THE CONSTRUCTION OF A DOUBLE TRACK GIRDER BRIDGE ACROSS THE JUMNA RIVER ON THE NORTH-WESTERN RAILWAY BETWEEN KALANOUR AND SARSAWA.

BY A. I. SLEIGH, F.C.H., ASSOC. M. INST. C. E.,
SUPERINTENDENT, KALKA-SIMLA RAILWAY.

The Jumna river rises in Garhwal close to a peak of the Himalayas called Bandurpanch 20,731 feet high. Its length from its source to the site of the bridge is about a hundred and fifty miles. The site chosen by the contractors and engineers, Messrs. Brassey, Wythes and Henfrey, who built the old Jumna bridge, was about thirty-six miles below where the river debouches from the hills, and just below the junction of two branches of the river. The design of this bridge was briefly as follows :—Length of bridge 2,663½ feet between abutments, waterway 2,376 feet, consisting of twenty-four spans of 99 feet clear. The abutments were carried on two wells (12'-6" diameter) backed by seven wells of seven feet diameter with wing walls carried back on more wells. The piers about seventeen feet high were carried on wells 12'-6" diameter, sunk about forty-four feet into the bed of the river. The girders were of the lattice type, 110 feet over-all and about nine feet in depth.

Successive floods in 1871 cracked the upstream wing wall of the Saharanpur abutment, scoured the foundations, and sucked away most of the earth behind the abutment, but the stream did not succeed in breaching the bank. Further damage was prevented by heaping block kunkar and Delhi stone round the abutments and piers, and since then a considerable quantity of stone has been thrown around the piers into the scour holes formed during summer floods.

The girders were strengthened in 1898 by means of vertical members, placed midway between the panel points with the idea of reducing the secondary stresses in the top boom, and a new system of cross and lateral bracing was also put in, but this strengthening only brought the girders up to 67 per cent. of Standard B of 1903.

In August 1907 Mr. Bagley, then Engineer-in-Chief, North-Western Railway, submitted a report on the advisability of building a new bridge three hundred feet above the present one on the Bell bund principle, *i.e.*, with deep foundations, the river being constricted between guide banks armoured with stone pitching. The original project provided for eight spans of 200 feet clear, with approaches and piers capable of taking a double line, but with only one track of girders up to Standard B of 1903 plus twenty-five per cent., as it was thought that the amount of traffic did not justify the expenditure on a double track bridge. This assumption was disproved soon after the opening of the new Beas and Sutlej bridges, and it was therefore decided to build a double track girder bridge over the Jumna river.

Benefitting by the experience gained from the new Sutlej and Beas bridges, it was decided to further constrict the Jumna river to seven spans of 200 feet clear, but it seems probable from the observations made, during the flood of 18th March 1911 (Water Level R. L. 873·5) when the river was constricted by construction works bunds to 560 feet waterway, and on the 11th September 1910 when a heavy flood (R. L. of flood = 877·3), flowed through the old bridge, that six spans would have provided sufficient waterway.

DESIGN OF THE NEW BRIDGE.

Alignment—

In order to make use of the existing guide bank on the left bank of the river (*vide* Plate No. 1) two alternative alignments presented themselves—

(*a*) The centre line of the new bridge to be at right angles to the bund, starting from a point two hundred feet above the Saharanpur abutment of the old bridge.

(*b*) The centre line of the bridge to be parallel to that of the existing bridge and at a distance of three hundred feet from it. Had this distance been less than two hundred feet, the scour holes, due to the obstruction of the piers of the new bridge, would have formed closed to the wells of the old bridge.

Alignment (*a*) was abandoned for the following reasons :—

(*i*) The extra expense involved by building a long approach bank on the Umballa side with comparatively very little shortening of the approach on the Saharanpur side.

(*ii*) An awkward entrance into Kalanour Station.

Approach Banks –

Prior to starting actual construction in the river bed, we were fortunate in having the experience of two heavy floods in the river, which gave most valuable information as to the correct height of the approach banks. On 13th August 1910 the difference of the water level measured under the bridge and behind the then existing left guide bank (2,800 feet long) was 3·5 feet, high flood level at the bridge being R. L. 876·8 (*vide* River Chart, Plate II). Subsequently, on 11th September of the same year, the river rose to R. L. 877·3, the difference in water level being 4·4 feet.

The flood of 11th September 1910 was the second highest on record at the bridge, the highest being 878·32 on 11th August 1872. It is probable, judging from the canal readings, that the flood of 1903 might have reached a higher level than 878·32, but for the breaching of both the guide bank, and the retired bunds, and of the line at the Budhi Jumna bridge about 2½ miles from the bridge on the Saharanpur side. From a note made by Mr. Bagley on these breaches it would appear that the difference in level was as much as five feet. It is therefore safe to assume that the flood level at the bridge will never rise above R. L. 881·00 and that the difference in level will never exceed 4·5 feet (the new guide bank being reduced to only half the length of the old guide bank), *i.e.*, the water level at the approach bank should never exceed R. L. 885·5. Allowing 2½ feet for free-board, the reduced level of the top of the approach bank was fixed at R. L. 888·00.

Guide Banks--

By adopting alignment (*b*) another problem had to be solved. The angle of the centre line of the left guide bank being 97° 27′ with that of the bridge, the question to settle was, whether the right guide bank should be at right angles to the line of the bridge or at the same angle as the left? It was decided that the right guide bank should be symmetrical with the left, *i.e.*, splayed out at an angle of 97° 27′ to the centre line of the bridge.

The molehead of the guide banks was designed on the same principle as the mole-heads of the Ganges bridges at Garhmukhtesar, the Chenab bridge at Jhand, the new Sutlej bridge at Phillour and the new Beas bridge at Beas, *i.e.*, built in a straight line with the rest of the guide bank. Curving the head of a bund only increases its length and cannot in any way coax the water from forming eddies, and the obvious method therefore is to face the action of the water by constructing a heavily armoured mole-head which will always remain the point of attack. With a curved head varying velocities in the river must necessarily produce different points of attack.

The amount of stone pitching on the guide banks was considerably reduced compared with what was used on the new Beas and Sutlej bridges, and a further reduction to only $1\frac{6}{7}$ feet, with an underlying layer of large ballast ($2\frac{1}{2}''$ mesh) or quarry chips, 6'' thick, would probably have been sufficient for the slopes. The width of the apron might also have been reduced by five feet. The length of the guide banks from abutment to mole-head was 1,460 feet, the length of the downstream portion being 300 feet.

The theory of constructing guide banks long enough to insure having a cushion of still water against the approach bank is a most excellent one, but since it is always found necessary to protect the slopes of the approach bank against wave lap with good turf, stone rip-rap, brick bats, etc., and as this protection is also eminently capable of withstanding the attack of water flowing at a velocity of, say, about five feet per second, it would be more economical to shorten the guide banks accordingly. On this reasoning the length of the guide banks at the Jumna bridge might have been reduced upstream to 900 or 1,000 feet at the maximum.

Plates 2 and 3 give detailed drawings of the two guide banks. It will be noticed that the borrow pits have been carried right up to the toe of the quadrant siding leading to the right guide bank, and a light apron put at the toe of the slope. The reason for not keeping the borrow pits away from the toe of the bank was, that a dam across an inundation channel (*vide* Plate 1) about half a mile upstream on the right bank, was liable to burst with a sudden rise in the river, and the water to flow along the approach bank. This channel would in time cut back into the bank, unless of course the edges of the borrow pits were protected with stone, but this would not have been a satisfactory or an economical solution.

Wells –

It was decided to adopt twin octagonal wells (*vide* Plates 4 and 6) twenty feet in diameter with 5' 6'' steining, instead of twin circular wells eighteen feet in diameter with 4' 3'' steining, as used on the new Beas and Sutlej bridges for the following reasons :—

(*i*) The difficulty the masons experienced in building parallel to the axis of circular wells, when the wells were tilted.

(*ii*) The wells did not sink very easily, and had to be weighted.

A polygonal siamised well was considered, but abandoned, partly because it appeared probable, after reading the account of the construction of the old bridge, that boulders might be encountered, but mainly because the girders were being designed for a double track, and therefore only required two points of support.

It was at first proposed to take down the abutment wells as far as those of the piers, but after due consideration it was decided that sixty-five feet would be ample, and considering the amount of pitching stone there is around the abutment wells, it would probably have been sufficient to have sunk them to a depth of only thirty feet below low water level.

The discharge of the Jumna river taken during the flood on 11th September 1910 was about 2,09,000 cusecs, and it is therefore probable, on the assumption* that the highest flood level will never be above R. L. 881·00, that the discharge in the river at the site of the bridge will never exceed 2,50,000 c. ft. per second.

As the strata are more or less the same across the width of the river, it will of necessity readily scour out an even channel, and allowing for an average maximum velocity of ten feet per second, the depth of channel will be :—

$$2{,}50{,}000 \times \frac{1}{\text{width of channel}\dagger} \times \frac{1}{10} \text{ feet}$$

$$= 2{,}50{,}000 \times \frac{1}{1491 - \frac{2}{3}(2 \times 90) - 1\frac{1}{2}(6 \times 20)} \times \frac{1}{10} \text{ feet}$$

$$= 2{,}50{,}000 \times \frac{1}{1191} \times \frac{1}{10} \text{ feet}$$

$$= 21 \text{ feet.}$$

* *Vide* page 3.

† *Note.*—Width of channel is considered as total span of bridge less $\frac{2}{3}$ (width of apron + width of guide-bank at abutments) less $1\frac{1}{2}$ times width of piers.

Allowing an extra depth of sixteen feet for scour at the piers, the total depth of scour below the assumed highest flood level 881·0 will be thirty-seven feet, *i.e.*, the reduced level of the bottom of the scour hole will be 844·0 (*vide* Plate 5 on which the depth of scour is shown).

The reduced level of the top of the wells is 863·0 (1½ feet below the recorded lowest water level), while the average depth of the pier wells being 80·3 feet, there will always be 61·3 feet of well in the river bed. Allowing for this depth of scour and height of maximum flood level, and assuming that the weight of the train girders, piers, and wells, is evenly distributed over the entire cross section of the area enclosed by the well curb, the intensity of pressure at the bottom of the well curb is (after deducting skin friction) about 3·5 tons per square foot. The skin friction was found to be about 3·3 cwt, per square foot.

Piers—

The girders being designed for a double track, and therefore only two points of support being required, it was not necessary to build a through pier connecting the two wells, but only two independent piers. Plate 6 shows a type drawing of a pier and well. The batter is circular, the connecting arch being put in ostensibly for architectural effect.

The intensity of pressure at full flood and with the maximum wind pressure,—allowing ten feet per second as the velocity of the river, and a factor of safety of two for the impact of floating debris coming down the river in floods,—varies between 6·3 and 6·7 tons per square foot at different sections of the pier. It will be noticed that the concrete bed blocks are wedge shaped, the reduction in width being obtained by stepping the brick-work. In similar work, it would in future be advisable to use either cut bricks, or else specially moulded bricks, as great difficulty was experienced in working the cement concrete into the stepping.

Girders—

The girders were designed by Messrs. Rendall and Robertson, the consulting Engineers to the Secretary of State for India, and are up to the strength required by the loadings of Indian State Railway Standard B of 1903 + 25 per cent. They are double track girders, 213′ between centres of bearings, the centres of the main girders being 31 feet 4 inches apart, and the maximum depth of a girder being 35 feet from centre to centre of booms. For general dimensions of the girders see Plates 7 and 8.

Though the actual weight of this type of girder worked out to practically the same as that of two single track girders, there were the following important points which favoured the double track girder :—

(*a*) Saving in the cost of erection, rivetting and painting.

(*b*) In a double track girder the loss due to fatigue of the metal is a minimum.

In order to strain this type of girder to the maximum stresses for which it is designed, two Standard B + 25 % loads would have to cross the centre of the span at full speed at identically the same moment, but this is an occurrence which will probably never happen ; and in the near future, a Standard B + 25 % load will often travel over a single track bridge. The bridge is designed to carry a roadway with ballast at sixteen cwts. per running foot. The stringer girders necessary for carrying the troughing of the roadway have also been supplied and rivetted up. The total weight of each span is 474 tons.

CONSTRUCTION OF THE BRIDGE.

PRELIMINARY.

Store Depot—

The site where the bridge crosses the river being less than forty miles from the point where it debouches from the hills, heavy and unexpected rises were certain to take place. It was, therefore, necessary to treat the river with great respect. To start work from the Kalanour side was evidently out of the question, as this would have entailed a long lead for all stores, tools, plant, etc. to the site of work, and the obvious and most convenient site for a Store depot was therefore behind the existing left guide bank.

As soon as the new Jumna Bridge Division was formed on 10th March 1910, work was immediately started on building part of the south approach bank, and the quadrant siding leading from the same to the existing left guide bank. The height of the earthwork was fixed at R. L. 881·00 feet, but an unexpected quick rise in the river topped and breached this bank as it was nearing completion, and this was but the forerunner of many other unexpected misfortunes due to extraordinarily high floods.

Brick burning—

The Civil authorities having afforded every possible assistance, the brickfields at Sarsawa and Jagadhri were soon in full swing. Permission to start work at Sarsawa was given on 26th March 1910, and by 21st April brick burning at this kiln was in progress. When the rains broke in June, 1910, there were thirteen lakhs of bricks in the Sarsawa kiln of which 7¼ lakhs had been burnt. Sufficient precautions had been taken at this kiln to cover the bricks, and the burning was not stopped with the first break of the rains. The Jagadhri kiln fared very badly; of the 6½ lakhs of bricks in the kiln, only the 3½ lakhs which had been burnt were saved. Rain water found its way into the kiln and turned the kuccha bricks into a pulp.

The loss of a few lakhs of kuccha bricks was immaterial compared with the enormous advantage gained by having 16½ lakhs of bricks in hand to start work with directly the rains were over. As a matter of fact, the working season was considerably interrupted by abnormally heavy rainfalls, and great difficulty was experienced in supplying the work with sufficient bricks.

Collection of Kunkur—

A certain amount of kunkur was quarried and collected at Sardhana, near Meerut, but this was found to be unsuitable for the work, and the kunkur required was eventually got from pits between Budhowal and Jagraon near Ludhiana, which had supplied the new Beas and Sutlej bridges.

Collection of pitching stone at Delhi—

The quarrying and collection of pitching stone for the guide banks was put into full swing during the summer months.

Collection of Stores and Plant—

From April to September 1910, the necessary tools, stores, plant, timber baulks, etc., were arranged for by transfer from the Beas and Sutlej bridges.

Janeshnagar station—

To facilitate the economical construction of the bridge, a temporary station was opened at Janeshnagar about three quarters of a mile from the south (Saharanpur) abutment of the bridge—the nearest station on this side of the river being Sarsawa at a distance of five miles from the bridge. This station was opened on 17th September 1910.

Sidings—

Plate 1 shows roughly the various sidings in use during the construction of the bridge, and the position of the store depot, lime kiln, workshops, offices, etc.

PROGRESS OF WORK.

Pitching of well curbs—

Heavy rainfall in October 1910 made it impossible to lay the sidings from Janeshnagar station to the river bed, owing to the sidings having to be laid through a cutting in the existing left guide bank, but the rise in the river was not so high as to prevent a start being made on the north abutment of the new bridge, and on the wells for piers Nos. 5 and 6. The well curbs for these wells and for those of piers Nos. 3 and 4 were unloaded off the existing bridge and dragged up the river bed to the site of the new bridge.

The curbs for wells of Nos. 2 and 3 piers were pitched on islands formed with sand bags, two bags in width at the base, and six feet in height, the top of the bags being brought up to R. L. 871·0. The bags were tied to four inches diameter ballis placed four feet apart, and driven eight feet into the bed of the river by a hand pile driver built up of old rails. Mattresses, twelve feet long by five feet in width, made with bamboos wired together, and pilchi six inches thick, were laid under the bags and projected out beyond the islands, the projecting portions being weighted with a few sand bags. The sand bags forming the islands were backed with sand.

Plate No. 9 shows the temporary bund for the diversion of the river prior to pitching the well curbs for pier No. 1. This bund fared very badly during January 1911, as it received the brunt of the floods, and the curbs were not pitched till the middle of February. A small bund built for the protection of No. 4 wells was not much damaged by the floods of January, and this was subsequently heightened.

By the end of November 1910, all the well curbs, excepting those for the wells of No. 1 pier, were pitched and hand rivetted. (Plate No. 4 shows details of the curbs used). A special heavy section of material was used, as it was anticipated that large boulders would be met, requiring the free use of dyna mite. The angle of the cone plate was 35 degrees.

Pile Bridge—

Great difficulty was experienced in obtaining suitable boats to ship the pile driver. About the 25th of October 1910, the first pile was driven with a twenty cwt. Lacour patent steam monkey. This worked without any trouble, and was found to be most economical, and in every way suitable to the class of labour employed. The dropping monkey M (*vide* Plate 10) is a cylinder 6 feet 5 inches long in which a piston head P, with a piston rod R, works The piston rod is a loose fit with the cylinder monkey M; instead of a gland there is a cast iron plug screwed in at B, which can be replaced when worn out. On the top of the cylinder M is a three way cock C. The monkey works up and down the vertical slides of the pile driver frame.

The monkey is let down (*vide* Plate 10, position 1) on to the top of the pile to be driven, by a hand winch, the piston being at the top of the monkey and fixed in that position by a set screw. Steam is admitted into the top of the cylinder or monkey M by turning the three way cock C. The pressure of steam lifts the monkey M, the piston rod R resting on the top of the pile W, hence the weight of the monkey is always bearing on the pile. The three way cock is then turned as shown in Plate 10 position 1, the steam in the cylinder escapes, and the monkey drops. The maximum lift is of course limited by the length of the piston rod. In a twenty cwt. monkey the lift should never exceed five feet. A short lift can be effected by turning the three way cock from Position 2 to position 1 before reaching the top of the stroke.

There is a hole E, $1\frac{1}{4}''$ diameter, permanently open at the bottom of the monkey to allow the steam or water, which has forced its way past the piston P, to escape. A small hole $\frac{3}{4}''$ diameter at H is provided for lubricating the piston with tallow etc. and is closed with a wooden plug while the monkey is at work. By slipping a bolt through a hole in the pile about two feet below the head, and passing the bolt through a large washer at the back of the slides of the pile driver frame, the pile is kept in position while being driven. The average time taken to hoist, pitch, and drive a pile sixteen feet into the bed of the river was about ten minutes. A 10 H. P. portable engine is all that is required to work this steam monkey.

The design of the pile bridge was as follows :—Two piles $12'' \times 12''$ Oregon pine, or sal ballis of mean diameter about $10''$)

carrying the road were placed six feet apart, and driven sixteen to eighteen feet into the bed of the river, the distance between these two piles and the next two (*i.e.*, the length of the bays) being about ten feet. The bays were crossbraced with 3" to 4" diameter hutting ballis bolted on to the piles, with a bolt through the ballis, and a wooden distance piece where the ballis crossed. The tops of the piles were notched to receive old sleepers stretching from pile to pile, and bolted down over these 12" × 12" Oregon pine baulks were laid, and on top of these baulks the permanent way.

In order to expedite the laying of the line to the north abutment, as soon as the pile bridge was about 350 feet long, and carried well over the low winter channel, the line was ramped down to the river bed at an inclination of nearly 1 in 6. This permitted the running of the first train, with a load of bricks, to the north abutment, on the 24th of November 1910, and at the same time the remainder of the pile bridge was constructed alongside this temporary location of the river bed siding. The pile bridge (total length 620 feet) served its purpose up to the 4th of January 1911, when the river rose to R. L. 872·3 (*vide* River chart Plate 11) and, washed away portions of the bridge between piers Nos. 1 and 2, Nos. 2 and 3, and Nos. 3 and 4. The last pile for repairing the bridge was about to be driven when a still higher flood on 27th January 1911 again breached it at the same places. To expedite the repairs, the length of the bays of the pile bridge was increased from ten to fifteen feet, this being about the maximum span for a 12" × 12" Oregon pine beam loaded with an O. & R. Ry. B class engine (six coupled with about eight tons axle load).

On the 22nd of February the first train with bricks since the 3rd of January passed over the pile bridge. On the 13th of March a flood again breached the bridge, carrying away short lengths between piers Nos. 1 and 4, and the bridge was finally destroyed for all practical purposes on the 18th of March, when the highest known winter flood came down the river and created sad havoc, piles driven twenty-five feet into the bed of the river being treated as if they were match-wood. After this bricks and mortar were trollied out on a hand-driven light pile bridge.

Masonry in wells—

Prior to crossing the river channel with the pile bridge, bricks had to be led to the north abutment and piers Nos. 4, 5 and 6, by donkeys, from the north abutment of the old bridge. The first brick of the steining was laid on the 9th of November 1910, in the upstream well of the north abutment. By the 6th of December, all work was in full swing except on the wells of pier No. 6, the curbs of which could not be pitched until the winter channel had been diverted. Plate No. 6 shows details of the steining.

The proportion of kunkur in the mortar was one of kunkur to two of sand, the kunkur being ground in Carter or Christy & Norris disintegrators with 1/16th inch mesh screens. The mortar was mixed in an ordinary steam driven seven foot diameter pan. Plate No. 12 shows the type of continuous kiln which was used on the bridge. In addition to these continuous kilns, there were six Telegu kilns sixty feet long. These Telegu kilns were only in use for a short time until we were able to obtain sufficient mortar from the continuous kilns. The kunkur was not washed before burning, as the thickness of steining was so great that the expense involved in producing a highly tensile mortar would not have been justified.

Well sinking—

The erection of shear legs was started on the 27th of November 1910, and by the 3rd of December, well sinking on the north abutment downstream well was in progress. Plate No. 13 shows the monthly progress in well sinking. Except for wells of piers Nos. 2 and 3 no difficulty was experienced in the sinking of the wells. This was due to the very great care taken in keeping the wells straight during sinking their first length, and the fact that a large sinking effort was provided in the design of the wells. In addition to watching the plumbobs, the well which was being sunk was propped against its sister well, and by keeping the wells on the move by exploding small charges (two ozs. or less) of dynamite, the likelihood of blows taking place was reduced. The wells practically sank by their own weight, the thickness of clay or kunkur never exceeding a foot. The amount of dynamite used was about forty lbs., requiring about two hundred and twenty No. 3-A detonators. Plate No. 14 shows the final position of the wells.

In the first week of January 1911, a heavy rise in the river tilted both wells of No. 2 pier and the upstream well of No. 3 pier. The latter was tilted over to an angle of 1 in 3·1 from the vertical, while the two wells of No. 2 pier were of less inclination, and the downstream well of No. 3 remained vertical.* The upstream well of No. 3 pier had only been sunk 7½ feet, while the other wells had been sunk their first length of 13 feet.

The river level remained abnormally high for the time of year up to the end of February, and it was only possible to get at the wells on the 2nd of March. After due consideration, it was decided that the only way of straightening these wells was to hold them up on the low side with timber baulks bolted to the steining rods, and then to excavate round them on the outside, and afterwards on the inside on the high side. By about 13th March 1911, the up-stream well of No. 2 pier had almost been straightened, but the work was of no avail, for on that date the river rose to R. L. 872·5 ; and later, on the 18th of the same month, the highest known winter flood came down (flood level 873·5) and again tilted the well over, as also the downstream well of No. 3 pier which had remained vertical during the previous floods.

Towards the end of April the river fell sufficiently to allow a sand bag and sand coffer dam to be put round these wells, and on the 4th May, straightening operations were again started.

The inclination of the wells from the vertical was :—

No. 2 Upstream	well	1 in 10·4
No. 2 Downstream	well	1 in 4·47
No. 3 Upstream	well	1 in 3·1
No. 3 Downstream	well	1 in 18

Between the 4th May and 28th May, all the wells were straightened and brought back to within six inches of their original position, except the upstream well of No. 3 pier, which was about a foot to the east of its original position.

The method employed by Mr. J. England, Works Foreman, consisted in laying two rows of four 12″ baulks, two baulks in depth and two in width, on the top of the steining of the well on either side of the hole. The baulks extended about ten feet beyond the outside of the well on either side. The cantilever so formed beyond the high side of the well was loaded with sand bags, and the projecting baulks on the low side were connected across with 12″ baulks under which two 200 tons hydraulic jacks were placed. On top of the two rows laid across and beyond the wells were placed two rows of two 12″ baulks laid one on top of the other, one

* For inclination of these wells, *vide* Plate 15.

row being close to the inside, and the other row close to the outside on the low side of the well. These rows projected about eight feet beyond the outside edge of the well, and were supported by props securely wedged. The two rows were securely fastened to the wells by cross pieces of 12" baulks bored through to allow the steining tie rods to thread them, the nuts at the end of the steining rods being tightened down on to the cross pieces.

All the timbering, props, jacks, etc. being in position, the sand outside the high side of the well was excavated to within four feet of the cutting edge, the dredger then worked on the inside of the well and was pulled over as it descended so as to excavate the sand from under the high side. So far there might appear to be nothing out of the common ; everything seems obvious, and the arrangement one that anyone would adopt, but the feature of the work was the beautiful timing of exploding 2 oz. charges of dynamite directly the well started to show signs of a blow, for the maximum effect of the explosion could only be obtained when the hole in the well was at its maximum depth, and it was of little use to set the dynamite off after the blow had taken place.

Another and far more important feature was the supervision of the props. After each explosion of dynamite the high side shook down, the low side being propped up remained more or less at the same level, but the top of the well moved forwards, with the low side embedded in sand acting as a pivot. The process consisted of tilting the well back in the opposite direction to the tilt it took under the action of the floods. As the top of the well moved forward, so did the timbering, and the props had in consequence to be changed in rotation, *i. e.* not all at one time.

It was a long time before the cleverest of the *mistris* could be trained to do this work of adjusting the props, and it had to be done almost entirely by the Works Foreman in person. The wells were not tackled together ; only one could be done at a time, as it was impossible to supervise the work on wells of different piers ; and work could not be carried out on two wells of the same pier simultaneously, as the wells had all tilted the same way, *i.e.* in the upstream direction. Wells have been straightened in the past, but not always brought back to their original position, the reason being that they have been allowed to sink.

The following is the progress which was made in straightening the upstream well of No. 3 pier, this being the last well tackled :—

23rd May 6-30 hours—Carriage of timbering, etc., started.

,, ,, 18-0 hours—Timbering in place, jacks in position, props wedged up, etc., etc.

,, ,, to 25th May—Work delayed as the Contractor had not got his head gear for dredging in position in time.

25th ,, 9-30 hours—Dredging started on outside of well.

26th ,, 9-0 hours—Dredging finished on outside of well, and started in the inside (the well being full of sand).

,, ,, 9-0 hours—Difference in level on the top of the well measured with a ten feet straight edge was ... 2' 0"

27th	May	6-30 hours—	Do.	Do.	$1' 6\frac{1}{2}''$
,,	,,	8-30 hours—	,,	,,	1' 3"
,,	,,	9-30 hours—	,,	,,	1' 1"
,,	,,	10-15 hours—	,,	,,	$11\frac{3}{4}''$
,,	,,	11-15 hours—	,,	,,	11"
,,	,,	11-45 hours—	,,	,,	$9\frac{1}{8}''$
,,	,,	15-0 hours—	,,	,,	$8\frac{1}{8}''$
,,	,,	15-45 hours—	,,	,,	8"
,,	,,	16-30 hours—	,,	,,	$7\frac{3}{4}''$
,,	,,	17-0 hours—	,,	,,	7"
,,	,,	18-0 hours—	,,	,,	$6\frac{1}{2}''$
28th	May	6-30 hours—	,,	,,	$3\frac{1}{8}''$
,,	,,	7-30 hours—	,,	,,	3"
,,	,,	8-30 hours—	,,	,,	$2\frac{1}{2}''$
,,	,,	9-0 hours—	,,	,,	$1\frac{3}{4}''$
,,	,,	9-45 hours—	,,	,,	Nil.

Work went on during the night of 27th and 28th but measurements were not recorded. The measurements were made after each explosion of a two ounce charge of dynamite.

Having straightened the wells, work was pushed on day and night up to 14th June, when the rains broke. It was then decided to fill both wells of No. 2 pier and the downstream well of No. 3 pier with sand to increase their stability, and to try to sink No. 3 upstream well a bit further. This well was sunk 10½ ft. and then stuck, so on 2nd July it was plugged with sand. The wells were then braced together with wire ropes, screw couplings, etc.

The depths of these wells below the highest recorded summer flood R. L. 878·3 were as follows :—

Upstream No. 2. 72·6 ft.
Downstream No. 2. 76·1 ft.
Upstream No. 3. 65·9 ft.
Downstream No. 3. 72·7 ft.

The lowest depth of scour measured in the river bed during 12th September 1910, when the river rose to 877·3, was R. L. 846·0, the depth of these well curbs below this being :—

Upstream No. 2. 40·3
Downstream No. 2. 43·8
Upstream No. 3. 33·6
Downstream No. 3. 39·8.

On the 3rd of October 1911, work on these wells was again started, and by the 11th of the same month, the sand plug of No. 2 upstream well had been removed.

On the 23rd November No. 2 upstream well was founded, and on the 5th December the downstream well of the pier was founded. No. 3 upstream well, however, gave us enormous difficulty. For five weeks (15th November to 21st December) the well refused to budge ; pig-iron, steel girders, rails, sand bags, and shear legs were all placed on top of the well, but it did nothing but blow, and defied our attempts to make it sink. There was nothing for it but to send divers down, and great delay occurred in getting a competent diver to go down and work under a depth of water exceeding sixty feet.

On the 9th of February 1912, a cement cask, filled solid with cement, was taken from under the cutting edge. After this was removed, the well sank a little, but again went crooked and right up to the 15th of April, we were continually taking out bits of wire rope, fish plates, remains of cement casks, sand bags, etc., from this well. Plate No. 15 shows the progress on this well during the working season 1911—1912 and the deviations of the well at various depths, but nothing can represent the enormous work entailed in getting it reasonably straight

The following points on well sinking should be noted :—

1. The shear legs should be so placed that the guy ropes of the same lie parallel with the centre line of the bridge so that they can be fixed to wells, and their anchorage, therefore, will not be disturbed by floods.

2. Suitable baulks should be at hand, so that when a flood comes down, the shear legs may be lashed to these baulks and carried on the top of the wells.

3. The use of sand bags and cement casks in making islands for the pitching of the curbs should be discouraged as far as possible, as they collect round the well during a flood and are liable to get under the curb when a blow takes place.

4. The depth of hole below the cutting edge should never exceed $4\frac{1}{2}$ feet in sand, else a blow is certain to take place. It is these blows which tend to throw the well out of its vertical position. A small charge of two ounces or less of dynamite is generally quite sufficient to get the well on the move.

5. Before building up the first length of masonry, the space inside the well curb should be filled up with sand to the top of the cone plate, otherwise there is a likelihood of the well tilting with the sinking of the first length.

6. When pitching the curb, half inch diameter wire ropes should be attached to the four corners. With the aid of a hook fastened to the dredger, the latter can then be directed as it descends to almost any point of the curb.

Founding of wells—

The wells were founded by super-imposing sixty tons of pig-iron on top and firing successive charges of six ounces of dynamite until the well did not move more than one-eighth of an inch. Plate No. 13 shows dates of founding of the wells.

Plugs –

The bottom plug consisted of sand filled to a height of fourteen feet above the cutting edge of the curb. Sand was used instead of concrete for this plug to ensure the complete filling of the steps in the corbelling. The second plug for a height of ten feet consisted of cement concrete in the proportion of one of cement, three of sand, and five of 1½ in. brick ballast. The well was then filled up with sand and capped with a ten feet plug of kunkur lime concrete in the proportion of two of lime, one of sand, and five of 1½ in. brick ballast. The concrete in the cement concrete plug was placed in position by means of a wooden skip 4 ft. × 4 ft. × 3 ft., which was lowered down by a steam hoist. As soon as the skip touched the top of the sand plug, the tension on the wire rope was released and the skip opened. No difficulty whatever was experienced in putting in the top kunkur lime concrete plug, as the cement concrete plug was absolutely watertight.

Piers—

Very little difficulty was experienced in working to the circular batter, as the courses were scribed very carefully as the work went up. Special moulded bricks were used for the face work; the bricks having distinguishing numbers inset in the frog corresponding to the layer in which they were to be laid. Plate No. 6 shows the details of a pier. The face masonry was laid in 1 to 3 cement mortar in ordinary English bond, and the hearting of nearly all the piers in 1 to 4 cement mortar in herring bone bond. The time taken to complete a pier averaged about three weeks.

The north and south abutments and piers Nos. 1, 4, 5 and 6 were completed in the working season 1910-1911.

Pier No. 2 was completed in January 1912, but the portion above the arch of pier No. 3 was not completed till the beginning of the working season 1912-1913.

Cement concrete Bed Blocks—

The cement concrete blocks consisted of stone ballast 25 per cent. ½ in. or less in gauge with 75 per cent. of 2½ in. gauge; the proportions of the mortar being one cement to two of sand. The quantity of mortar was two-thirds that of the ballast.

The tops of the bed blocks were finished with half an inch of cement plaster, the top of the plaster being criss crossed with grooves ¼ in. wide and ⅛ in. deep, the grooves forming a square with a side four inches long. This was done to ensure the lead sheet under the girder bearings getting a good grip of its seat. The plaster was kept under water for fourteen days after completion.

When we came to lay the lead sheeting, about nine months after the bed blocks had been completed, it was found that some of the plaster had lifted ; this was detected by sharply tapping the plaster with a 2 lb. hammer. The loose plaster was removed and replaced by hard asphalte.

Guide Banks—

During the season 1910-11, part of the existing left guide bank was remodelled by adding a few feet to the width of its sand core and bringing the top of the core up to R. L. 886 ; at the same time an extra five feet was added to the width, and about 2¼ feet to the depth of the stone pitching in the apron. All the stone on the slopes was considered too small, and was replaced with stone averaging a maund in weight per stone, but the abandoned portion of the existing guide bank was not cleared away to allow the completion of the nose of the new guide bank till 1912, as the earth was required for laying a siding to work ballast trains. A considerable amount of stone (about 9·6 lakhs c. ft.), was obtained from the nose and the apron of the abandoned half of the existing left guide bank,—this was partly Delhi stone and partly large blocks of kunkur. The rest of the stone (about 19·7 lakhs c. ft. in all) was brought from Delhi in stone train rakes of forty-five trucks, each rake on an average bringing about 12,500 c. ft.; one train a day being supplied.

An enormous saving in cost of stone pitching was effected by running the stone trains along the quadrant siding on to the guide bank, and from the end of the guide bank ramping the siding down to the river bed over a light pile bridge across the apron, the siding extending a sufficient distance up the river bed to allow for a back shunt along the edge of the apron. No lead of stone, no shifting, and no slewing of lines was necessary For the slopes of the guide banks and half the width of the apron, the stone was tumbled out of the trucks and then rolled down the guide banks. Only the stone on the slopes of the bank was dressed. Underneath the stone pitching, six inches of stone ballast or quarry chips was laid. Plates 2 and 3 show details of the completed guide banks. The reserve of pitching stone supplied to each guide bank was 50,000 c. ft.

Approach Banks —

All the south approach bank and part of the north approach bank was completed during the working season of 1910-11, practically the entire work being completed by Ghilzais and their donkeys. An old scour-hole about nineteen feet deep behind the south abutment (*vide* Plate 5) was filled by ballast trains, bringing earth from the abandoned portion of the left guide bank. On this work there was a slight mishap, caused by a pile bridge (with a factor of safety of unity collapsing. The trucks, however, were soon recovered from the pool, and a similar bridge did the required work.

Flood damages –

As already mentioned * heavy floods took place on the 4th of January, 27th January, 13th and 18th March and 14th of June 1911, and it was only natural to expect that a certain amount of plant would be lost. In fact, the flood of the 27th January washed away the piles on which a hoist and a portable engine were placed. Not a portion of this machinery was visible, nor could we find where it had all gone to. The machinery was, therefore, written off and considered lost. About 18th February 1912, *i. e.* after thirteen months, when the river was very low, a wheel of the hoist appeared just below water level about a hundred feet below where the hoist was formerly placed. With this wheel as centre and a radius of forty feet, a circular coffer-dam of sand bags was made. An eight inch centrifugal pump was kept going day and night while coolies were busy excavating the sand which kept flowing into the excavated hole. As the water was pumped out and the sand excavated the coffer-dam of sand bags sank, and could only be kept above low water level by adding successive layers of sand bags. Days and nights of strenuous work enabled us to recover the hoist on the 26th February, and on the 29th February the portable engine was safely brought to the workshops. The hoist and engine had been lashed together and thus remained close to each other. Except the gauge glasses, and a foot-plate and its bracket which were broken no damage was done. A lick of paint and a little emery cloth made the hoist and portable engine look as new as the day they were turned out of the shops. This particular hoist, I understand, played the same game on the Sutlej bridge.

The total cost of plant lost in floods amounted to about Rs. 6,500. In addition to this, however, a considerable amount of timber, sleepers, etc., was washed away. An abstract of the losses due to flood damages by sub-heads of works will be found on page 49.

* See page 11.

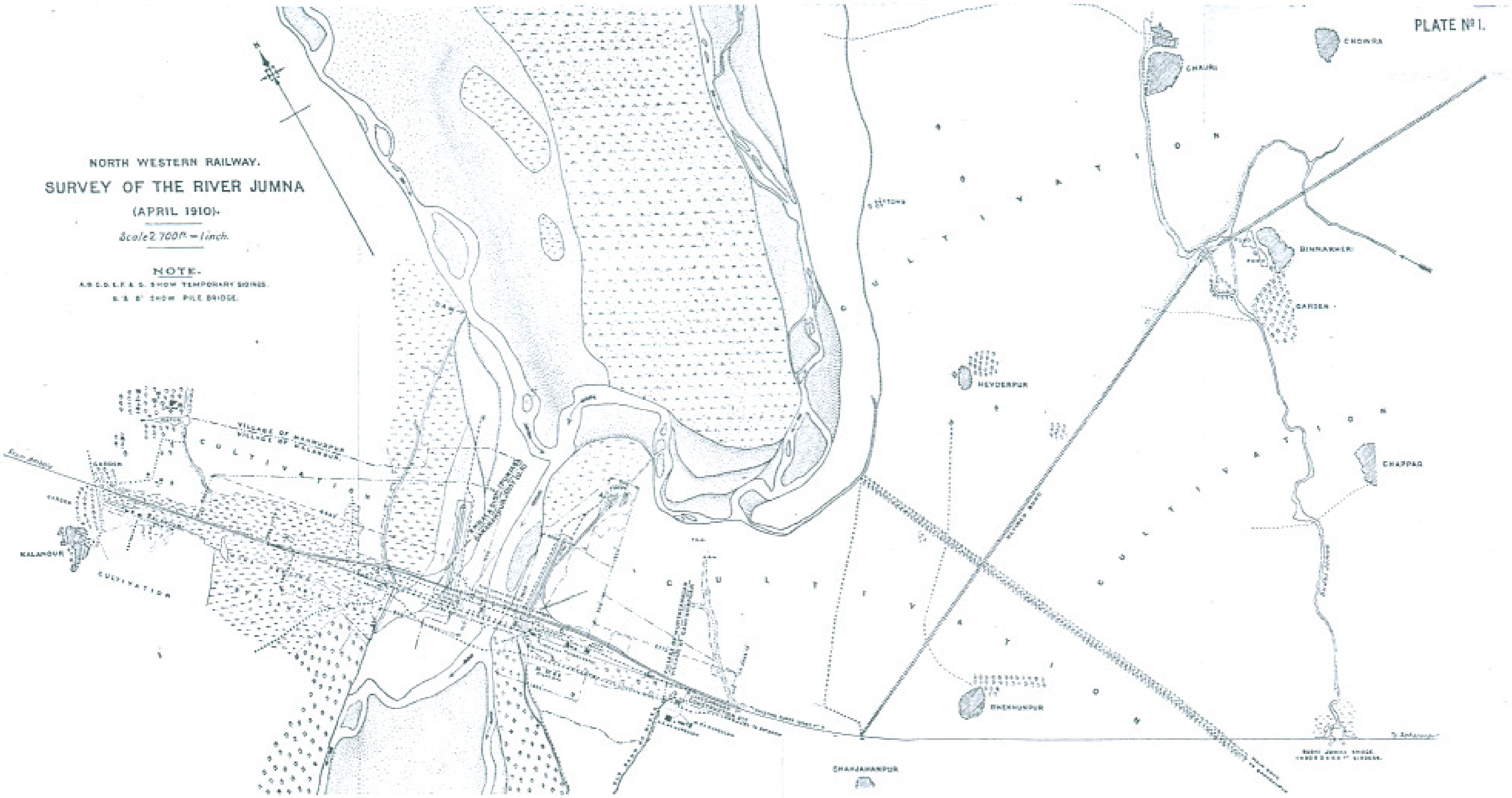
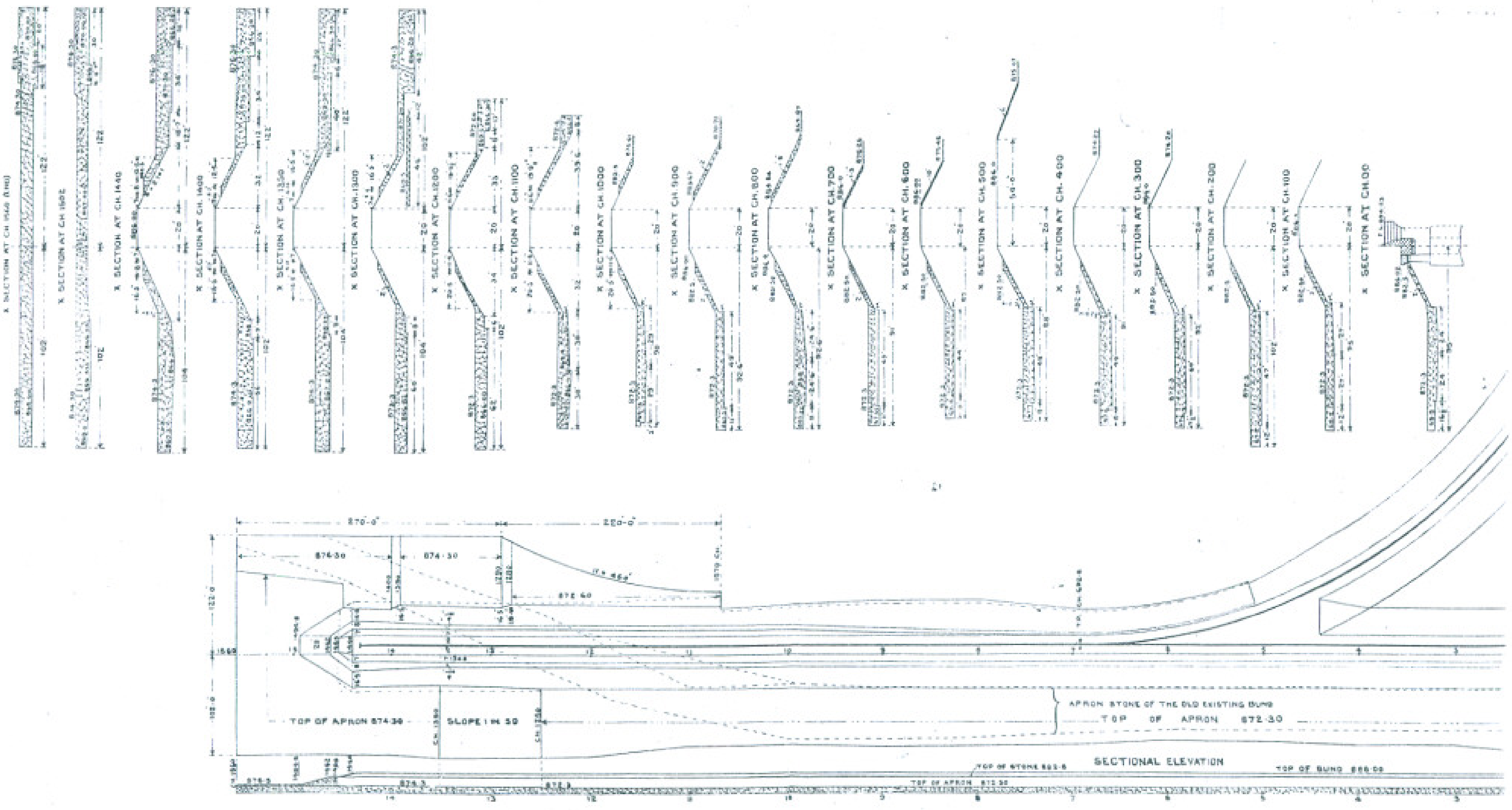
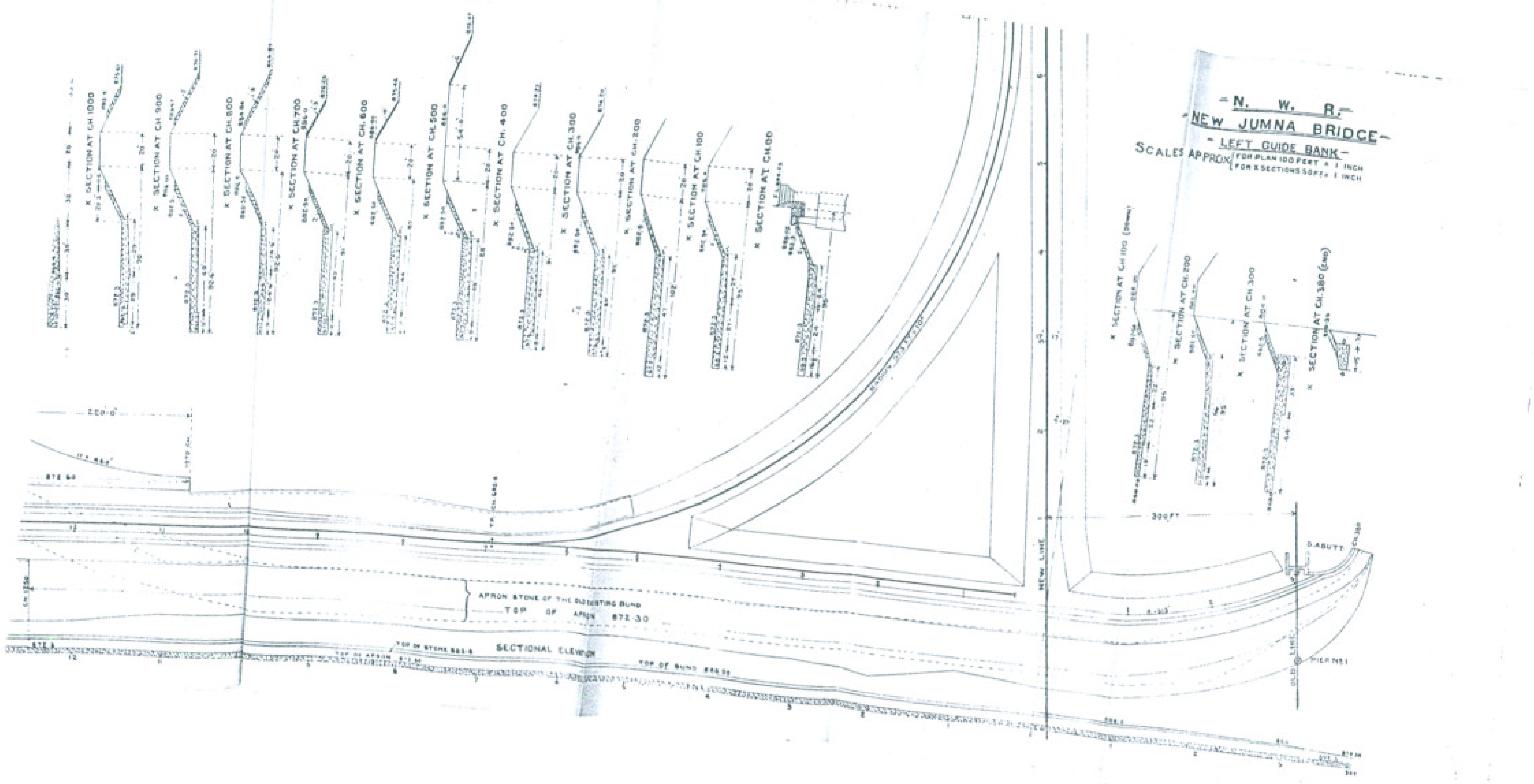


PLATE No. 1.
NORTH WESTERN RAILWAY.
SURVEY OF THE RIVER JUMNA
(APRIL 1910).
Scale 2,700 ft = 1 inch.
NOTE.
A.B.C.D.E.F. & G. SHOW TEMPORARY SIDINGS.
B. & B'. SHOW PILE BRIDGE.
CHOWRA
CHAURI
BINNAKHERI
GARDEN
HEYDERPUR
CHAPPAG
RHEKHUNPUR
SHAHJAHANPUR
KALANOUR
CULTIVATION
VILLAGE OF MAHMUDPUR
VILLAGE OF KALANOUR


X SECTION AT CH.1560 (END)
X SECTION AT CH.1500
X SECTION AT CH.1440
X SECTION AT CH.1400
X SECTION AT CH.1350
X SECTION AT CH.1300
X SECTION AT CH.1200
X SECTION AT CH.1100
X SECTION AT CH.1000
X SECTION AT CH.900
X SECTION AT CH.800
X SECTION AT CH.700
X SECTION AT CH.600
X SECTION AT CH.500
X SECTION AT CH. 400
X SECTION AT CH.300
X SECTION AT CH.200
X SECTION AT CH.100
X SECTION AT CH.00
270'-0"
220'-0"
874.30
874.30
872.60
TOP OF APRON 874.30
SLOPE 1 IN 50
APRON STONE OF THE OLD EXISTING BUND
TOP OF APRON 872.30
SECTIONAL ELEVATION
TOP OF STONE 882.5
TOP OF BUND 886.00
TOP OF APRON 872.30



- N. W. R. -
- NEW JUMNA BRIDGE -
- LEFT GUIDE BANK -
SCALES APPROX. FOR PLAN 100 FEET = 1 INCH
FOR X SECTIONS 50 FEET = 1 INCH
X SECTION AT CH.100 (DOWN)
X SECTION AT CH.200
X SECTION AT CH 300
X SECTION AT CH.380 (END)
X SECTION AT CH.00
X SECTION AT CH.100
X SECTION AT CH.200
X SECTION AT CH.300
X SECTION AT CH.400
X SECTION AT CH.500
X SECTION AT CH.600
X SECTION AT CH.700
X SECTION AT CH.800
X SECTION AT CH.900
X SECTION AT CH.1000
NEW LINE
OLD LINE
PIER NO.1
D. ABUTT.
300 FT
APRON STONE OF THE EXISTING BUND
TOP OF APRON 872.30
SECTIONAL ELEVATION
TOP OF BUND 888.00

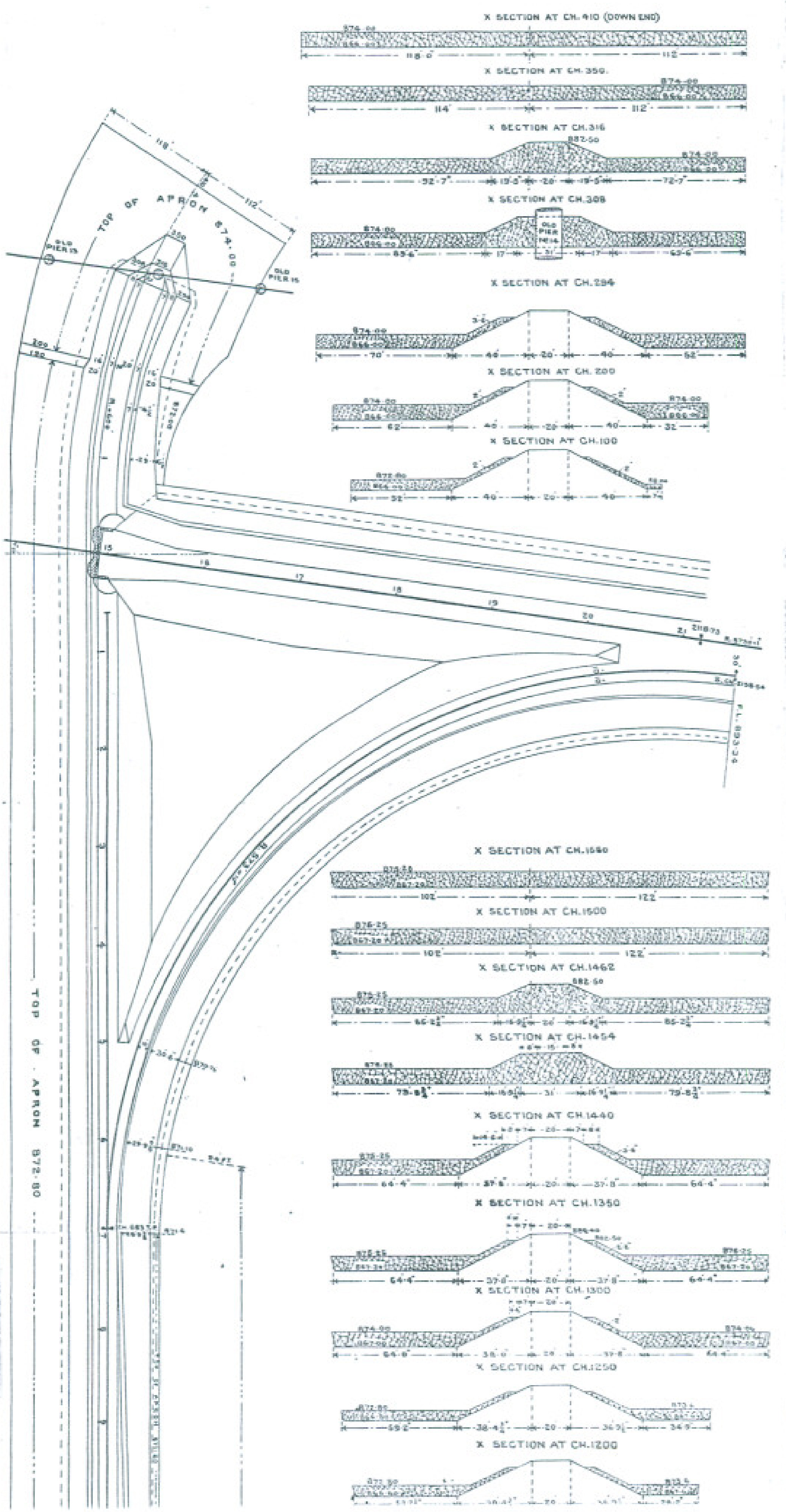
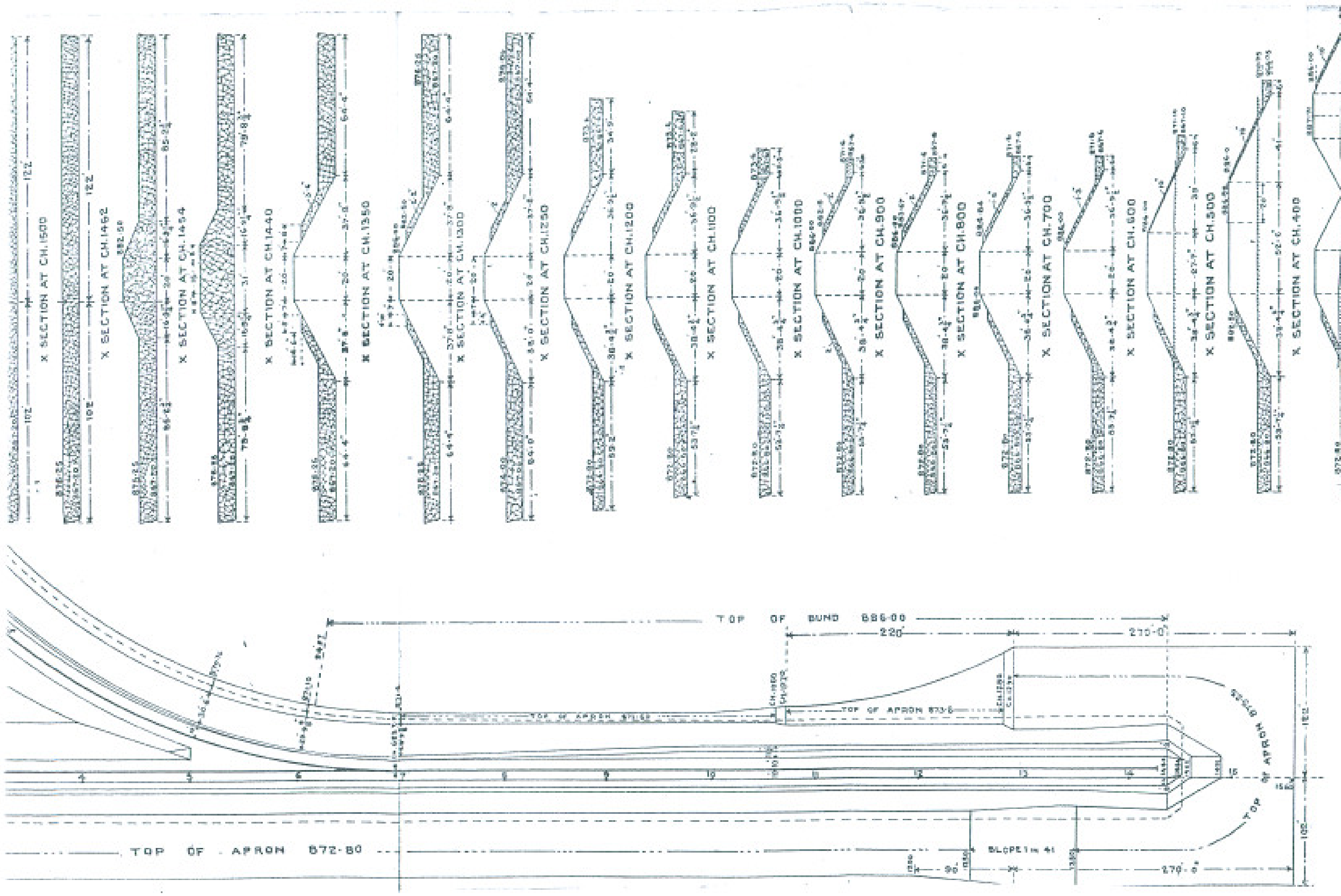

X SECTION AT CH. 410 (DOWN END)
X SECTION AT CH. 350.
X SECTION AT CH. 316
X SECTION AT CH. 308
OLD PIER No.14
X SECTION AT CH. 294
X SECTION AT CH. 200
X SECTION AT CH. 100
TOP OF APRON 874.00
OLD PIER 15
X SECTION AT CH. 1550
X SECTION AT CH. 1500
X SECTION AT CH. 1462
X SECTION AT CH. 1454
X SECTION AT CH. 1440
X SECTION AT CH. 1350
X SECTION AT CH. 1300
X SECTION AT CH. 1250
X SECTION AT CH. 1200
TOP OF APRON 872.80

PLATE 3



– N. W. R. –

– NEW JUMNA BRIDGE –

– RIGHT GUIDE BANK –

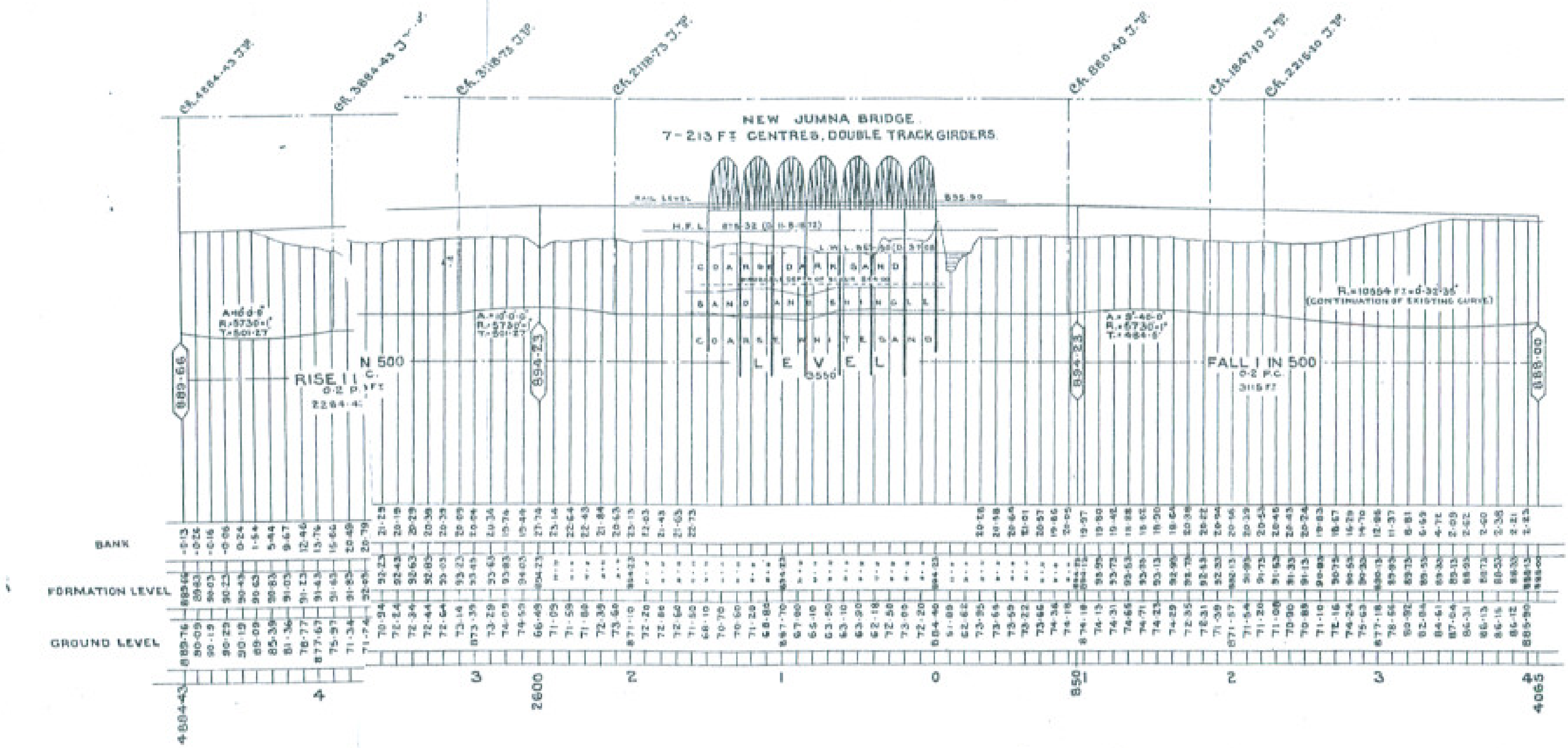
SCALES { FOR PLAN 100 FEET = 1 INCH.
{ FOR X SECTIONS 50 FT = 1 INCH.

-N. W. R.-

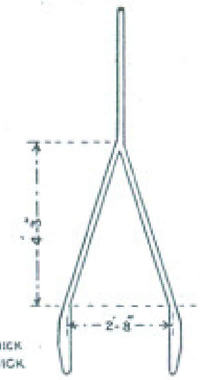
- NEW JUMNA BRIDGE -

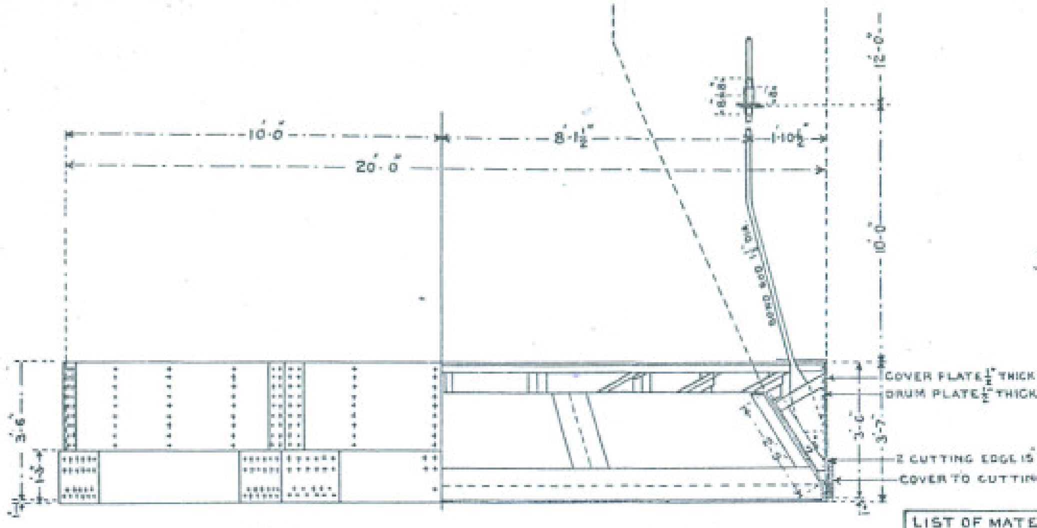
SECTION OF APPROACHES

SCALES { HOR. 800 FEET = 1 INCH. VER. 80 FEET = 1 INCH.



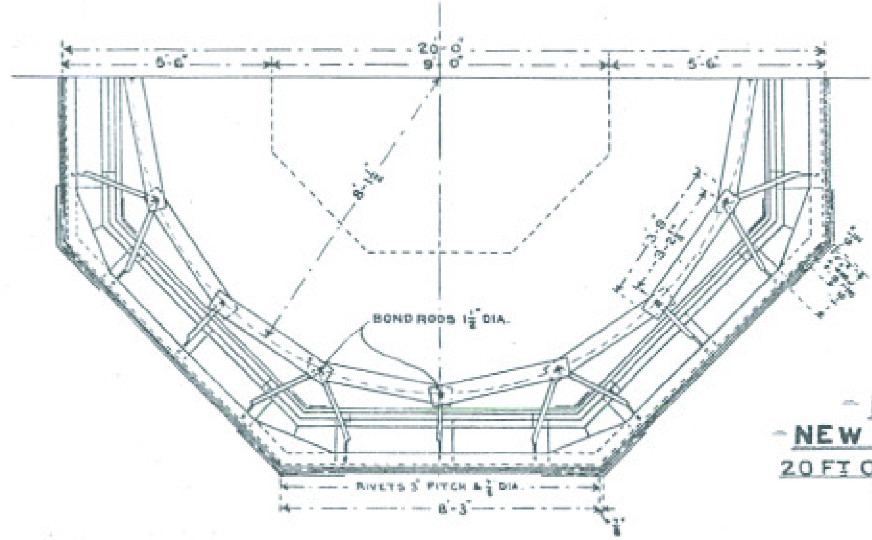
ELEVATION OF CORNER PALM ROD





HALF ELEVATION

HALF SECTION



HALF PLAN

LIST OF MATERIALS FOR 1 WELL. EXCLUSIVE OF 5% FOR WASTAGE		
NAME	No. REQUIRED	
1½" PALMROD INTERMEDIATE	8	8
Do. Do. CORNER	8	8
1½" BOND ROD 12 FT	16×6	80
1½" Do. Do. 6 FT	16	16
3'-9"×6"×½" BOND BARS	16×7	112
BOTTLE NUTS	16×7	112
WELL CURBS		1

NOTE—

ALL RIVETS ⅞" DIA. & 3" PITCH.

— N. W. R. —

— NEW JUMNA BRIDGE —

20 FT OCTAGONAL WELL CURB

SCALE 4 FEET = 1 IN.