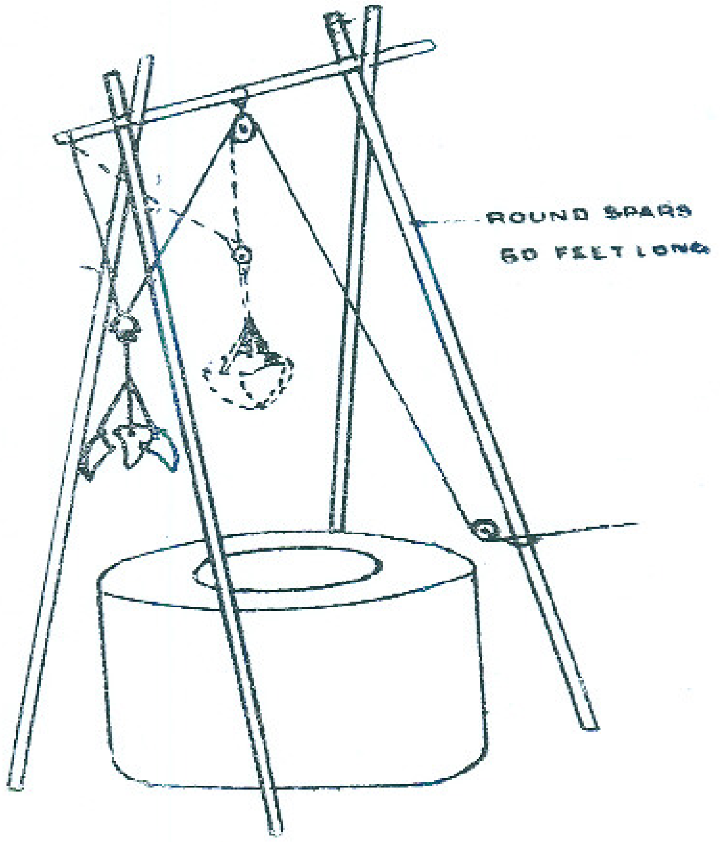
The abutment wells were oval, 26′-6″ by 20′-6″, with 5′-6″ steining.

After the first three feet of brickwork above the curbs had been laid in 1 : 2 cement mortar, a lime mortar, consisting of 3 parts of kankar lime to 1 part of white lime and 1 part of sand, was used for the rest of the work—plain kankar lime not having been found altogether satisfactory. As the bond rods were in 10 feet lengths, the brickwork was built up 10 feet at a time, and it was not found necessary to wait for the green brickwork to set, before commencing sinking, provided that care was taken to sink the well straight, and to clear away the spoil as it was dredged.

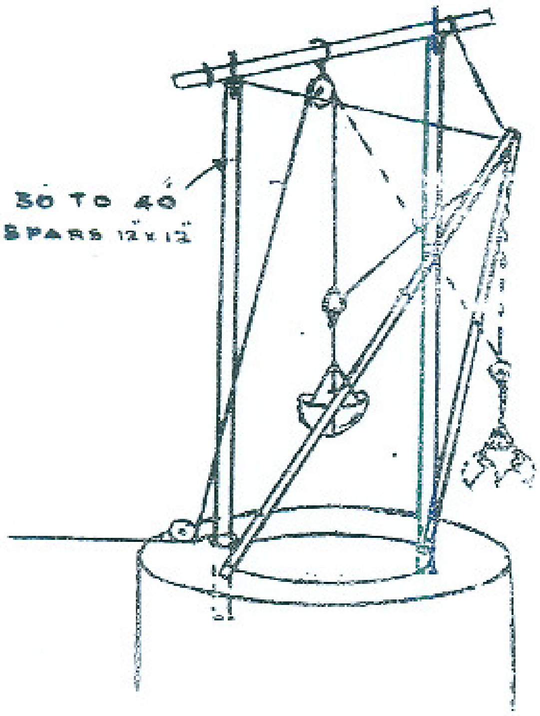
The intention was to sink all the wells to a minimum depth of 80 feet below bed level, with at least 25 feet in clay, in the case of the Chenab; and 75 feet below bed level, with 23 feet in clay, in the case of the Palkhu. The actual depths are shewn in the Table on Plate No. 2. The Chenab abutment wells were only sunk 41 feet, as they were behind the stone bunds, but the Palkhu abutment wells, not being protected, were sunk 52′-6″ and 69 feet respectively. Clay was encountered at an average depth of 62 feet, and was of such a tenacious character that in many cases it was found possible to dredge out a deep hole under a curb without the well sinking.

Gantries.

The usual type of double shear leg gantry was used for well sinking,



except where, owing to subsidence of the ground caused by "blows," or scour by the river, it was not possible to maintain this type of gantry, and a special type had to be used. This consisted of two uprights fitted into recesses in the steining, with a transom across the top and a jib for swinging the dredger outside the well. With this



type of gantry, three feet of brick-work in mud was built on top of the steining, and over this a grillage of rails was laid to carry the pig-iron load. The object of the brick-work in mud was to allow of the well being sunk down to, or even a little below, ground level without the grillage fouling the spoil from the dredging. The disadvantage of this type of gantry was that it had to be taken down and re-erected for each fresh rod of steining, and consequently it was only employed when the ground was too bad to use a double shear leg gantry.

Methods of Sinking.

Apart from straightforward dredging the following methods were employed in sinking the wells :—

Loading—All wells were loaded with pig-iron, up to 250 tons, to increase the sinking effort.

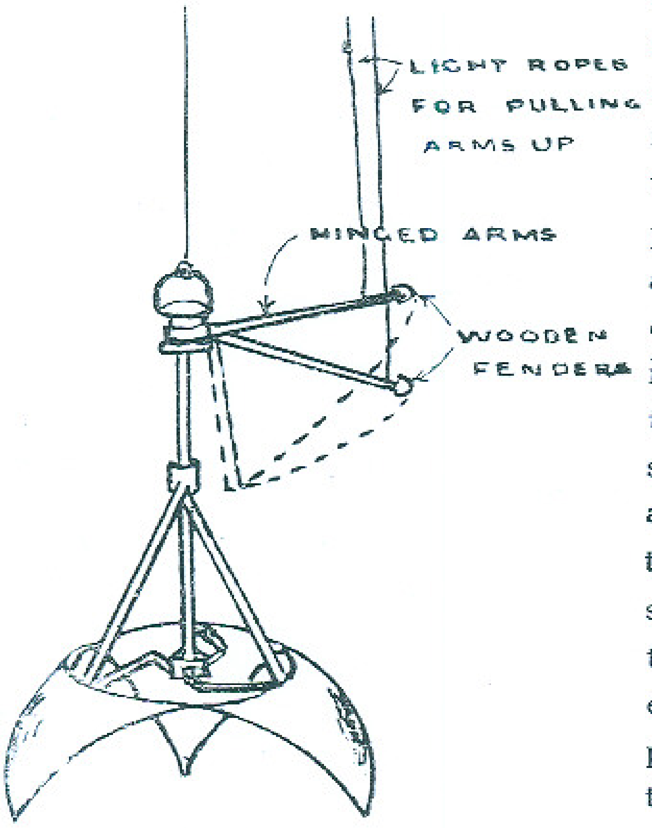
Baling.—The water inside the well was lowered by baling with a leather bag (*charsa*), with the result that water tended to force its way in from below, and scour under the curb. In a few cases the clay was sufficiently watertight to allow of the wells being baled out dry, before sending men down to undercut the curbs.

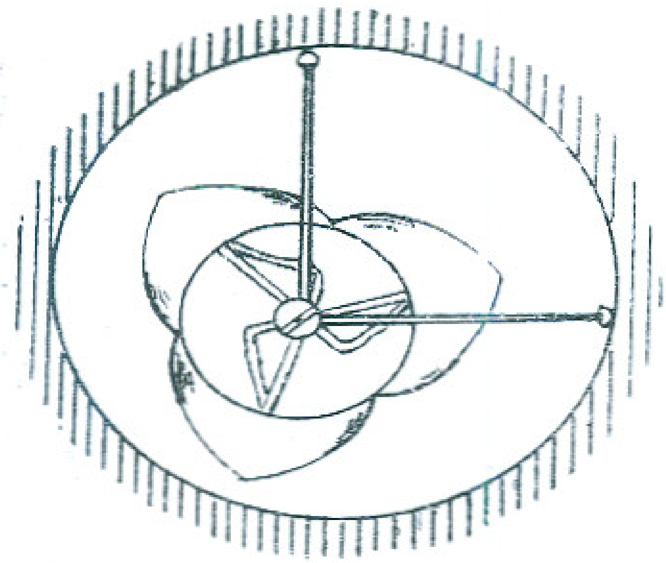
Explosive Charges.—Two to eight cartridges of dynamite were fired at a time when the water had been lowered as much as possible by baling.

Use of Cutters.—Various types of cutters were employed. That illustrated on Plate No. 3 was designed by Mr. E. Verrieres of the North-Western Railway, and consisted of three rails, 17 feet long, with a cutting edge at the bottom and a special automatic sling. The main rope R had a harp shaped attachment H of $\frac{3}{4}''$ round iron fastened at K, over which the loop E of the sling B D C was hooked so as to take the weight of the cutter while it was being lowered down the well by the rope R, while the position of the tie at D regulated the angle at which the cutter descended. This was made the same as the angle of the curb, so that when the cutter reached the curb it slid under it and cut into the clay. Further lowering was supposed to slacken the loop, so that it fell off the harp shaped attachment, with the result that when it was pulled up by the rope R, the cutter acted as a lever against the upper edge of the curb, and scooped out the hachured lump of clay marked C on the drawing. The subsidiary rope S was for re-hooking the loop over the harp shaped attachment preparatory to lowering for another cut. In practice, the loop often fell off whilst lowering, owing to the cutter sticking in the joints of the brickwork, while at other times it failed to disengage at all, and as refixing the loop proved difficult, and took time, and the cutter could only work where the undercutting was already sufficient to admit of the use of the upper edge of the curb as a fulcrum, it was not very successful. Used without the loop, by letting it drop down next the steining, it proved more useful.

A modified form of the side cutter described by Mr. W. B. Gordon in *Notes on Well Sinking Works—Nadrai Aqueduct*, 1888 (Plate No. 4) was used when the undercutting (*kundi*) was sufficiently deep to allow of the arm swinging right up, and judging by the amount of spoil afterwards dredged up, this cutter was most successful. It scooped out pits up to 16 feet in diameter as compared with 7 feet obtained with a Bruce dredger.

The Bruce dredger was the type of dredger generally preferred for both sand and clay, and the marginal sketches illustrate a device of Mr. Anderton's which proved most useful in straightening a tilted well. This consisted of a pair of hinged arms, at right angles, attached to the top collar of the dredger, which were raised into a horizontal position when the dredger was being lowered, so that the wooden fenders came against the steining and forced the dredger over against the high side of the well. When raising the dredger the arms were allowed to drop so that there was no possibility of their catching under the curb.





Sinking in sand was paid for at the rate of Rs. 8-8-0 a foot for the first ten feet. This was increased by Rs. 7 a foot for each succeeding ten feet, while sinking in clay was paid for at the uniform rate of Rs. 136 per foot of depth. The average total cost of sinking a well 62 feet through sand and 25 feet in clay was Rs. 5,061, or an average rate of Rs. 58-3-0 per foot.

Rate of Progress.

Plate No. 2 shews the progress on each well. The time preparatory to sinking (column 7) was occupied in riveting the cutting edge, placing the reinforcement in position, making the brickwork forms, pouring the concrete and waiting for it to set, laying the first ten feet of steining and erecting the gantry. The average rate of sinking in sand was 28 feet a month or approximately two months for the average depth of 60 feet. In clay the average was only 3½ feet per month, but this slow rate is largely accounted for by the fact that the time taken to sink some of the wells included two monsoon seasons, when no sinking could be done. These averages exclude the bigger abutment wells, which had to be sunk several feet before reaching the assumed bed level from which all depths were measured. The four wells which were incomplete at the close of the 1918-19 working season, having only just penetrated the clay, were cut down to water level and filled with sand to increase their stability against the monsoon floods.

Difficulties Encountered.

Some of the wells gave trouble. Well No. 2 in the Palkhu was so badly tilted out of position that it had to be founded in 15′-3″ of clay. It had, however, been undercut to a further depth of 8 feet and the cavity (*kundi*) was plugged with cement concrete to give additional depth. Similarly well No. 16 in the Chenab was 4 feet out, towards the north, when it was founded in 16′-9″ of clay, with 10′-6″ of concrete filling up the *kundi* under the curb. The last well to be founded was No. 4 in the Chenab, and this gave considerable trouble in its final stages, owing to the difficulty of maintaining a *kundi* with a fairly high river. To avoid holding up the girder erection for the whole of the hot weather, the well was ultimately founded at a depth of 81′-7″ below bed level, but, owing to the height of the river, the pier had to be started four feet above bed level, and this was boxed in with false-work in cement the following autumn.

Filling Wells.

After founding a well, sand was filled in to the top of the corbelling above the curb, and the well was then plugged for 10 feet with cement concrete in the proportion of 1 cement : 3 Chenab sand : 6 stone ballast. Sand was then filled into within ten feet of the top of the well, the water was baled out, and the well filled up with a well rammed lime concrete plug in the proportion of 1 lime : 2 Chenab sand : 4 brick ballast.

Construction of Piers.

The piers were 20 feet long by 8′-8″ wide, and were therefore a foot longer than the external diameter of the wells, so that, even in the case of accurately sunk wells, the noses of the piers were corbelled out six inches. In the case of wells out of position the corbelling was correspondingly increased, and where the overhang became too great, concrete slabs, reinforced with rails, were used to avoid excessive corbelling. The lateral deflection of 2′-4″ in No. 2 well in the Palkhu was got over by such a slab, while the longitudinal error of 5′-4⅞″ was adjusted by shortening the girders of the middle span and bringing the abutment forward on the abutment well.

Bed Plates.

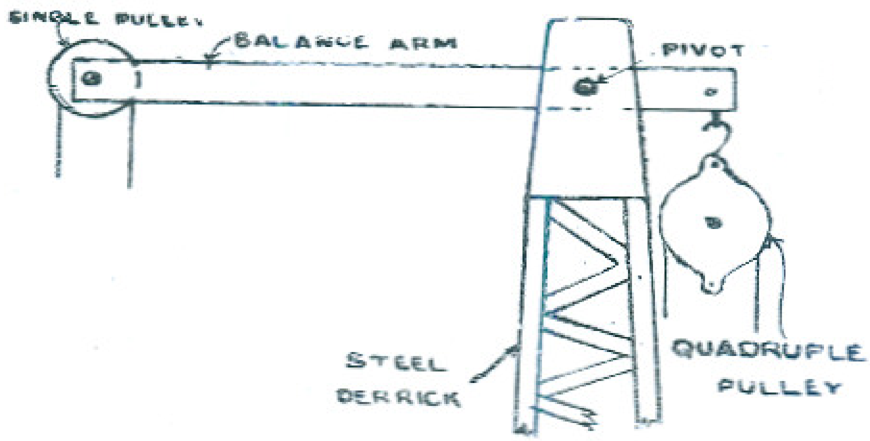
The bed plates 7′-11″ long by 4′-0″ wide and 2′-6″ deep, consisting of 1 : 2 : 4 cement concrete, were cast in position on top of the piers.

Cost of Girders.

The price charged for the old girders was Rs. 70 a ton, but these had to be very considerably strengthened—25 per cent. additional material being required to reinforce the booms, while 33 per cent. of the main web members and their connections had to be strengthened. New cross girders had to be provided 5′-3″ apart, as well as wind bracing for the main girders and new roller rocker bearings. The estimated cost of this girder work, including erection, was Rs. 265 a ton as compared with Rs. 700 a ton for new girders in the open market. This work was entirely in the hands of the North-Western Railway Bridge Department under the supervision of Mr. W. T. Everall, Bridge Engineer. Modern pneumatic machinery was used throughout and the total weight of the iron and steel work handled amounted to 2,500 tons.

Methods of Erection.

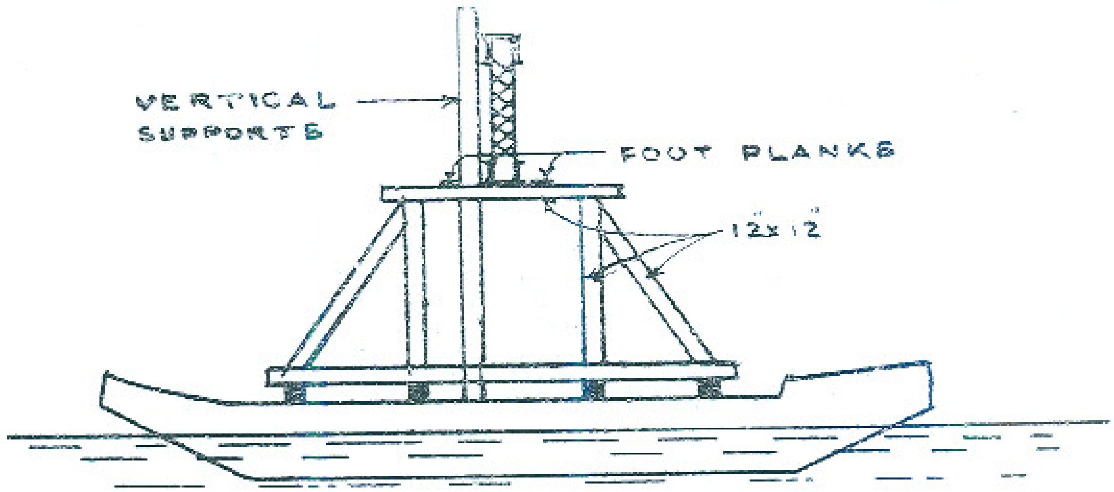
The cold weather channel during the spring of 1921 was on the south side of the river bed, so that it was possible to hoist eleven spans at the north end of the bridge into position by means of two 60 foot derricks, each operated by a powerful steam hoist. These steel derricks were of special construction, being portable, and made in sections which could be extended to 100 feet. An interesting device was the balance head, which transmitted the resultant load through the centre of the derrick, and facilitated easy attachment of the tackle and ropes. This consisted of a pivoted arm on top of the derrick carrying a quadruple



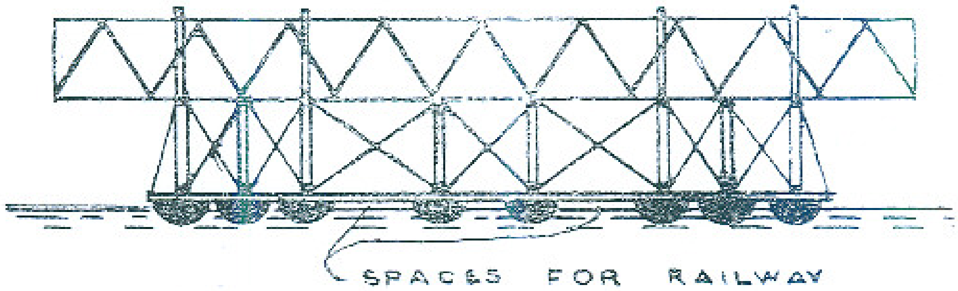
sheaf pulley on the lifting side, and on the other side of the arm a single pulley, but, as the length of this arm was four times that of the lifting arm, the resultant passed through the balancing pivot in the centre of the derrick. The girders, weighing 45 tons apiece, were riveted up and moved to the site on trolleys specially designed with side bracings.

The girders for the spans over the cold weather channel were stacked between the girders of the last three land spans. Rails were then clamped on the top booms of these land spans, and on these were placed two pairs of travelling carriages, each pair being connected by a couple of steel joists, extending from girder to girder, from which the girders to be boomed out could be slung by chains. The girder was then raised and the travellers moved forward till the girder projected about 40 feet beyond the pier, when the end was supported on a trestle stage built on three large country boats. The forward pair of travellers were then removed, and the floating stage drawn across by ferry ropes to the next pier, where the end of the girder was placed on its bed plate. Provision was made for an adjustment of three feet in the height of the floating stage to allow for variations in the water level, while an extension fitted to the forward end of the girder already in position allowed the back pair of travellers to bring the inner end of the girder, which was being boomed out, to its final position. As each pair of girders were boomed out and laid in position they were secured with cross girders, and side struts fixed underneath as wind bracing, and then used in turn for booming out the girders for the next span.

The girders for the Palkhu were railed to Wazirabad and then slung from the railway bridge on to a floating stage by a couple of 30 ton steam



cranes. The floating stage was supported on eight large country boats spaced so that the bows of the boats could get under the railway bridge

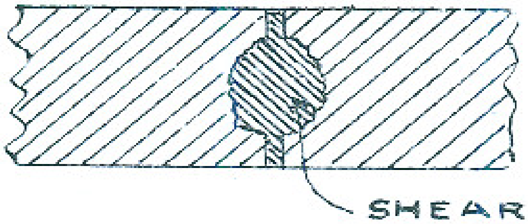


without fouling the piers. There was a trestle on each boat, built of 12″×12″ timbers, and these were suitably braced together with steel channels, while four long vertical timbers were provided to which the girder was lashed to prevent its overturning. As soon as a girder was placed on the stage, the boats were hauled downstream to the site of the new bridge, and the girder was transferred to the piers with the aid of screw jacks and timber packing.

The cross girders, wind bracing and hand railing of both bridges were erected *in situ* partly by hand and partly by pneumatic plant.

Reinforced Concrete Decking.

Partly to avoid the cost of centering and the delay while the concrete was setting, and partly to give the contractor work to do during the flood season, the reinforced concrete decking was precast in slabs 5′-3″ × 3′-0″ × 7″, but when some of the slabs were tested they broke under an average load of 17 tons, so that allowing a factor of safety of 4, with 25 per cent. for impact with a travelling load, the slabs were only safe for $17 \times \frac{1}{4} \times \frac{4}{5} = 3{\cdot}4$ tons, or approximately the weight of the rear wheel of a 10 ton roller, instead of being safe for a 15 ton roller. This weakness was due to the width of the slabs, which had been made equal to the width of a roller wheel, plus an angle of dispersion of 45° usual in English practice, not being sufficient to allow of the load being fully dispersed. To strengthen them, at Mr. Everall's suggestion, the sides were grooved and joints grouted with 1 : 1 cement mortar to form shear locks, while the wearing coat, composed of four



inches of rich concrete, increased the effective thickness of the slabs. It was considered that this surface coat might be allowed to wear down $1\frac{3}{4}''$ before resurfacing would be necessary. The slabs were accordingly retested with the cement grouted shear locks and $2\frac{1}{4}''$ surface coat, when they only broke under a load of $33\frac{1}{4}$ tons. The grooving for the shear locks was first done with pneumatic chisels, but the compressed air being insufficient, hand chiselling was resorted to—the cost working out to about four annas a slab. The surface coat was further strengthened by a grid of $\frac{1}{4}''$ bars, spaced 8″ apart, 2″ below the surface, which also helped to prevent temperature cracks.

The average rate of laying the slabs was sixty a day, so that a span was completed in three days. To ensure a good bearing, the top flange of the cross girders was plastered with $\frac{1}{4}''$ to $\frac{1}{2}''$ of cement mortar, and great care was taken to see that the bearing was the full three inches available.

The wearing coat was 4″ in the centre and 3″ at the edge, giving a camber of an inch in ten feet. This was $\frac{1}{2}''$ more than the Palkhu, where, after a shower, the water tended to collect in pools and could not flow off fast enough through the drainage openings.

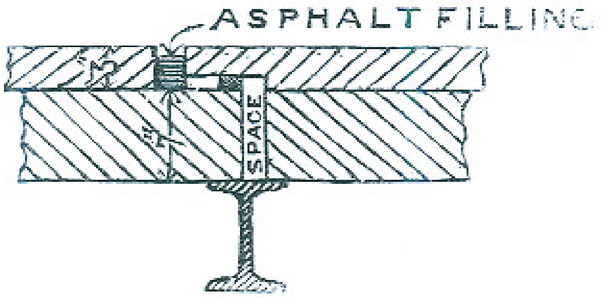
Considerable progress had been made with the erection of the cross girders and hand railing before it was realised that the dead load of the decking was going to cause a deflection of $1\frac{1}{4}''$ to $1\frac{1}{2}''$ in the main girders, and alter a camber varying from $\frac{1}{2}''$ to $\frac{3}{4}''$ into a sag of $\frac{3}{4}''$ to $\frac{1}{2}''$. The result was that, as the decking was laid, the railings assumed parabolic curves, which were plainly noticeable, while there were marked sags in the wheel guards. To remedy this, the top and intermediate rails in the centre of each span were raised to the level of the end posts, but at a cost of approximately Rs. 3,000. The wheel guards of all spans had also to be levelled, and in the last six spans the thickness of the wearing coat was reduced by an inch at the ends of the spans and gradually increased to its full thickness at mid span.

Water for the concrete was supplied through the hand rail pipes from an elevated tank on the bridge, which was fed by a No. 4 pulsometer, and the concrete decking was kept flooded with 2″—3″ of water for ten days.

Expansion Joints.

The maximum expansion for the extreme ranges of temperature likely to be experienced was calculated for one of the spans, and found to be about half inch. The expansion joints were accordingly made from $\frac{5}{8}''$ to $\frac{3}{4}''$ wide and filled with a mixture of equal parts of asphalt and sand, to which, as the weather was at the time cold, a small quantity of tar was added to prevent the mixture setting too quickly.

The joints as constructed were 10″ to 11″ deep. Had they been made as sketched, with the wearing coat extended a few inches beyond the joint in the slabs, they might have proved more successful, as the upper joint only would then have been filled with the asphalt mixture, and the quantity squeezed out by the expansion of the main girders would have been greatly reduced.



As soon as the concrete decking had been completed the roadway was given a coat of boiling tar, over which a thin layer of sand was sprinkled, and this formed a remarkably fine surface for traffic.

Damage from Floods.

On the whole the work was very little impeded by floods. A telephone had been installed between the Executive Engineer's office and the Headworks of the Upper Chenab Canal at Merala, and as the Headworks were in telephonic communication with Riasi, 40 miles farther upstream, where gauge readings were taken twice daily, a clear 24 hours' notice of a flood could generally be reckoned on.

On 5th February 1920, a two foot flood in the Chenab did a certain amount of damage, tilting over well No. 3, which was just ready for sinking, with ten feet of brickwork on the curb, to an angle of 1 in 4. This was straightened by hand dredging inside and outside the well and by pulling it upstream by means of a heavy tackle attached to the corresponding railway pier. The same flood tilted well No. 7, which had been sunk 25 feet, to an angle of 1 in 12, and so badly damaged the island for wells Nos. 4, 5 and 6, that further work on these wells was abandoned for that working season. On 15th March 1920, a six foot flood caused five gantries to collapse, and partially washed away the pile bridge and the broad gauge construction line in the river bed.

APPENDIX A.

As a guide towards the preparation of estimates for similar works elsewhere some of the rates paid are quoted below—

	Rs.	A.	P.	
Earthwork in cutting or filling including lift and lead not exceeding 600 feet	10	0	0	per %ₒ c.ft.
Additional lead for earthwork per chain beyond 600 feet	0	8	0	per %ₒ c.ft.
Sand from the Harro river	29	8	0	per % c.ft.
First class bricks 10″×5″×3″	12	0	0	per %ₒ
Lime concrete	23	0	0	per % c.ft.
Cement concrete 1 : 3 : 6, with Chenab sand, and stone ballast	0	12	0	per c.ft.
Cement concrete in well curbs (including forms and centering) 1 : 1½ : 3, with Chenab sand, and stone ballast.	1	8	0	per c.ft.
Reinforced concrete in decking (including forms and centering) 1 : 2 : 4, with Chenab sand, and stone ballast	5	0	0	per c.ft.
Brickwork in 1 : 2 cement mortar	89	0	0	per % c.ft.
Brickwork in lime mortar	40	0	0	per % c.ft.
Brickwork in lime mortar in arch work ..	50	0	0	per % c.ft.
Extra for special moulded bricks	5	0	0	per % c.ft.
Cement pointing with 1 : 2 cement mortar ..	7	0	0	per % s.ft.
Lime pointing	3	0	0	per % s.ft.
Cement plaster 1 : 2	9	0	0	per % s.ft.
Lime plaster	5	0	0	per % s.ft.
Mud plaster, leeping and whitewashing ..	1	0	0	per % s.ft.
Oregon pine baulks, 12″×12″, up to 40 feet long	6	2	4	per c.ft.
,, ,, ,, 12″×6″, up to 30 ft. long ..	3	1	8	per c.ft.
Yang baulks 12″×6″, 30—34 ft. long ..	7	1	4	per c.ft.
Round Fir spars, 60 feet long	305	9	0	each.
Loading cutting-edges	1	0	0	per ton.
Unloading cutting-edges	1	0	0	per ton.
Erecting and dismantling large gantries, each time, after the first erection	150	0	0	each.
Erecting and dismantling short gantries on top of wells as often as necessary to sink the well, including carriage of all materials	1,500	0	0	each.
Island, exclusive of ballies, but including the carriage of all materials, completed and maintained until such time as the curb and steining had been sunk to a safe depth ..	6,000	0	0	each.
Laying permanent-way	0	6	0	per yard.
Well sinking in sand, including loading of well and removal of sand—the contractor being supplied with plant, timber, etc., but not coal—for first ten feet	8	8	0	per foot.
Extra for every additional ten feet	7	0	0	per foot.
Well sinking in clay, including loading of wells and removal of spoil dredged	136	0	0	per foot.

APPENDIX B.

Analysis of rate for reinforced concrete decking, laid in situ, *on one span of the Palkhu Bridge, during April* 1921.

Length of span 142′-0″. Width of roadway 20′-6″. Depth of coat 0′-7″.

Form Work.

Three $1\frac{1}{2}''$ planks were obtained from each Kail wood sleeper $(12' \times 10'' \times 5'')$, while two planks, placed end to end, formed the width of the roadway ; then deducting from the length of the bridge the space occupied by the flanges of twenty-eight cross girders left a nett length of $142' \times 12'' - 28 \times 6'' = 1{,}536$ inches, so that the number of planks required was $2 \times 1{,}536 \div 10 = 307$ or say 102 sleepers.

The perimeter of each wheel-guard was $10\frac{1}{2}'' + 17\frac{1}{2}'' = 28''$, or the width of three planks obtained from a single sleeper, so that the two wheel-guards required $2 \times 142 \div 12 = 24$ sleepers.

Seven battens $5\frac{1}{6}' \times 5'' \times 3''$ were used in each bay except the end ones, so that $27 \times 7 = 189$ battens were used in all, corresponding to $189 \div 6 = 32$ sleepers.

The short pieces cut off these sleepers supplied the supports and wedges under the battens, so that $102 + 24 + 32 = 158$ or say 160 sleepers were required for the form work of one span.

The labour charges for sawing the sleepers amounted to Rs. 74, and for fixing the false work in position Rs. 83-8-0.

Form work was only made for two spans of the Palkhu Bridge—that used on the first span being used again on the third span—so that only two-thirds of the cost of the sleepers and labour in sawing is debitable to each span. Also, since the new planks cost about six annas per square foot, and allowing for an average depreciation of 50 per cent. in their value after use on the work, the planks used on the bridge might reasonably be expected to realise $2 \times 128 \times 25\frac{1}{2} \times 3 \div 16 =$ Rs. 1,224 or Rs. 408 per span, adding Rs. 100 for removing the false work from the three spans, the ultimate cost of the false work for one span worked out to—

	Rs.	A.	P.
Sleepers $\frac{2}{3} \times 160$ at Rs. 7-2-0 per sleeper .. =	760	0	0
Sawing $\frac{2}{3} \times$ Rs. 74 .. .. .. =	50	0	0
Fixing .. .. =	83	8	0
Removing false work .. .. =	33	5	0
Total ..	927	0	0
Deduct value of planking after use ..	408	0	0
Nett cost of form work	519	0	0 say Rs. 520

Reinforcement.

Half inch diameter bars were used throughout and the actual quantity required for one span amounted to 6·6 tons. The rate per cwt. was Rs. 23-8-0, made up of the cost of the bars Rs. 17 per cwt., freight Rs. 4 per cwt., and labour in bending and fixing Rs. 2-8-0 per cwt., so that the total cost of the reinforcement for one span amounted to 6·6 × 20 × Rs. 23-8-0 = Rs. 3,102.

Concrete.

Total quantity required in one span—

Floor	..	$142 \times 19\frac{1}{2} \times \frac{7}{12}$	= 1,665 c.ft.
Wheel-guards	..	$2 \times 142 \times \frac{1}{2} \times 1\frac{1}{2}$	= 213 c.ft.
Total	..	1,878 c.ft.	say 1,880 c.ft.

Taking the voids in the ballast at 40 per cent. with 1 : 2 : 4 concrete, there will be 1·6 c.ft. of voids in each 4 c.ft. of ballast. Also 3 c.ft. dry mixture of cement and sand were reduced to 2·6 c.ft. by the addition of water, so that there was one cubic foot of mortar surplus after filling the voids, and consequently the volume of the wet concrete was only 5 c.ft. as compared with 7 c.ft. dry mixture, consequently the following quantities were required for one span :—

Cement	.. $\frac{1}{5}$ of 1880 = 376 c.ft.
Sand	.. $\frac{2}{5}$ of 1880 = 752 c.ft.
Ballast	.. $\frac{4}{5}$ of 1880 = 1,504 c.ft.

The actual labour charges in handling the concrete, including the pay of three munshies, amounted to Rs. 263, so that the actual cost of the concrete was—

		Rs.	A.	P.
Ballast 1,504 c.ft. at Rs. 26 per % c.ft.. .	=	391	0	0
Sand 752 c.ft. at Rs. 35 per % c.ft. ..	=	263	3	0
Cement 376 c.ft. = 15·11 tons at Rs. 70 per ton	=	1,057	11	0
Labour charges		263	0	0
Coolies for watering 3 × 15 at Re. 0-12-0		33	12	0
Total ..		2,008	10	0, say Rs. 2,010

Therefore the total cost of the decking was—

	Rs.
False-work	520
Reinforcement	3,102
Concrete	2,010
Total ..	5,632

∴ actual rate worked out to 5,632 ÷ 1,880 = Rs. 3 per c.ft. as compared with the *contract* rate of Rs. 5 per c.ft.

Analysis of the rate of the cement concrete wearing coat on the Chenab Bridge.

Without reinforcement.

Eight panels were done daily, the labour charges amounting to Rs. 30, and as $8 \times 5\frac{1}{3} \times 20 \times 3\frac{1}{2} \times \frac{1}{12}$ = 249 c.ft. of concrete was laid, while the voids actually measured 32 per cent., 249 × 100 ÷ 68 = 366 c.ft. of material was actually required for a day's work.

The proportions used were 1 : 1½ : 3, so that in 366 c.ft. of material there were—

	C.ft.
Cement	67
Sand	99
Bajri	200

and taking a cubic foot of cement as weighing 90 lbs. this cost :—

	Rs.
Cement $\frac{67 \times 90}{2,240}$ at Rs. 70 a ton .. .. =	188
Sand 99 c.ft. at Rs. 35 % c.ft. .. .. =	36
Bajri 200 c.ft. at Rs. 50 % c.ft. .. =	100
Add the daily cost of working the pulsometer which supplied the water .. .. =	10
Also the actual daily cost of transporting the material including coal for crane .. .. =	32
And labour charges as above .. .. =	30
Making the total cost of 249 c.ft. of concrete .. =	395, say Rs. 1-9-0 per c.ft.

With reinforcement.

2,365 r. feet of ½″ diameter rods, used in eight panels, weighed 3·5 cwt., costing as follows :—

	Rs.
3·5 cwts. steel at Rs. 20 per cwt. .. .. =	70
4 blacksmiths at Rs. 2 a day .. .. =	8
8 coolies at Re. 0-12-0 a day .. .. =	6
Total ..	84
Add cost of unreinforced concrete	395
Making the total cost	479, say Rs. 1-15-0 per c. ft.

Details of cost of painting the Chenab Bridge.

The painting consisted of five operations—

(1) Scraping.
(2) Oiling.
(3) Priming coat (red lead).
(4) Grey paint (first coat).
(5) Grey paint (second coat).

(1). Scraping averaged Rs. 60 per span.

(2). Eighteen men were employed for a day and a half in applying four gallons of oil to one span. The oil at Rs. 11 per gallon cost Rs. 44, while Rs. 40 was paid to the labour, so that the total cost of oiling was Rs. 84.

(3). Four cwts. of dry lead paint, mixed with sixteen gallons of oil, were applied to a span in four days—the cost being—

	Rs.
4 cwts. of red lead at Rs. 55 per cwt. .. =	220
16 gallons of oil at Rs. 11 per gallon .. =	176
Labour at Rs. 30 per diem	120
Total ..	516

(4). Five cwts. of grey paint were used in the first coat at a cost of Rs. 55 per cwt., while labour charges amounted to Rs. 30 a day, for three days, so that the total cost was Rs. 365.

(5). Three cwts. were probably used in the second coat, when labour cost Rs. 60 in all, making the total cost Rs. 225.

The total cost was thus—

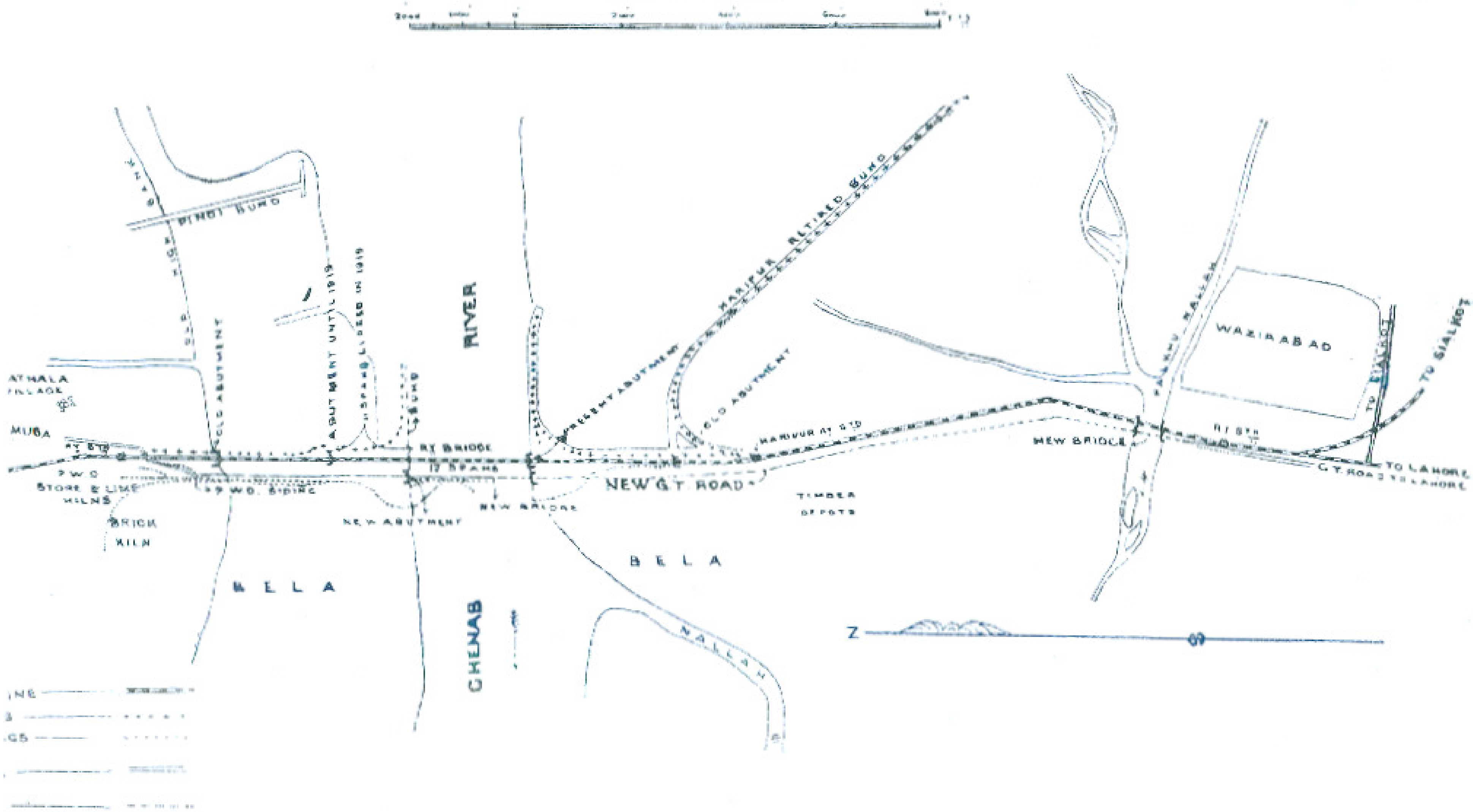
	Rs.
Scraping	60
Oiling	84
Priming coat	516
First coat	365
Second coat	225
Brushes, etc.	20
Total cost of painting 110 tons ..	1,270

Therefore rate per ton was 1,270 ÷ 110 = Rs. 11-9-0, whereas the contract allowed a rate of Rs. 15 per ton.

PLATE No. 1

GENERAL PLAN OF CHENAB AND PALKHU BRIDGES

SCALE 2 - 1 MILE



DETAILS OF WELL SINKING. PLATE No. 2

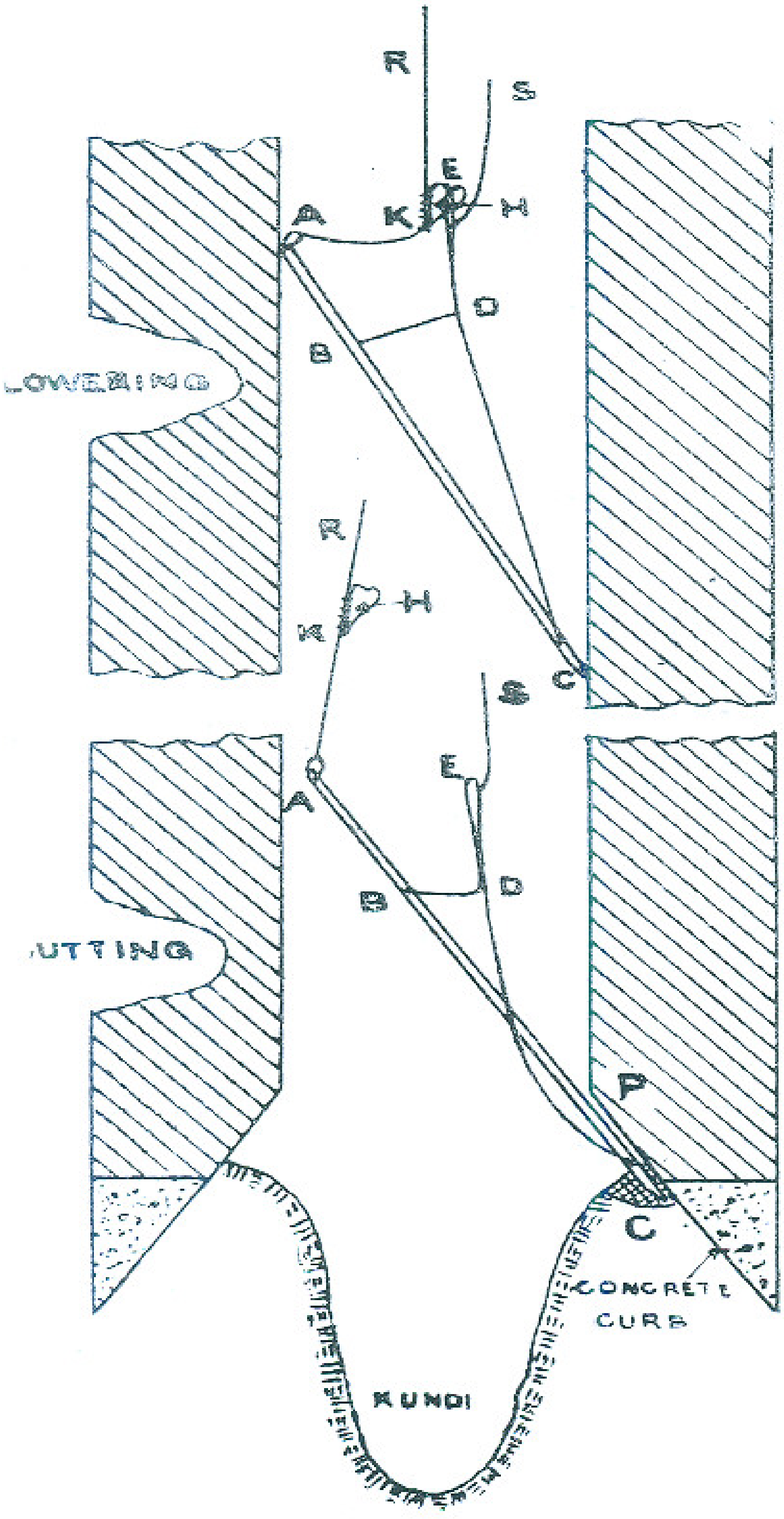
Well No.	Type of curb.	Date of laying the cutting edge.	Date of commencement of sinking.	Date when clay was struck.	Date when well was founded.	Time taken in months. Preparatory to sinking.	Sinking in sand.	Sinking in clay.	Total time.	Depth at which clay was struck.	Depth at which well was founded.	Movement of well from true position. Longitudinally.	Laterally.
						CHENAB BRIDGE.							
1	Concrete	27-12-19	16-2-20	..	15-5-20	1 2/3	3*	..	4 2/3	..	41′-0″	0′-6″ S.	1′-5″ E.
2	Steel	13-12-19	19-1-20	25-5-20	15-11-20	1¼	4¼	5½	11	62′-0″	88′-5″	0′-1″ S.	0′-1″ W.
3	Steel	21-1-20	11-2-20	2-5-20	11-2-21	2/3	2¾	9 1/3	12¾	62′-0″	86′-11″	1′-3″ N.	0′-8″ E.
4	Steel	4-11-20	11-11-20	19-1-21	7-5-21	¼	2¼	3½	6	62′-0″	81′-7″	0′-5″ S.	0′-10″ E.
5	Concrete	3-10-20	20-10-20	2-12-20	18-3-21	½	1½	3½	5½	59′-0″	84′-0″	0′-6″ S.	0′-3″ E.
6	Steel	18-10-20	26-10-20	17-12-20	19-2-21	¼	1¾	2	4	61′-0″	85′-9¼″	0′-2″ S.	0′-1″ W.
7	Steel	21-1-20	6-2-20	26-4-20	30-12-20	½	2 2/3	8 1/6	11 1/3	66′-0″	91′-0″	1′-0″ N.	1′-1″ W.
8	Steel	16-11-19	17-12-19	29-4-20	17-3-21	1	4 1/3	10 2/3	16	65′-0″	84′-9″	0′-9″ S.	0′-9″ E.
9	Steel	12-11-19	14-12-19	18-1-20	13-3-21	1	1¼	13¾	16	64′-0″	84′-10¼″	0′-9″ S.	0′-5″ W.
10	Steel	15-10-19	28-11-19	25-2-20	31-1-21	1½	2¾	11¼	15½	66′-0″	84′-2¼″	..	2′-0″ E.
11	Steel	12-10-19	19-11-19	26-1-20	22-11-20	1¼	2 1/3	9¾	13 1/3	62′-0″	87′-0″	0′-7″ N.	0′-5″ E.
12	Concrete	17-10-19	4-12-19	13-4-20	16-11-20	1½	4½	7	13	64′-0″	90′-0″	0′-6″ S.	0′-8″ E.
13	Steel	2-3-20	14-3-20	18-6-20	17-12-20	1/3	3 1/6	6	9½	63′-0″	88′-0″	1′-8″ S.	0′-2″ E.
14	Concrete	11-3-19	8-4-19	13-6-19	12-4-20	5/6	2 1/6	10	13	57′-0″	81′-3″	0′-9″ N.	0′-2″ E.
15	Concrete	8-3-19	4-4-19	2-6-19	30-10-20	1	2	16¾	19¾	57′-0″	82′-1″	0′-3″ N.	..
16	Concrete	2-3-19	30-3-19	20-5-19	16-12-20	1	1 2/3	18 5/6	21½	57′-0″	73′-9″	4′-0½″ N.	0′-1″ W.
17	Concrete	24-2-19	23-3-19	4-5-19	28-3-20	1	1 1/3	10¾	13 1/6	57′-0″	81′-9″	1′-1½″ N.	0′-8″ E.
18	Concrete	14-2-20	29-3-19	..	31-10-20	1½	7†	..	8½	..	41′-0″	1′-6″ S.	0′-7″ E.
						PALKHU NALLAH.							
1	Concrete	8-9-19	16-2-20	31-5-20	15-6-20	5¼	3½	½	9¼	48′-9″	52′-7½″	3′-5¾″ N.	1′-1½″ W.
2	Concrete	22-2-20	29-3-20	30-6-20	20-10-20	1 1/3	3	3 2/3	8	51′-0″	66′-3″	5′-4 7/8″ N.	2′-4″ W.
3	Concrete	6-4-19	12-5-19	19-6-19	15-9-19	1¼	1¼	2 5/6	5 1/3	54′-0″	76′-0″	..	..
4	Concrete	1-4-19	18-5-19	14-10-19	14-12-19	1½	5	2	8½	54′-0″	69′-0″	2′-2½″ N.	0′-0½″ W.

* Well No. 1, Chenab, extra 2′-6″ of sinking above assumed bed level as the well curb was laid on the bank.

† Well No. 18, Chenab, extra 13′-0″ of sinking above assumed bed level as the well curb was laid on top of the Bell Bund.

PLATE No. 3

VERRIER'S RAIL CUTTER



DETAIL
OF
RAIL CUTTER

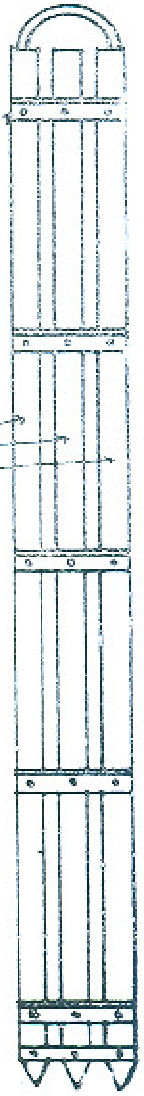
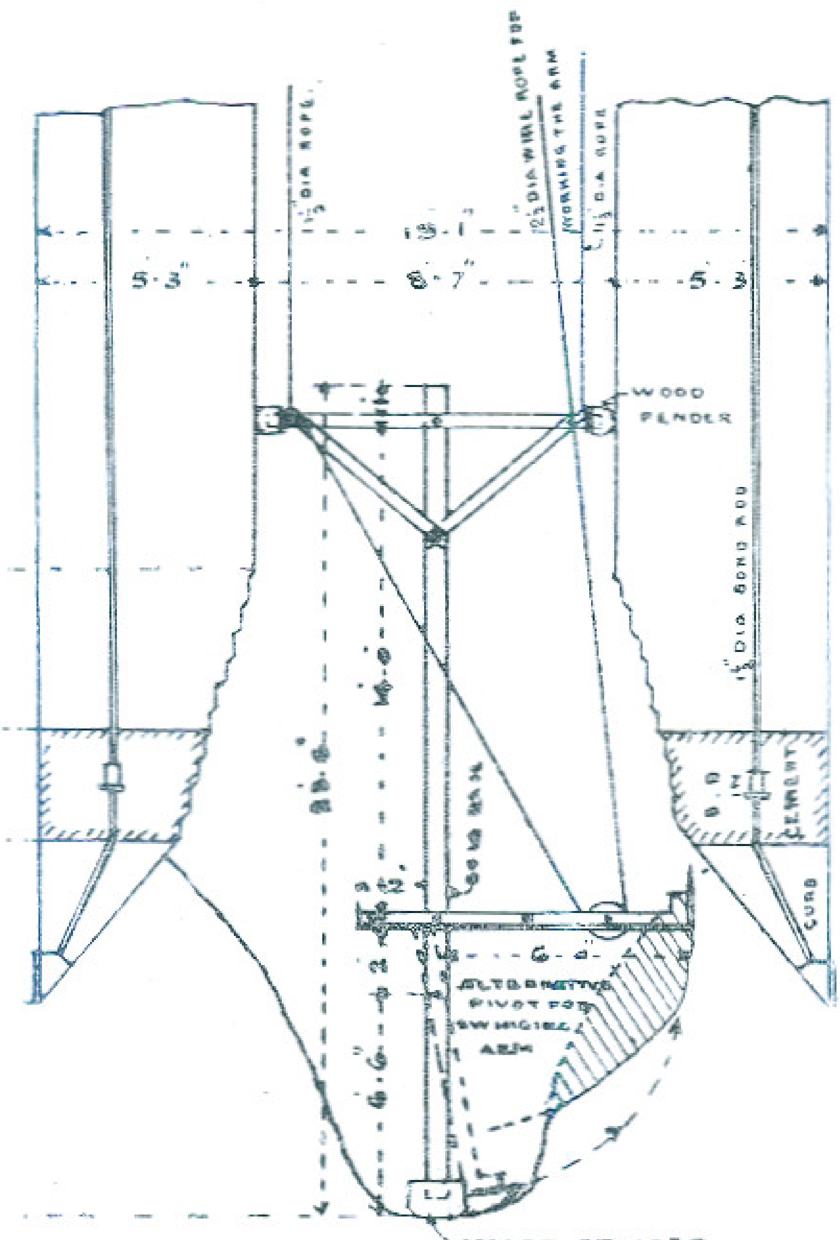
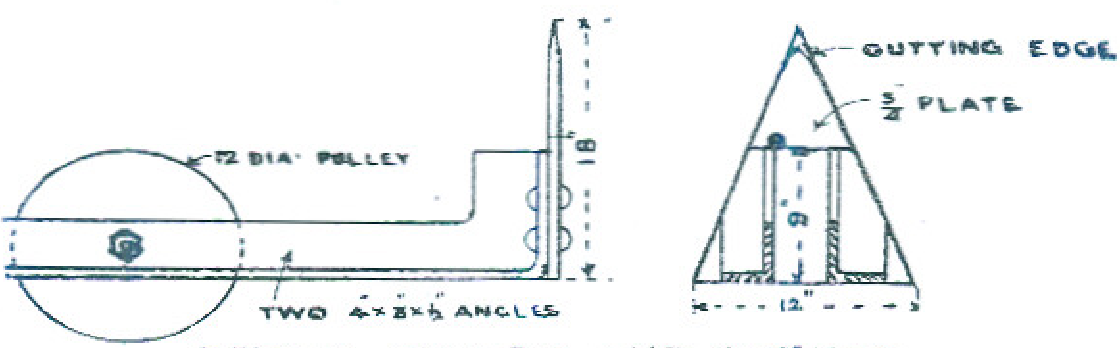


PLATE No. 4

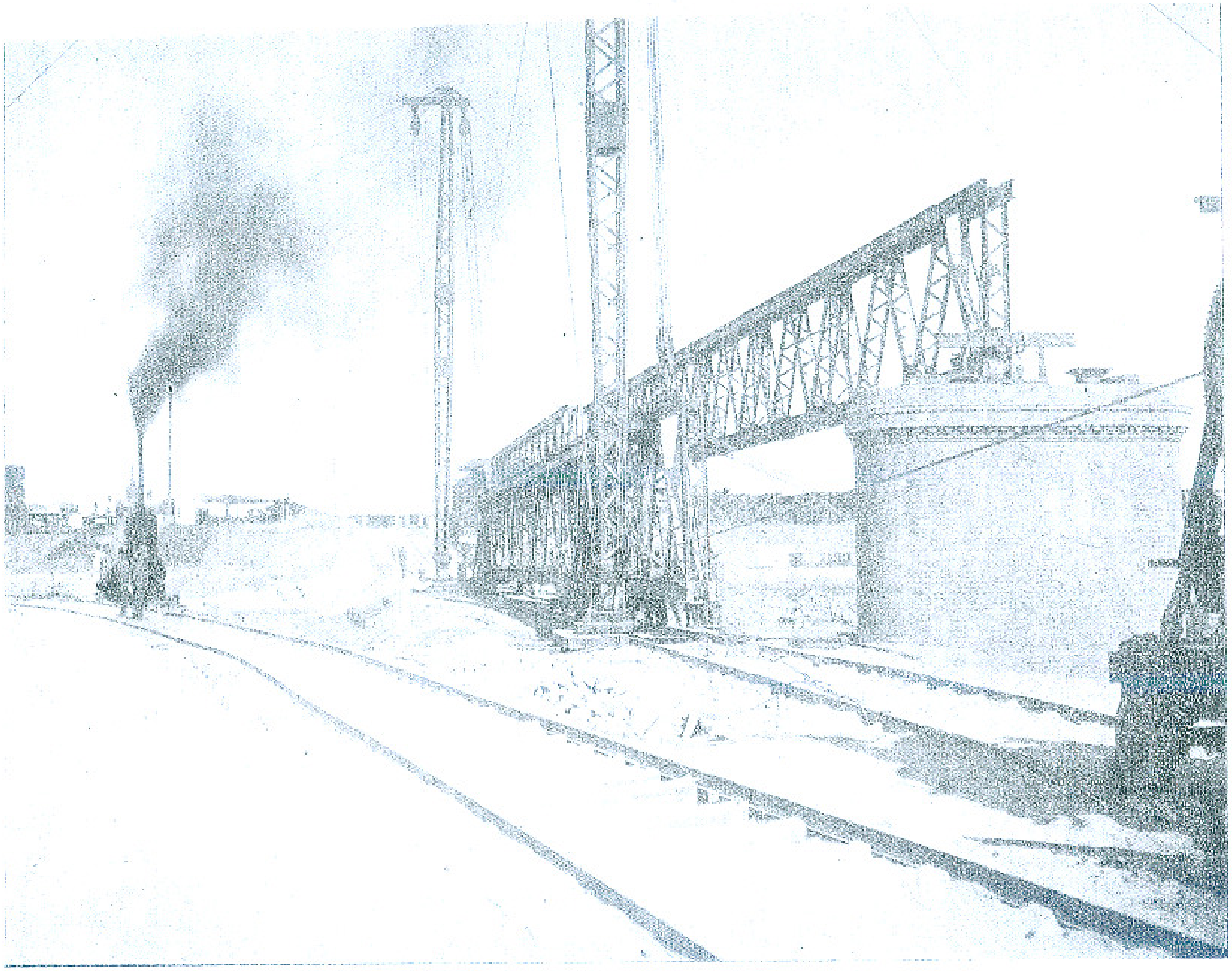
GORDON'S SIDE CUTTER





DETAIL OF ARM AND CUTTER

CHENAB BRIDGE—WELL-SINKING OPERATIONS. PLATE No. 5.



CHENAB BRIDGE—GIRDER ERECTION,

PLATE No. 6.

DISCUSSION.

THE AUTHOR introducing his paper stated he had nothing to add to the paper, which had been compiled from the official records, which owing to financial stringency had not been printed by the Public Works Department.

The Author had not been engaged on the construction of the Bridge himself and regretted that Messrs. Armstrong, Macfarlane, Everall, Anderson and Freak all of whom had been connected with the construction work were not present to contribute towards the discussion.

He hoped that Mr. Champa Lal who had been employed on the works for a short time and who was present, would speak. There was one point of interest however which he would like to draw attention to, *viz*., that the concrete proportions as used in the Sutlej Valley Project did not tally with Mr. Anderson's figures for the concrete used on the Palkhu Bridge. It was interesting also to note that the labour charges for the reinforced concrete decking of this Bridge came to about Rs. 15 per hundred cubic feet. The rate for similar work at Ambala which the Author had been connected with was about Rs. 22.

MR. F. H. BURKITT stated he did not quite understand why steel well curbs had been used in preference to reinforced concrete well curbs.

The well curbs used on the Sutlej Valley Project were of wedge shaped reinforced concrete with steel cutting edge and were very successful and easily constructed and had given no difficulty whatsoever, and he considered that well curbs of this type were preferable to steel curbs. With regard to the method of plugging of the wells mentioned on page 29, many engineers considered it was of no advantage to put in plugs.

He considered that circular wells of the type described in the paper were a bad shape, and the experience at the North-Western Railway Bridge at Ferozepore was that they tended to cause a long trail downstream of each pier to be subject to scour action. He observed that some of the cappings to the wells were constructed with rail reinforcements and suggested this was expensive and that it might have been cheaper to provide reinforced concrete cappings over all wells.

L. MAKHAN LAL observed that on page 25 it was stated "the intention was to sink all wells to a minimum depth of 80 feet below bed level with at least 25 feet in clay." This did not agree with the figures on plate No. 2 giving the actual details of well sinking as carried out and he wished to know why the original intentions had not been adhered to and what were the reasons which caused the designers to arrive at the conclusion that it was necessary to go 25 feet into the clay. If clay had not been found say up to 150 feet depth, would it have been necessary still to sink the wells deeper.

MR. H. W. NICHOLSON stated he was very interested in this work as the bulk of the plant had been purchased by him for Suleimanki Weir construction. Mr. Dorman on page 24 mentioned that the ultimate cost of the bridges worked out to Rs. 27,10,240. Did this represent the final cost?

He was strongly in favour of reinforced concrete well curbs, which were easily constructed and the concrete work set in a few days, which enabled work to continue on the construction and sinking of the wells without undue delay.

Mr. Burkitt had already described one type of reinforced concrete well curb. At Suleimanki, however, the speaker had employed a different type suitable for wet work, consisting of a wedge shaped curb built of $\frac{1}{16}$ inch sheet iron, into which the cement concrete was placed. The sheet iron acted as the mould for the concrete and also as the reinforcement, and cutting edge.

On page 26 the author had described how well sinking had been proceeded with by lowering the water level inside the well by *charsa*.

The speaker had tried the effect of blasting with wells full of water and also with water level lowered as much as possible and had found there was no improvement in results as the effect of dewatering.

He considered that there was no advantage in sinking with great effort wells into clay provided that the excavated hole in the clay could be kept open. The hole could then be made to the required depth and filled in with concrete.

It would have been interesting to learn whether the asphalt expansion joints described on page 33 were satisfactory.

Mr. D. A. Howell said that in his experience there was very little advantage if any in providing cutting edges to well curbs and that he had found no difficulty on sinking wells with reinforced concrete curbs without cutting edges, to depths of from 60 to 100 feet.

Sirdar Prabh Singh agreed with the views of the last speaker. The country wells in the Punjab were frequently provided with hard wood curbs of rectangular section and were sunk quite easily.

Mr. Allan Ferrie said he had used well curbs of the type described by Mr. Nicholson as well as ordinary reinforced concrete curbs, at Islam Weir, and had found the cost of both types nearly equal. If wood centering was employed for the construction of the reinforced concrete curbs, the cost of the centering worked out much more than that of the reinforced concrete itself, and for this reason brick work centering was more suitable in the Punjab because of its cheapness.

Referring to the quantities of ballast found necessary to produce the concrete work described on pages 36 and 37, it had been found on the Islam weir construction works that for 1 : 4 : 8 concrete, about 129 cubic feet of Nalaghar ballast (containing about 20 per cent. of fine material below $\frac{1}{4}$ inch mesh) was required to produce 100 cubic feet of consolidated concrete.

Mr. Tinsley said that on the lining works of the Bikaner canal, Sutlej Valley Project, the first estimate for lime concrete construction allowed for 110 cubic feet of kankar ballast per 100 cubic feet of consolidated concrete but after the work had gone on for some time, as the result of actual measurements it was found that 120 cubic feet of ballast was actually used for each 100 cubic feet of concrete.

The raw kankar was screened mechanically into 4 sizes into separate hoppers and was measured in tip wagons.

The lime concrete lining work was laid in slabs 44 feet long and was carefully measured with the tape.

He could not agree that the concrete well curb lined with sheet iron described by Mr. Nicholson was a reinforced concrete curb as the sheet iron, being merely an envelope, did not act as a reinforcement.

L. Champa Lal said that he had the pleasure of serving as an apprentice engineer for 4 months on the construction of the works described in the paper. Referring to Mr. Nicholson's remarks concerning the value of partially dewatering the wells in order to cause easier sinking, he had found that in this case, there was a decidedly good effect obtained by lowering the water by *charsas*, as the higher water pressure on the outside of the base of the wells tended to cause small "blows" which softened or loosened the clay bottom.

Mr. W. P. Thompson referred to Mr. Tinsley's remarks with regard to the quantities of ballast required for each 100 cubic feet of concrete on the lining of the Bikaner canal and pointed out that owing to the small thickness of the lining it was not practicable to measure accurately the volume of the work; a slight over-thickness would have made an appreciable percentage variation of the volume. Under these circumstances it was not safe to rely on the figures given.

The Author replying to the discussion stated he was under the disadvantage of not having served on the works described in his paper but he would do his best to answer the criticisms made.

In reply to Mr. Burkitt he presumed that the main object of using steel curbs for the wells in place of reinforced concrete, was that the steel curbs were more rapidly built.

With regard to the objection raised to circular wells, the North-Western Railway Engineers were consulted before the design of the bridges was settled, and they advised that the wells should be made circular. He was sorry that he could not answer the points raised by R. B. Makhan Lal regarding depths of wells. As a clay bed was actually found into which the wells were sunk, the point as to what depths it would have been necessary to continue well sinking if no clay was met, did not arise. In regard to the final costs of the work, this had not been settled yet owing to endless correspondence with the North-Western Railway, which was still going on.

The figures of concrete volumes given by Mr. Ferrie and Mr. Tinsley were interesting and agreed closely.