"CHENAB AND PALKHU ROAD BRIDGES."

By DONALD MACFARLANE,
Executive Engineer, Buildings and Road Branch,
and
WILLIAM TEAGUE EVERALL, A. M. Inst. C. E.,
Bridge Engineer, North-Western Railway.

This work was started as an urgent military necessity in the autumn of 1918.

The bridge over the Palkhu consists of 3 spans of 142′ 1″ centre to centre, and will replace an old boat bridge which is unsuitable for heavy motor transport.

The Chenab bridge consists of 17 spans, also 142′ 1″ centre to centre, the total length of the bridge being just under half a mile.

The only method at present of getting ordinary road traffic across the Chenab consists of a ferry train which runs once a day between Wazirabad and Kathala, the next station on the other side of the river. This will, of course, be discontinued on completion of the new road bridge. The Chenab is the last of the five rivers of the Punjab to be bridged by a road bridge, so that on its completion there will be an uninterrupted road from Delhi to Peshawar.

The girders for both the Chenab and Palkhu Bridges have been obtained from the North-Western Railway Bridge, which was reduced in length by 11 spans. The girders on the railway bridge are double, whereas those on the road bridges are single. The 44 single girders so obtained therefore provide for the 17 spans of the Chenab and the 3 spans of the Palkhu with 2 spans to spare.

The original railway bridge consisted of no less than 64 spans, and its reduction to its present length is dealt with in Mr. Pavry's paper before the Congress of 1920. The old abutments of the railway bridge with what remains of the protection works are still to be seen some considerable distance north and south of the present abutments. The original railway bridge called the Alexandra Bridge was opened by the late King Edward VII, and the silver rivet fixed by him may be seen in its new position in the centre of the first span on the downstream side.

The work of both the road bridges as far as wells, piers and approach roads are concerned is being done entirely by contract; the contractor being Rai Bahadur Narain Singh of Delhi, who keeps an agent with power of attorney resident on the work.

The original combined estimate for the Chenab and Palkhu Bridges amounted to Rs. 18,69,729. The revised estimate, which is under sanction, was prepared in August 1920 amounting to Rs. 25,35,649, of which the cost of the Chenab bridge itself, apart from the approach roads, is Rs. 20,22,154, or roughly Rs. 837 per foot run.

Work was commenced on the 12th of October 1918, but owing to the difficulties in collecting materials, tools and plant only four wells were started that working season.

Laying out.—The laying out of the Chenab Bridge was facilitated by the fact that it is exactly parallel to the railway bridge, 400 feet downstream, each pier being exactly opposite the corresponding one of the railway bridge. Points were fixed accurately on the centres of each of the railway piers, and from these theodolite readings were taken from downstream. Two brick pillars were built at both ends of the bridge to finished level, and all gantries were erected diagonally so as to facilitate sighting through from one pillar to the other with the theodolite.

Owing to the fact that when the Upper Chenab Canal is closed the river water extends practically from bank to bank, the method adopted on the Ravi Bridge of fixing accurately laid out pillars around the four sides of each well was not practicable, and in consequence all checking was done with the theodolite readings as described above.

Well curbs.—Owing to the difficulty in procuring steel plates during the early stages of the work reinforced concrete curbs were constructed. These are described in Mr. Armstrong's paper before the Congress of 1920. Considerable disadvantage was experienced with this type of curb owing to the time taken for the concrete to set and the risk of a flood occurring prior to sinking. Thus in one case a flood caused one well to tilt over to an angle of 1 in 4 when the sinking had only just been started, and considerable trouble was experienced in putting it right again. At a later date, when steel plates became available, the concrete construction was abandoned in favour of steel curbs. Altogether ten steel curbs have been constructed, the concrete ones being Nos. 1, 2, 3 and 4 on the Palkhu and 1, 5, 12, 14, 15, 16, 17 and 18 on the Chenab.

Wells.—The wells are of circular construction, 19 feet diameter, with 5' 3" thick steining (with the exception of abutment wells, which are oval 26' 6" by 20' 6" with 5' 6" steining). On the Chenab they are being sunk to a minimum

depth of 80 feet below bed level and a minimum depth of 25 feet in clay, whilst on the Palkhu they are sunk to a minimum depth of 75 feet below bed level and 20 feet in clay. When founded they are plugged at the bottom with cement concrete in the proportion of 1:3:6 to a height of 10 feet starting from the top of the brick corbelling. The top plug, 10 feet in height, consists of lime concrete in the proportion of 1 lime, 2 Chenab sand, 4 brick ballast. The intermediate core between the bottom and top plugs consists of sand only. Clay has been met at an average depth of 62 feet below bed level, and is of a very tenacious nature. Sinking in sand is being paid for at a rate of Rs. 8-8-0 per foot for the first 10 feet with an increase of Rs. 7 per foot for each succeeding 10 feet, whilst sinking in clay is paid for at a rate of Rs. 136 per foot. The total average cost of sinking a well, *i.e.* 62 feet in sand and 25 feet in clay, amounts to Rs. 5,061, or an average rate of Rs. 58-3-0 per foot. The following statement gives the progress of each well :—

Well No.	Date of laying curb.	Date of founding.	Depth when founded.	Time taken in months.
		CHENAB.		
			ft. in.	
1	27th December 1919	15th May 1920 ...	41 0	4⅔
2	13th December 1919	15th November 1920	88 5	11
3	21st January 1920 ...	11th February 1921	86 11	12¾
4	4th November 1920...	In progress	...	...
5	3rd October 1920 ..	18th March 1921 ...	84 0	5½
6	18th October 1920 ...	19th February 1921...	85 9½	4
7	21st January 1920 ...	30th December 1920	91 0	11⅓
8	16th November 1919	17th March 1921 ...	84 9	16
9	12th November 1919	13th March 1921 ...	84 10¼	16
10	15th October 1919 ...	31st January 1921 ...	84 2¼	15½
11	12th October 1919 ...	22nd November 1920	87 0	13⅓
12	17th October 1919 ...	16th November 1920	90 0	13
13	2nd March 1920 ..	17th December 1920	88 0	9½
14	11th March 1919 ...	12th April 1920 ...	81 3	13
15	8th March 1919 ...	30th October 1920 ...	82 1	19¾
16	2nd March 1919 ...	16th December 1920	73 9	21½
17	24th February 1919	28th March 1920 ...	81 9	13¼
18	14th February 1920	31st October 1920 ...	41 0	8½
		PALKHU.		
1	8th September 1919	15th June 1920 ...	52 7½	9¼
2	22nd February 1920	20th October 1920 ...	66 3	8
3	6th April 1919 ..	15th September 1919	76 3	5⅓
4	1st April 1919 ...	14th December 1919	69 0	8½

On the whole the wells have been sunk satisfactorily without very great difficulty, although in all cases the sinking of the last few feet in clay has been very slow indeed. In most cases in sinking in clay the method adopted has been to obtain by dredging as deep a "kundi" as possible, *i.e.*, anything from 6 to 20 feet ; the water has then been removed to as great a depth as possible by means of a "charsa," and this causes the wells to sink, aided by blasting charges consisting of anything from 2 to 8 cartridges of gelignite per charge. In the final stages the formation of this "kundi" is often a lenghthy process owing to the occurrence of blows. In cases where the stiffness of the clay interferes with the efficiency of the dredger, matters have been helped out by the use of a straight chisel rail-cutter, and in extreme cases of wells which have stuck badly, the "kundi" has been widened out to a width of 12 feet all round by means of an under-cutter worked with a lever arm.

The following is a brief description of wells which gave trouble :—

No. 2 well, Palkhu.—This well became badly tilted, out of position, and sinking was extremely slow in its latter stages. All efforts to sink it to its specified depth having failed, it was founded at a depth of 66¼ feet below bed level and 15¼ feet in clay. The "kundi" beneath the well, which was 8 feet deep at the time of founding, was plugged with cement concrete. The final position of the well was 5' 3⅜" out to the north and 2' 4" to the west.

No. 16, Chenab.—This well in its latter stages was 4 feet out to the north, and further sinking, which was accomplished only with very great difficulty, was accompanied by further side movement at the rate of about quarter of an inch for every six inches of sinking. This well was, therefore, founded 73¾ feet below bed level and 17 feet only in clay. The 10½ foot "kundi" beneath it was plugged with cement concrete.

No. 10, Chenab.—This well having reached a depth of 84' 2½" below bed level and 18' 2½" in clay, further movement was found impossible, and as its non-completion was about to hold up girder erecting work, the well was founded at this depth, the 12-foot "kundi" being plugged with cement concrete.

Nos. 9 & 8, Chenab.—These two wells stuck at a depth of 84 feet below bed level and 20 feet in clay in spite of the formation of good deep "kundies" which were widened with the under-cutter to a width of 12 feet. They were, therefore, founded in that position, their "kundies" being cement plugged.

The only well now unfinished is No. 4, which was started in the middle of October last, and has still roughly 13 feet to go.

Piers.—The piers are 20 feet long by 8'-8" wide. They are, therefore, 1 foot longer than the external diameter of the wells, so that even in the case of a well being sunk accurately in position, the noses of the piers have to be corbelled out 6 inches on each side beyond the well. In cases of wells which are at all out of position, this corbelling is, of course, further increased, and in some cases the over-hang was so great that concrete slabs reinforced with rails have been adopted to avoid excessive corbelling with its attendant difficulty in the shape of masonry construction below water-level. Thus in the case of No. 2 well on the Palkhu, which, as already stated, was 5' $3\frac{3}{8}$" out longitudinally and 2' 4" out laterally, the corbelling would have been very excessive. The 2' 4" error was got over by means of a slab as described above. As regards the longitudinal error of 5' $3\frac{3}{8}$", this was compensated for by bringing the abutment forward to this extent and cutting down the girders of the central span accordingly.

Floods and Accidents.—So far the work from its start has been attended on the whole by good fortune, the river having behaved extremely well. There is a telephone from the Executive Engineer's house to the Head Works of the Upper Chenab Canal at Marala and these Head Works are in telegraphic communication with Riasi, 40 miles further upstream, where gauge readings are taken twice daily, so that in most cases a clear 24 hours' warning is given of a flood.

On 5th February 1920 a 2-foot flood did a certain amount of damage ; well No. 3 on the Chenab with 10 feet of masonry was just ready for sinking when the flood occurred, tilting the well over 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 heavy tackles attached to the corresponding railway pier. In the same flood well No. 7, which had been sunk 25 feet, was tilted to an angle of 1 in 12, and the islands

for wells Nos. 4, 5 and 6 were so badly damaged that further work on these wells was abandoned for that working season. On 15th March 1920 a 6-foot flood caused five gantries to collapse, and partially washed away the pile bridge and construction line in the river bed.

Superstructure.—The dismantling of the girders on the North-Western Railway Bridge and their subsequent strengthening, remodelling and re-erection complete on the road bridges is entirely in the hands of the North-Western Railway, Bridge Department, under the supervision of Mr. W. T. Everall, Bridge Engineer, North-Western Railway. This work was commenced in January 1920. The dismantling of the girders was done under railway traffic without interfering with the running of trains, the girders being placed on a girder dump at right angles to the Railway Bridge.

These girders were originally in a meter gauge bridge, afterwards being utilised in the present Railway Chenab Bridge, where, even when using four to a span, they are overstressed under existing S. G. engine loads. They were made up in the form of a through type with a flooring system carried on the bottom booms.

The new road bridge spans are of a deck type with a 22' width of roadway carried on the top booms of two main girders. The latter have been considerably remodelled and strengthened to carry the loads required, which include a reinforced concrete floor weighing 95lbs. per square foot, and live loads equivalent to 90lbs. per square foot taken over the whole surface, or a maximum unit loading of a 15-ton steam roller or a 20-ton tractor. These conform to the requirements for a modern highway, including heavy mechanical transport.

The remodelling work entailed reinforcing with 25 per cent. of additional metal on the booms, strengthening of 33 per cent. of the main web members and their connections, the provision of new cross girders spaced 5 feet apart throughout the bridge, cross and lateral bracings to the main girders, and new roller rocker bearings. To give some idea of the extent of this work, considerably over 80 tons of rivets have been used for the remodelling and put into the structure in the girder yard. The estimated cost of the work for the superstructure erected on the piers, excluding the concrete slabs, is Rs. 205 a ton. It is interesting to note that new material, if purchased from England or local firms, capable of carrying the same loads, works out at

Rs. 700 a ton. The remodelling work for both the Chenab and Palkhu bridges has all been done at one depot, modern pneumatic machinery and machine tools being used throughout. The total weight of iron and steel work remodelled and handled amounts to 2,500 tons.

Erection of girders of Chenab Bridge.—The eleven spans from the north abutment have been erected by means of two 60' steel derricks, operated by two powerful steam hoists. Each girder lifted weighed 50 tons. The steel derricks are of special construction, being portable and made in sections capable of being extended to a length of 100 feet. An interesting device has been arranged in the form of a balance head, which enables the load resultant to pass down through the centre of the derrick pole and facilitates the easy attachment of the tackle and ropes. The girders are moved to the erection site in one piece all rivetted up, being first traversed across the remodelling yard on specially designed trolleys; then traversed down at right angles along the surface track on small trucks provided with special frame bracings. From pier No. 7 onwards to the south abutment the girders will have to be erected over the water channels. The procedure adopted is to group 18 girders on the piers of the three land spans 7-8, 8-9 and 9-10. Each girder will be boomed out by means of two small gantries running on the top booms of two outer girders, the latter being already in their final position and spaced 12' centre to centre. The girder to be erected will be traversed out so that the end is at a distance of about 40' from the pier. When in this position it will be placed on three boats joined together in the form of a pontoon carrying timber trestling of a suitable height to receive the end of the boomed outer girder. At this stage one gantry operating towards the centre of the girder will be removed. The girder on the boats can then be floated across to the opposite pier and placed in the final position. Stout anchorages have already been placed on the upstream side of the bridge to form holdfasts for the ferry rope which it is proposed to stretch across from pier to pier, so that while the girders are being traversed across the boats will not be diverted by the river current. To provide for a variation in water levels, a provision of 3' adjustment will be made on the top of the trestles themselves. The details of the process of this method of erection will explain themselves more fully when actually seen at the bridge site.

Palkhu Bridge.—In the case of Palkhu Bridge the girders have already been erected. This was done by means of floating out on boats, a girder being carried on staging similar to the system adopted for the erection of the Ravi Bridge. The girders, weighing 50 tons each, were brought singly from the Chenab to the Railway Palkhu Bridge, a distance of three miles, and were handled and placed on the boat staging by means of two powerful 30-ton steam cranes the boats then being hauled downstream to the site of the new bridge and transferred to the piers by means of ordinary screw jacks and timber packings.

Decking.—Both the bridges are to be provided with reinforced concrete decking. In the first instance partly to avoid the cost of centering, and partly to give the contractor work to do during the flood season ; this decking was precast in the form of slabs 3' wide and 7" thick. During their construction in December 1919 some of these slabs were tested, and they were found to break at an average load of 17 tons. Allowing for a factor of safety of 4 and 25 per cent. for impact, the slabs were safe for only $17 \times \frac{1}{4} \times 4/5$ equal to 3·4 tons, or approximately the weight of the rear wheel of a 10-ton roller instead of a 15-ton roller as required. This weakness was attributed to the insufficient dispersion of the load owing to the insufficient width of 3' as opposed to a continuous slab.

The slab unit should have been cast with a width not less than twice the span. The effective width E can then be taken. $E = 0{\cdot}6 \times l + 1{\cdot}7$ feet, where l = length of slab, which in this case amounts to 4·7 feet for the dispersion of stress under a concentrated load, *vide* Hool and Johnson's Concrete Engineers' Handbook, page 604.

To strengthen these slabs, of which over fourteen spans have already been moulded, Mr. Everall proposed grooving the sides and grouting the joints to form shear locks, the top wearing coat, which is to be cement concrete, being made 4" thick, so as to increase the effective thickness of the slabs. This method was tested with only $2\frac{1}{4}$ thickness of cement wearing coat, and the slabs so tested did not break until a load of $33\frac{1}{4}$ tons was applied, thus clearly shewing that the shear locks had transmitted a part of the load on to the two adjoining slabs. This method has therefore been approved of and grooving is now being done. A further grid of $\frac{1}{4}$" bars, 8" apart and 2"

below the surface of the top coat, will, however, also be added to prevent temperature cracks and to increase the strength of the whole construction. The shear locks are being grooved out by pneumatic chippers.

For the remainder, *i.e.*, $2\frac{1}{4}$ spans of the Chenab and the whole of the Palkhu, the concrete decking is being cast *in situ*, the top wearing coat on the Palkhu Bridge being only 3″ thick. One span of the Palkhu has already been completed.

The process of hoisting the slabs on to the bridge and lowering them accurately into position will be one of some difficulty, and it is a great question whether it would not have been better to have them moulded *in situ* throughout as suggested and originally designed by the Bridge Engineer of the North-Western Railway.