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CONSTRUCTION OF A RAILWAY BRIDGE OVER THE RIVER INDUS AT KALABAGH.

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Introduction.

This paper has been written as an interim paper before the completion of the bridge as it may be of interest to have an account of a work of this nature during the process of construction.

The fact that the work is not yet complete imposes heavy limitations and it will readily be understood that it is expedient neither to enter into any matters dealing with cost and rates, nor to make any statement that may bring the Conditions of Contract into controversy. Such matters can only be dealt with adequately on the completion of the work.

History.

The bridge over the River Indus at Kalabagh will connect the broad gauge (5′-6″) system of the North-Western Railway south-east of the Indus with its narrow gauge (2′-6″) Railway north-west of that river. It will initiate the first stage towards conversion of the 2′-6″ gauge Railway from Kalabagh to Bannu to broad gauge and its extension on that gauge to Mirali. The bridge will form an important link in the chain of through railway communication between the Punjab and Waziristan (see Plate No. 1) and displace the existing ferry with its inherent transportation handicaps. With the completion of the bridge over the Chenab at Chiniot and that over the Jhelum near Khushab an alternative speedier and easier graded route from Lahore to this part of the frontier is made available; while on the completion of the Lyallpur-Chananwala Connection, work on which is unfortunately suspended temporarily, the frontier will have an additional line of communication with Delhi. Commercially therefore the bridge is destined to play no small part in the development of inter-communication between the Frontier Province and the rest of India, with all that this implies. There is no need to dwell on its obvious strategical importance.

The construction of a bridge over the Indus at or near Kalabagh had been proposed and discussed for many years. The first survey was carried out by Mr. Ramsay in 1888, and further investigations and proposals were made by Mr. Verrieres in 1919 and Col. Cowie in 1921. A proposal for a Transporter Bridge was also put forward and examined by Mr. Hallidy in 1923, but the idea was abandoned.

An alternative proposal was for a combined Weir and Railway Bridge. This was rejected partly because sanction to the Thal Canal Project, of which the Weir formed a part, was uncertain, and principally because the site of the weir would have entailed a crossing 4,500′ long instead of 2,500′ at the adopted site.

Finally in 1927 a project for a bridge costing Rs. 40·36 lakhs was submitted to the Railway Board and was sanctioned in May of that year. It comprised 9 girder spans 250′ clear and 263′ centre to centre of piers. The girders of standard M. L. of 1926 (for 22½ ton axle loads and a train of 2·3 tons per foot run behind the engine) are designed to carry a single broad gauge line of Railway. No provision for roadways has been made owing to the absence of road communications.

Site.

The site selected for the bridge is about 1¼ miles below the mouth of the gorge from which the Indus debouches into the plains. It is just under a mile below Mari Ghat, the present ferry terminus, and immediately below the junction of the Nihal Shah Nullah (see Plate No. II, and Photo No. 1). The course of the river at this site is stable. There is no danger of the river forming loops upstream on account of the hills which define its bed, and for some distance below the bridge the configuration of the country is such as to prevent the river meandering and looping back close to the approaches. At the reach selected, the river maintains the regime of a mountain river flowing between high and stable banks. This condition ensures the permanency of the channel and makes the security of the approaches a simple matter. The existing site has a further advantage in facilitating the alignment of the approaches. Graveyards abound, especially on the Kalabagh side, and the position of the site chosen enabled these to be avoided without difficulty.

Character of the Bed of the River.

In 1919, 1920 and 1921 borings were carried out at the proposed site of the bridge, but they failed to penetrate to depths sufficient to give adequate information concerning the nature of the substrata. The 1919 borings were unsatisfactory and those in 1921, though better, reached a maximum depth at R. L. 633 or 29 feet only below the lowest bed level. It being considered that the deep water wells would have to be carried to a greater depth, a Star Drilling Plant was obtained from America in 1924 and two further borings carried out in that year, one of which was carried to R. L. 597 and the other to R.L. 624, the former being 65 feet below lowest bed level. Plate III shows the borings of 1920, 1921 and 1924. It will be seen that from the left (Mari) bank half the width of the bed consists of an uppermost layer of fine sand covering a layer of coarser and sharper sand with small pebbles, each layer being about 6′ thick. The uppermost layers of sand disappear as the deep water channel is approached. Below these is a compact stratum averaging 45′ thick of boulders set hard in sand. The bed of the deep water channel in the other half of the river consists of loose pebbles and boulders above the compact boulder bed. It was found possible to gauge approximately the size of the boulders in the deep water bed by lowering a steel pipe from a boat drifting with the current. By listening at the top end of the tube to the sounds made by the other end dragging along the bottom of the river it was concluded from the varying long and short tapping sounds that the bed of the deep channel was composed generally of stones 7 or 8 inches in diameter with occasional large boulders.

The borings indicated what was termed a stratum of "conglomerate boulders" below a level of R.L. 620 on the Mari side and R. L. 631 on the Kalabagh side of the river. It has never been clear what was meant by this term, but it is probable that it was intended to convey the idea of a stratum of boulders and sand rendered compact under pressure. The term "conglomerate" is rather a misnomer. The sand between the boulders, though compressed, possesses no matrical properties whatever.

Cross sections taken from 1921 onwards show little or no variation in the depth of the deep channel and the indications were that all floods passed without deepening the main channel and that only the top layer of sand on the Mari side was scoured away.

It has been of great interest to compare the strata actually passed through during the process of sinking the foundation wells with the results of the borings. Plate IV shows the strata as actually penetrated. Apart from a stratum of fine sand and clay on the Kalabagh side of the river the stratum underlying the surface layers of sand consists uniformly of compact boulders in sand to the lowest depth penetrated. The sand sometimes has an admixture of silt, which has a glutinous effect. The boulders are of varying dimensions, from small boulders about 3" in diameter to bigger ones up to eighteen inches in diameter. Occasional large ones are met with, sometimes up to 4 or 5 feet in diameter (see Photo No. 2). A section of the exposed boulder cliff on the Mari bank (see Photo No. 3) represents with fair accuracy the nature of the substratum. The photo does not give an impression of the compactness of the substratum. This is only to be expected as the surface is exposed.

The result shows that while ordinary borings through strata of this nature cannot give really accurate results (nothing but a core drill would do this) the indications obtained were sufficient to give a good idea of the subsoil.

Discharge.

Very extensive and careful investigations and surveys were carried out by the Punjab Irrigation Department for the Thal Canal Project of 1919, and it was considered that no better figures or more reliable data could be obtained.

The Irrigation Department records show that there occurred in 1878 an extraordinarily high flood, and as there had been nothing approaching it since then, it was taken as the greatest ever likely to occur.

The following is a copy of paragraph 4 of Appendix M (1) of the report on the above-mentioned project :—

"*Methods adopted to calculate the maximum flood discharge.*— The reduced level of the maximum flood at Kalabagh gauge has been accepted as 706·0, and the discharge computed in two ways :—

" (1) A discharge curve was drawn for the Kalabagh gauge and produced to cut the 1878 flood gauge ordinate. The data used for this purpose were discharge observations made in the cold weather of 1916-17, discharges calculated from observations made during the hot weather of 1917, and the discharge calculated for the 1889 flood.

" (2) The surface of the water for the 1878 flood was constructed on the longitudinal section from consideration of surface slopes of the 1889 and 1916 floods, and the discharge calculated therefrom.

		Cusecs.
The results were	1st method	7,57,000
	2nd „	7,70,000

For the purposes of design, etc., the maximum flood is being taken as 8,00,000 cusecs."

The following further information was gleaned from Irrigation sources.

In 1889 there was a flood of which the reduced level was 703·66, with a calculated discharge 6·45 lakhs of cusecs.

During the last few years, the Irrigation Department has maintained a gauging station at Mari Indus, and accurate observations of the flood of 1924 (which until 1929 is the highest since 1889) were taken.

On the 26th July 1924, observations gave a discharge of 4·46 lakhs of cusecs, and a surface velocity at the gauging station of 17·2 feet per second. The station was then temporarily abandoned, and readings were continued on the Kalabagh gauge. The highest reading recorded was equivalent to R. L. 698·7 from which the discharge was computed to be 5·20 lakhs of cusecs.

It is said that a level of R. L. 699·6 was reached on the gauge, and this is corroborated by a level given by Mr. Hallidy, the Superintendent of the Kalabagh-Bannu Railway. The discharge corresponding to this reading would be over 6 lakhs of cusecs.

From Appendix U (1) of the report on the Thal Canal Project (1919), it is found that the average high flood level for the 35 years from 1882 to 1916 is 15·05 (R. L. 694·75).

Independent investigations were made to cross-check the above conclusions. Enquiries were instituted from railway officers who had been stationed at Kalabagh for any length of time. The following extracts from an account of the Indus at Kalabagh by Mr. H. A. Brown who had 13 years experience of the river and had been in charge of the Kalabagh Ferry Steamers is of interest :—

" I have been on it (the Indus), in it, and under it (when I went down the hole of a whirlpool). I have been on it on log rafts, canvas coracles, various small boats, launches and steamers. I have very great respect for its power and moods. Its angriest moods very often last for a day or sometimes less and only those who have been on the spot can really know what the Indus can do. There are generally a few odd days every flood season, which is roughly from early May to September, when heavy rain plus melting snows turn the river into raging torrents, full of overfalls, swirls, rips, under-currents and whirlpools.

"During these occasional times the river from opposite Mari Ghat upwards resembles somewhat a tide rip as is encountered off headlands on the sea coast. If you have been on the sea close to the shore at Portland Bill, Selsea Bill, St. Albans, St. Catherine's or other places you may know what I mean. Of course the current on the river is stronger; this in very bad times reaches 15 to 20 m.p.h.

"Between Mari Ghat and Kalabagh Ghat the river is more orderly and the current raises fairly orderly lines of waves across the river. Those are really big rollers with small breaking crests that are unsafe for the steamer to get into. I have been through them both in the steamer (by accident) and in a small boat (by intention). I should judge these waves to be at their worst 12 to 15 feet from trough to crest.

"These waves do not move in relation to the land and will not therefore beat against the piers of your bridge but they are very formidable rollers worthy of the sea. Why they are caused I cannot rightly say. They take place on a dead still day and I do not think it is the resistance of the air itself on the water travelling at say 15 to 20 m.p.h. It has I think more to do with the depths of water in relation to the speed of the current.

"Another peculiarity is that the lines of waves diminish and increase at short periods with no very apparent rhyme or reason. A line will start opposite Kalabagh Ghat and within half an hour there will be many rows of these waves reaching nearly up to Mari Ghat; they may then gradually drop back again and repeat the performance several times a day. I imagine this is due to fluctuation in the speed of the current but in the absence of reliable measuring apparatus, cannot say for certain. I hope I have made it clear that these waves all run upstream and therefore do not break on either bank.

"The maximum speed of our two best steamers when running light is 11 m.p.h. and the speed of the launches about 9 m.p.h. Judging from the rate that these go backwards in relation to the bank while steaming hard up against the current, I should estimate the latter to be 10 to 12 m.p.h. in ordinary strong floods and 15 to 20 m.p.h. in abnormal ones. Probably between Mari Ghat and Kalabagh Ghat the maximum near the proposed bridge site is 15 m.p.h. while above Mari Ghat it is probably near 20 m.p.h."

Mr. Brown gave an estimate of maximum surface velocity at 15 to 20 miles per hour (22 to 29 feet per second). Another officer gave the velocity at high flood at 12 m.p.h. or 18 feet per second.

A set of observations of surface velocities were made in September 1921 with the river at about half flood, when a maximum surface velocity of 8 m.p.h. (11·77 f.p.s.) was observed. These being the only actual observations available they were used as a basis of estimating the discharge at high flood level. The H.F.L. at the Irrigation Gauge at Kalabagh is given as R.L. 706·00. At the site of the bridge 2,910 feet downstream the corresponding H.F.L. is R.L. 704·1.

The surface velocities observed in 1921 were reduced to mean velocities (0·89 of the surface velocity) and plotted, *vide* full curve AA', Plate V, which was produced (dotted) to show the probable velocities near the banks.

On the basis of this curve, the dotted curve BB', for mean velocities with water level 704·1 (level of flood of 1878) has been drawn.

Assuming that in this heavy flood the layer of fine sand was scoured away, the result would be, not only an increase in section, but also an increase in velocity proportional to $\sqrt{\frac{D}{d}}$, where d=original depth, and D=scoured depth.

The left hand end of the curve has been corrected for this higher velocity, shown in dash and dot. As the right bank is of more stable material, no allowance has been made for any scour on that side. Using the curve of mean velocities, and taking the area between H.F.L. 704·1 and datum line FF, (=79,357 s.ft.) a discharge is arrived at of 7,95,000 cusecs.

Mean velocity over whole cross section $= \frac{79,500}{79,357}$

$= 10·0$ f.p.s.

Maximum mean velocity (from curve) $= 12·7$ f.p.s.

Maximum surface velocity $= 14·4$ f.p.s.

It will be seen that the discharge estimated by this method is in practical agreement with that of the Irrigation Department. As the figure of 8,00,000 cusecs had also been accepted by officers responsible for previous projects for the bridge it was concluded that it was acceptable and it was decided to base the provision of waterway on this discharge, which had occurred 50 years previously and had never been approached since.

Waterway.

In the design of the waterway it was estimated that the bed of sharp sand and small stones underlying the bed of fine sand was scourable; its area was therefore included in the waterway of the bridge. Assuming this bed to have been scoured the increased depth of water would result in an increased velocity, shown by the uppermost curve (see Plate V).

Calculating discharges span by span (see table below) it is seen that nine spans will pass the flood:—

Discharge through nine spans of 250 feet clear.

(Area of protection works allowed for.)

Span No.	Area.	Mean velocity.	Discharge.	Progressive Totals.
	S. ft.	f. p. s.	Cusecs.	Cusecs.
1	5,230	8·8	46,000	46,000
2	9,683	11·0	1,06,700	1,5[illegible],700
3	9,467	12·3	1,16,400	2,69,100
4	8,990	12·0	1,07,900	3,77,000
5	8,868	12·0	1,06,500	4,83,500
6	8,746	11·75	1,00,700	5,84,200
7	8,091	11·25	91,000	6,75,200
8	6,806	10·5	71,400	7,46,600
9	4,706	10·0	47,0[illegible]0	7,93,660
	70.587		7,93,660	

$$\text{Mean velocity} = \frac{7,93,660}{70,587} = 11{\cdot}34 \text{ ft. per second.}$$

Nine spans of 250 feet were accordingly provided.

The addition of an approach span of 60 feet at each end of the bridge was considered. This arrangement was deemed unsatisfactory, as the first of the main piers would come at the junction of the apron and the toe of the pitched slope, and interfere with their natural action. Again, the first main pier being close to the abutment, and the intervening channel being partially blocked with the protection bank, dangerous turbulence was likely to be set up. In view of the very high velocity of the stream through the bridge, it was felt that any interference would be unsafe.

The two previous projects were (*a*) for 10 spans of 250 feet and (*b*) for 12 spans of 250 feet with two approach spans of 60 feet.

The reduction in waterway arrived at is due to the mean velocity having been taken at a much higher value than taken in the two original designs.

The failure every year of steamers capable of 11 m.p.h. to make headway against the stream, combined with the observed and calculated velocities justified the assumption of increased velocities. This assumption has been confirmed by a series of velocity observations made in 1930,

General Design of Bridge.

Plate VI shows the general design of the bridge. The decision to provide nine spans 250 feet clear and 263 feet centre to centre of piers involved a restriction of the natural waterway between the Mari and Kalabagh banks of about 700 feet. A protection bund 500 feet long upstream and 200 feet long downstream was designed for the Mari abutment (see Plate VII). This bund was designed with a heavily armoured nose at the upstream end; the front slope pitching is 5 feet thick carried to R.L. 710, the top of the bund, or 6 feet above H.F.L.; a stone apron 50 feet wide and 6 feet thick is provided. The Kalabagh abutment (see Plate VIII) was protected by heavy pitching, 20 feet thick at the base and carried 6 feet above H.F.L. to R.L. 710. The upstream pitching was taken 350 feet along the upstream side of the approach to protect the bank from possible erosion from the Nihal Shah Nullah, which enters the Indus immediately above the bridge, the top of the pitching being R.L. 708. In addition an apron 6 feet thick and 50 feet in width was laid round the toe of the Kalabagh abutment protection.

Depth of Wells.—In the project as designed it was proposed to carry the deep water wells to the stratum of "conglomerate boulders," and the depths are as shown on Plate IX. The term "basic depths" was employed as it was intended to execute the work on a Lump Sum Contract and it was necessary to give definite figures for depths to enable contractors to tender, making provision in the terms of the contract for deviations from the drawings if found necessary during construction. The depths fixed were those considered as probable safe depths. It will be seen that the deep water wells were taken 40 feet into the boulder stratum leaving 36 feet of the well and pier exposed at high flood level. As stated before little if any scour was anticipated in the deep water channel, but even if 15 feet of scour occurred, one-third of the well would still be embedded in a compact sand and boulder stratum. This depth was therefore considered adequate. The remaining shallow water wells were reduced in depth according to the velocities that were likely to occur, and were fixed at the levels shown in Plate IX.

Wells.—The wells are of the twin octagonal type 38′-3″ long by 22′-1½″ wide. The steining is 6′-11¾″ thick, leaving two circular dredging holes each 8′-2″ in diameter. The dredging holes were made circular to enable the pneumatic process to be employed in sinking if found desirable. The internal dimensions were fixed in the design to conform to the requirements of certain pneumatic sinking plant that was available on the B. B. & C. I. Railway. The well masonry was designed to be built of concrete blocks. The specification for the concrete blocks was as follows:—

The blocks shall be 1 : 3 : 6 Portland Cement Concrete.

Concrete shall not be discharged into the form from a height greater than five feet.

The concrete when in the form shall be well rammed and spaded.

The surface shall be levelled clean and true.

The date of mixing shall be shown on each block.

The concrete shall be put in place and ramming completed within 20 minutes of first adding water to the mixture.

The holes for T headed lifting bolts are to be cast in steining blocks and the recesses for lifting dogs are to be moulded in pier blocks.

The forms shall be such that a clean block to the form shown in the drawing will result.

The sides of the forms may be removed 24 hours after mixing. The blocks shall be kept in water for ten days after mixing when they may be moved to the stacking ground.

The blocks shall not be used for six weeks after mixing.

Caissons.—As some of the wells had to be sunk in deep water and as it was considered that pneumatic sinking would certainly be necessary after the lighter soil had been penetrated and the compact boulder stratum encountered, all well curbs took the form of caissons which would permit of the attachment of air domes and shafts for pneumatic work. These were designed by Messrs. Rendell Palmer & Tritton, Consulting Engineers to the Government of India, and are shown on Plate X. The design admits of open dredging to be carried out and a change made to pneumatic work if considered necessary. Alternatively pneumatic sinking can be employed throughout. The caissons are 11′-0″ deep, and provision was made for additional strakes, each 4 feet in depth, to be added as required for the deep water wells. Plate X. A shows the design of the caissons.

The following figures regarding the caissons are of interest :—

Weight of curb	.. 38·8 tons.
No. of field rivets	.. 2,578 = 66 per ton of curb.
No. of shop rivets	.. 7,682 = 198 per ton of curb.
Total No. of rivets	.. 10,260 = 264 per ton of curb.
Weight of one 4 feet strake	.. 8·85 tons.
No. of rivets	.. 3,400 = 38 per ton.

The space between the drum and cant plates of the caisson is filled with 1 : 2 : 4 concrete.

Hearting of Wells.—The wells are designed to be plugged at the bottom first with a 12″ layer of sand to ensure filling in of interstices at the base of the caisson ; over this is a 14 feet thick concrete plug 1 : 2 : 4 if laid under water or 1 : 3 : 6 with 20 per cent. plum stones if put in under compressed air. The dredging holes are then filled with sand and the top sealed with a concrete seal 1 : 3 : 6 with 20 per cent. plum stones 6′-9″ deep.

Piers.—Plate XI shows the design of the piers. They were designed to be constructed of concrete blocks as shown. It is intended, however, to construct them of mass concrete 1 : 2½ : 5 to avoid the handling of blocks. They will rest on a 2 feet thick 1 : 2 : 4 reinforced concrete base keyed into the top of the well as shown in the drawing. The maximum intensity of pressure at the base of the pier is 9·5 tons per square foot.

Girders.—These comprise nine spans 258 feet between centres of bearing and 263 feet between centres of piers.

The live load is carried directly on an open flooring of cross girders and stringers by N type through trusses with curved top chords and eight sub-divided panels, the maximum depth of truss being 38′-7½″. The load is transmitted to the piers through knuckle bearings. Temperature and elastic extension is provided for by roller bearings at one end of each span, there being one pair of fixed and one pair of roller bearings on each pier.

The girders are designed to Standard M. L. of 1926 (permitting an axle load of 22½ tons and a train of 2·3 tons per foot run behind the engine). Each span weighs 330 tons.

The general scheme of erection is to provide trestles, partly permanent and partly temporary on the wells in the first instance ; the girders will then be assembled at a low level and the trestles utilised for jacking up the girders to their final positions. The temporary portions of the trestles will then be removed and the permanent portion encased in the mass concrete of the piers. The spans over the dry bed will be assembled on a low level staging in the river bed ; those over water will be assembled on low level staging near the water edge and launched out on pontoons to their correct positions for jacking up to final level.

The method proposed for erecting the girders is only briefly touched upon in this paper as girder erection was not commenced at the time the paper was written, and it is considered that a detailed description of the erection methods and operations will be more suitably dealt with on the completion of the work.

Sanction to Construction.

The project and estimate were submitted to the Railway Board in February 1927 and sanction to the construction was accorded in May 1927. The Board decided that the sub-structure of the bridge should be given out on a Lump Sum Contract.

Tenders for the steelwork of the girders were called for in England and India. The contract was eventually given to Messrs. McLellan and Co. of Glasgow.

The Director-General of Stores, India Office, obtained tenders for the caissons in England, as they involved work which could not be done in India. The contract was given to Messrs. Head Wrightson & Co. of Thornaby-on-Tees.

In order to call for tenders for the substructure on a Lump Sum Contract a set of contract drawings were prepared, and Conditions of Contract, drawn up under legal advice, compiled to suit the special conditions of the work. Public tenders were then called for, a period of 3½ months being allowed for contractors to make all investigations and submit tenders. The contract included all substructure work from the top of the piers to the bases of the wells, together with the earthwork in the bridge approaches. It excluded the supply of the caissons for reasons given above but included the supply of any additional strakes required. The work was given to the All-India Construction Company of Bombay in January 1928.

Working Season, 1927-28.

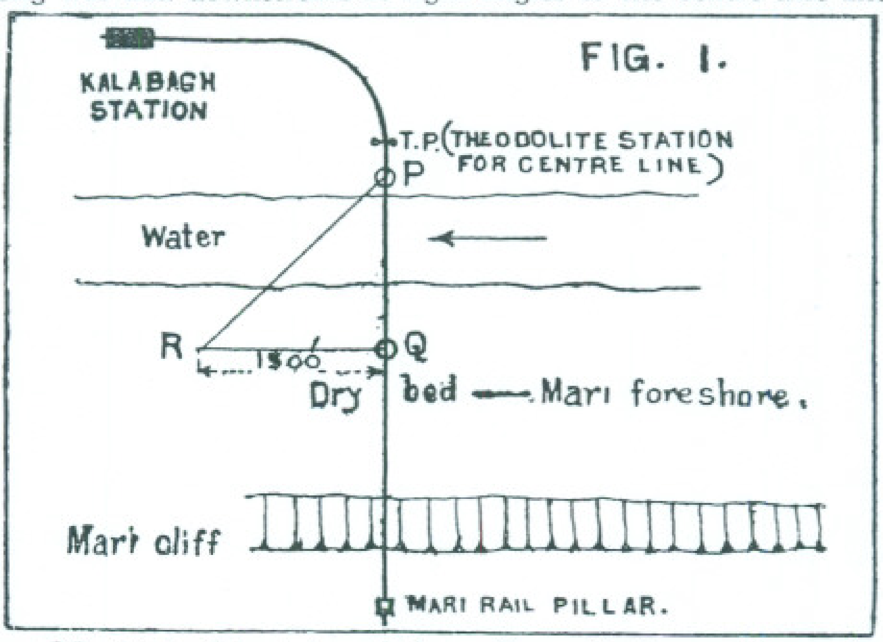
The caissons from England were due to arrive in January 1928 but it was not until the 6th of April that they arrived at Mari Indus. In the meantime the contractor collected staff and plant, prepared his block-yard, commenced the manufacture of blocks and laid necessary sidings for accommodation works.

The contractor decided to attempt to carry out all sinking work by open dredging and made no provision for pneumatic sinking.

Setting out Centre Line and Fixing Position of Wells.

The centre line was set out with an eight inch theodolite sighting from the tangent point of the curve between the bridge and Kalabagh station to a rail pillar on the brow of the Mari cliff (see Fig. 1). The sight was about 4,000 feet and the work was done in the evening to get the sun behind the instrument and to avoid the daytime shimmer. With the above sight a permanent peg P. was put in just behind the Kalabagh abutment. Pegs on the Mari foreshore were put in by setting up on the Mari rail-pillar and sighting across to the peg behind the Kalabagh abutment and depressing the telescope to sight into the river bed.

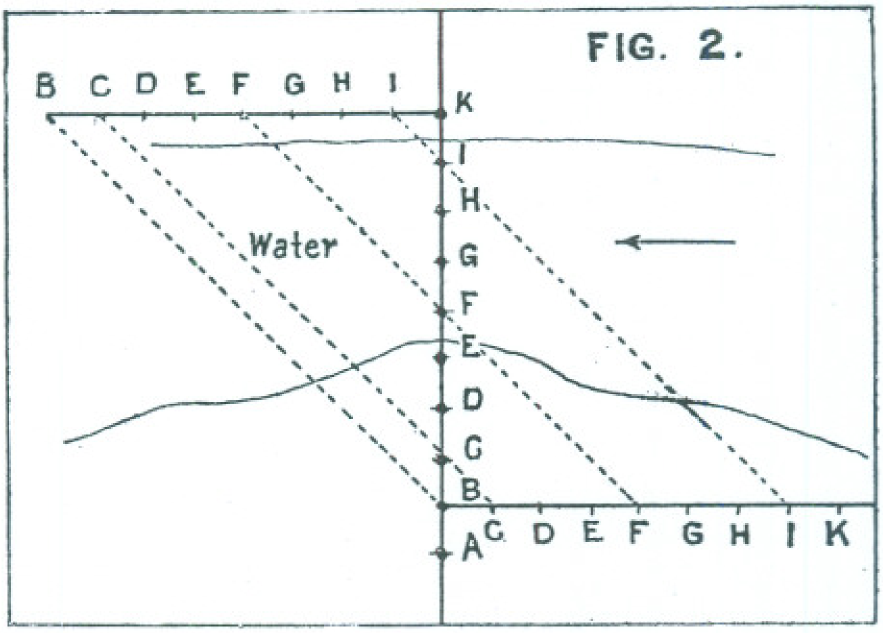
In the spring of 1928 it was necessary to fix the position of wells A, B and C. The theodolite was set up on a peg Q arbitrarily fixed on the centre line on the Mari foreshore (see Fig. 1). A base line QR 1,500 feet long was laid downstream at right angles to the centre line and the



distance QP obtained by triangulation. From Q the positions of wells A, B and C were laid off by direct measurement from peg Q and of well K from peg P. The base line was measured with a 300 feet Invar tape, laid out over pegs 25 feet apart, the tops of which were levelled. The tape was stretched with a 20 lb. pull and correction made for extension.

In the autumn of 1928 it was necessary to fix the position of the other wells. A base line of 8 spans long was laid off from well B upstream as it was possible to obtain the full distance BK on dry land at this point. On the Kalabagh bank a similar base line was set out at right angles to and downstream of the centre line. Setting out stations were made at every 263 feet (this being the distance between centres of piers) along both these lines as shown in Fig. 2. By sighting from any station to

FIG. 2.



the corresponding station on the other bank a true 45° angle was obtained; this eliminated any instrument error and the position of each well was accurately fixed.

Blockmaking.

The blocks for steining masonry were made in a long tank divided into sections, each section holding a day's outturn (21 blocks=one course). A travelling gantry straddled the tanks and carried two ¼ yard mixers which delivered direct into the block moulds.

It was found possible to reduce the interval provided in the specification between mixing and stripping the forms, and also the period stipulated for maturing after removal from the tank. The blocks could safely be used immediately after removal from the tank. The portion of the specification relating to this was amended as follows:—

"The sides of the form shall not be disturbed for at least 18 hours after the block was cast.

"Water shall not be let into any tank containing blocks until at least 18 hours after the casting of the blocks therein had been completed, and every block shall be completely immersed in water within 30 hours after it was cast.

"The blocks shall thereafter be kept in water for not less than nine days, after which they may be used.

Well "C."—This was the first well commenced. The site was about $1\frac{1}{2}$ feet under water and an island had therefore to be made. Erection of the caisson was commenced on the 18th April and the well curb and a portion of the lower strake erected by the 11th May. The curb was supported by small pieces of 12″ × 12″ timbers, one under each side of the octagon, and was kept level by hard wood wedges driven in between each timber and the cutting edge.

Riveting was started with one pneumatic riveting set and one day shift. Gradually two shifts of 10 hours each were instituted with two riveting sets in each shift. The average number of rivets turned out by a set varied from 150 to 200 per shift. The caisson was erected by the 14th May and open dredging commenced on the 19th May.

A dredger was worked in each dredging hole by means of a double drum steam hoist. Progress was slow and by the 8th June the continued rising of the river necessitated the removal of all plant from the well and work was stopped. The level of the cutting edge was R. L. 679, the well being only 11 feet below island level and 7 feet in the bed. The river rose to R. L. 695·3, scour occurred and the well took a longitudinal tilt of 3′-6″.

Wells "A" & "B."—Though late in the season work on these wells was attempted. Well curb "B" was riveted up by the 4th June and concreted by the 6th June. Owing to the rapid rise of the river it was not possible to do more than partially concrete "A" and well curbs "A" & "B" were at this time left pitched on the bed of the river. Eventually, however "B" settled down and came to rest on a level bed of shingle but well "A" tilted about $4\frac{1}{2}$ feet. "B" was at this time unapproachable but work could be carried out on "A" and the tilt was rectified by undercutting the downstream cutting edge. Work had to be stopped for the season on the 30th June with the curbs resting on the river bed, "A" being level and "B" having tilted 2 feet during the rise in the river.

Well "K."—The erection of the caisson for well "K" was commenced on the 30th May and completed by the end of June. Work was not commenced on this earlier as it was sited high up on the Kalabagh bank and work could proceed throughout the flood season. Efficiency in riveting improved and a set of riveters with one set was able to turn out 300 rivets in a shift of 10 hours.

The concreting was finished by the 5th July. As the site of "K" was about $3\frac{1}{2}$ feet above water level the first 4 feet were sunk dry and then from the 29th July open dredging with a steam hoist and Priestman dredger worked off a Scotch derrick was carried out. The average time per dredger trip was about 4 minutes. The first four feet of soil at "K" was clay followed by a stratum of clay small boulders and sand interspersed with pockets of pure clay and of larger boulders. A large accumulation of big boulders 4 to 5 feet thick was encountered at R. L. 651. The largest boulder obtained had a girth of 9 feet. Dredging alternated with periods of stoppage for laying steining blocks. Between 100 and a 150 tons of sandbag and pig iron kentledge was used on the well. By the end of October " K " had gone down to R. L. 659, *i.e.*, about 39 feet below ground level.

The position of the work at the end of flood season of 1928 was as follows :—

Well " A " Curb pitched, concreting completed.

Well " B " Curb pitched, 75 per cent. concreting completed. Longitudinal tilt 2 feet.

Well " C " Curb pitched, R. L. 679, Tilt 3′-6″.

Well " K " Level of cutting edge R. L. 659.

The actual working season except for Well " K" was of necessity very short as it was only at the beginning of January that the contract was given.

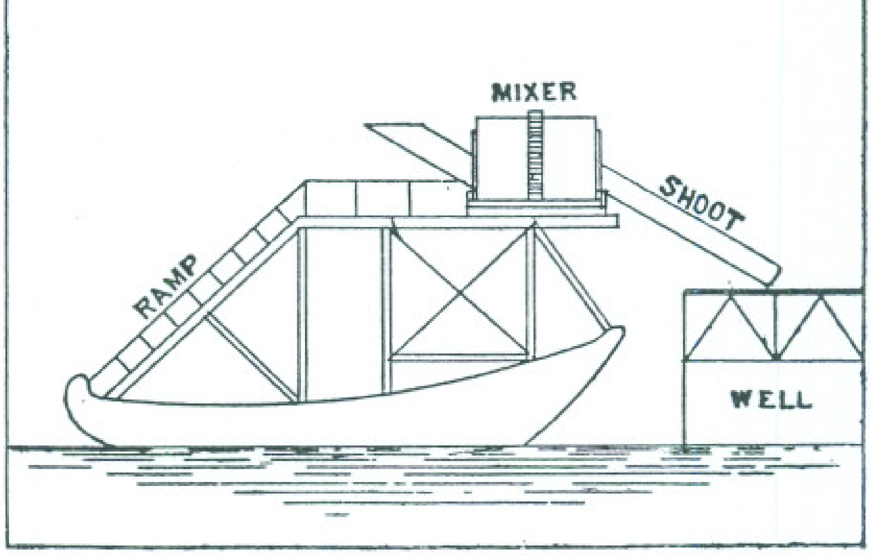
Working Season, 1928-29.

As a result of the experience gained during the first season's work the contractor obtained more plant. Two 35 feet jib 4-ton cranes, two 20 feet jib 7-ton cranes and one small 8-ton crane were obtained for the job.

The original design provided for the steining being built up of concrete blocks varying from 5 to 7 tons in weight in 2′-9″ courses, but the difficulty of handling blocks, especially in the midwater wells, was represented by the contractor and he was permitted to use mass concrete instead. Mass concrete had the further advantage that a course is laid in one piece instead of 21 pieces and could be easily cast in one day, while it was difficult to lay 21 blocks in one day. Added to this was the necessity of using floating cranes for blocklaying. No blocks were therefore made after September 1928 and wells " F, " " H " & " I " had their steining built up of mass concrete. The blocks made were used up in wells " A " to " E " and " K. "

For pouring mass concrete two $\frac{1}{4}$ yard Rex Mixers were mounted on a raised platform on a country barge (capable of supporting 30 tons) (See Fig. 3).

FIG. 3.



A mixer barge was anchored on either side along with the subsidiary sand, ballast and cement boats. The mixers were each 6 cubic feet capacity and a mixing cycle took 3 minutes. A course (containing 1,700 cubic feet of concrete) therefore took 7 hours to complete. Allowing time for setting and re-erection of shuttering a course was done in every two days.

These tower boats proved most useful, not only for their original purpose of carrying mixers but also for loading and unloading pig iron kentledge for wells.

Well "*A.*"—Preparations for resuming work in this well were made by the 12th September 1928. A steel gantry was erected on the well and a Priestman Grab was worked off this by means of an electric hoist mounted on the gantry. A trolley running on a 8′-6″ gauge was provided for receiving the spoil from the grab and dumping it just clear of the well from where it was shovelled away. There was little or no movement however till the 23rd of September. In the last week of the month however 2½ feet of progress was achieved. The well moved with difficulty though steadily till it was sunk to its designed depth of R. L. 655·72 on the 10th December. The well was then plugged and the R. C. footing and 5′-6″ of pier masonry built.

The various methods employed to move the well were :—

(1) Dredging all round the well between 10 to 15 feet below ground level to relieve skin friction.

(2) Loading up about 250 tons of kentledge on the well.

(3) Occasional dewatering with pulsometers, though the water could not be lowered more than 10 feet.

(4) Employing a water jet for undermining the cutting edge. The last 8 feet was sunk mainly by the aid of the water jet. A Worthington 4″ suction pump was used for the purpose.

Well "*B.*"—The season commenced with this well tilted longitudinally 2 feet. Dredging was commenced on the 24th of September and it was straightened by the 4th of October. The grab was worked off a derrick made of ballies erected on the well itself, the power being supplied by a steam hoist. Steady progress of sinking about 6 inches per day was obtained from the 4th to the 16th of October and sinking continued steadily till the 9th December by which time the well had gone down to R. L. 657. The well showed signs of sticking as it was moving with great difficulty after blasting, although about 200 tons of pig iron had now been loaded on the well. Four pulsometers, as many as could work at one time, were employed on the well till the 21st December when dredging was resumed. The remaining 8 feet of sinking on the well to R. L. 647·85 within a foot of the designed depth was completed on 16th February 1929 with great difficulty. Rail chisels were used but they were not effective. Water jets were also used.

The well was then plugged according to the design and the R. C. pier footing and 5′-6″ of pier masonry were completed before the flood season of 1929.

Well "*C.*"—Work on well " C," which had a longitudinal tilt of 3′-6″, was commenced on the 12th October 1928 and the tilt removed by the 26th. In addition to the tilt it was ascertained that during the monsoon floods the well moved obliquely and was skew to the longitudinal axis to the extent of 1 in 18. Endeavours were made to rectify this by dredging outside the well at opposite corners, simultaneously with the inside dredging, but without success. The displacement had no practical disadvantage as there was ample room on the well to build the pier in its correct position.

By the 22nd November 4 courses of blocks were finished and a 35 feet jib crane commenced open dredging on that date. Steady progress was maintained till the 21st December when the well was over 30 feet embedded. Although rail chisels were worked no effect was observed on the well. There was not the slightest progress for seven consecutive days, in spite of outside dredging. On the 9th of February pulsometers were fitted up on well "C" to dewater the well, which had still got 8 feet to go.

The well was completely sunk by the 2nd April to R. L. 643·14 giving an average progress of 2¼ inches per dredging day for the last stage of 6 feet.

The well was plugged at 5 feet short of its designed depth. Permission had been given to the contractor to found the well at this level as it was impossible to get the well down any further and it was considered that the depth reached was sufficient for this comparatively shallow portion of the river.

Well " *D.*"—As the river subsided a siding was pushed out to reach the sites of "D" and "E" wells. At "D" the water was 1½ feet deep and at "E" 8 feet deep. The siding between "D" and "E" and the island for "E" were protected by a double row of piling 8 feet to 16 feet deep with brush-wood in between. The siding was built up to R. L. 691 so that work could be continued till late in the season.

At this stage of the work the difficulty in sinking was attributed partly to the design of the cutting edge. The Consulting Engineers had designed 2 types, Figs. A and B. Plate XII. Type B had been approved by the Chief Engineer, but type A had been manufactured and sent out. The cutting edge as used had a bearing area of 67 square feet and in the stiff boulder soil had insufficient penetrating power. To remedy the defect a new design Fig. C, Plate XII, was made with a reduced bearing area of 50 square feet.

A reference to Plate XIII which shows the diagram of sinking progress gives the following results :—

		From R. L.	*To R. L.*	*Feet.*	*Time Days.*	*Inches per day.*
Well	"A"	..677·5	656	21.5	43	6
,,	"B"	..675	666	9	15	7·2
,,	"C"	..672·5	662	10·5	20	6·2
,,	"D"	..667·5	654	13·5	17	8·0

Of the above, caisson D had the improved cutting edge, and it will be seen that distinct advantage was obtained. Similar cutting edges were therefore provided for the remaining caissons.

The caisson for well "D" was erected between the 20th of November and 20th December, concreted by the 27th of December and dredging with one 35 feet jib crane commenced on the 28th. By the 11th of January the well had sunk 12 feet below the top of the island. Sinking continued steadily till the end of February after which progress diminished slightly till the 21st of March when the well began to give difficulty. Additional dredgers and water jets were used and the sinking was completed by the 1st May. The progress was slow averaging about 2¼ inches per dredging day. Sinking was stopped 12 feet short of the designed depth at R. L. 641·04, the same reasons applying as for "C" well.

Well "E."—From experience on the other wells it was found that after a well had been sunk about 20 feet progress depended on the rapidity of undercutting inside the caissons by divers, as the dredgers were not able to break up the compact shingle or boulder soil. In consequence divers were used to a greater extent.

The caisson for "E" was erected on an island by the 21st January, concreting finished by the 28th of January, and dredging with one crane—later on two—commenced on the 30th of January.

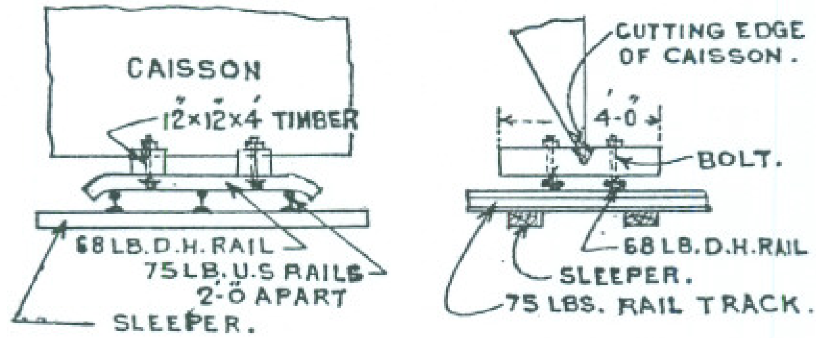
The first 8 feet of sinking was through the made up island. Progress was therefore rapid averaging 17 inches per day till the 7th of February. Dredging with occasional stoppages for block laying went on till the 24th of March, the average progress per dredging day from the 17th February being 8½ inches, though towards the end it was about 5 inches per day. The well had now gone down 23 feet into the bed. It was giving trouble at this stage, and divers had to be employed ; three courses of dry blocks aggregating 330 tons were added as kentledge but the well would only move an inch or two per day. Progress was slow and work was stopped for the season on the 28th of May, the progress achieved in the previous 13 days being only 4 inches. The cutting edge was then at R. L. 645·84.

Well " I".—This was the first of the four wells requiring the caisson to be floated out, the others being " F, " " G " and " H " all in the deep water channel.

The caisson was erected on the Kalabagh bank. It was slid out on a slipway made of six lines of rails as shown in Figs. 4 and 5. The

FIG. 4.

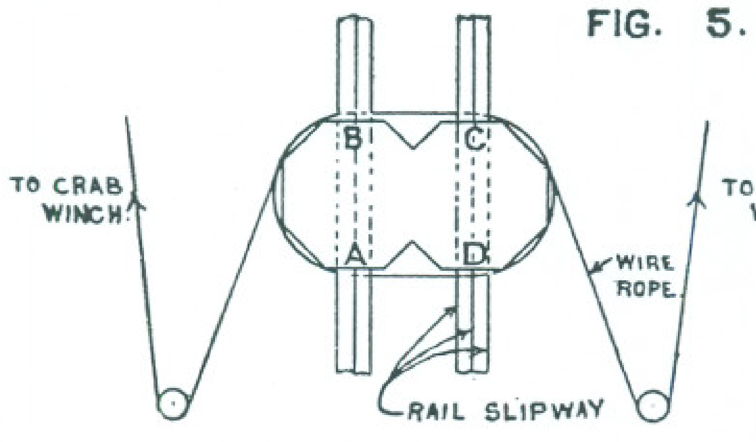
CARRIAGE



slipway extended into 8 feet depth of water. The track was linked up outside and then lowered into the water where it was adjusted by a diver. The slope of the track was 1 in 13 and it was greased throughout. The caisson was provided with carriages as shown in Fig. 4.

A wire rope passing round the caisson with the ends bound on two crab winches was used to give the caisson initial movement. (See Fig. 5). The caisson then slid down the slipway and floated. Photo No. 4 shows the caisson launched.

FIG. 5.



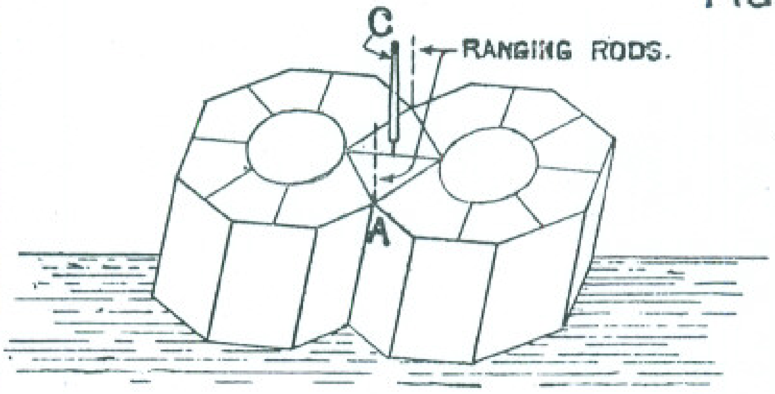
A CARRIAGE PROVIDED
AT EACH OF THE POINTS
A, B, C AND D.

After launching the caisson on the 15th December it was towed between two country boats to a flat which was moored so that the caisson came approximately in its correct position. The caisson was filled with concrete until it grounded, after which a further 20 to 30 tons of concrete was put in it.

The domes closing the tops of the working chambers had been previously fitted in position, and a 1 inch pipe line led to each from a portable compressor on one of the barges. On driving the water out of the working chambers with compressed air, the resulting lift was sufficient to raise the caisson from the river bed, so that it could be moved to its true position and grounded by letting the air out through 3 inches valves fitted on the domes. Concrete mixers were ready to start pouring in more concrete as soon as the caisson was grounded in its right place, so that it should bite into the river bed.

To get the caisson square to the centre line two ranging rods were mounted in the re-entrant angles A, as shown by the dotted lines (See Fig. 6) and the caisson adjusted until they covered the corresponding

FIG. 6



rod on the shore. This was done before the centre pole C was put in its socket. When the caisson had been got square to the centre line, the centre pole P was put up, and sighted on by two theodolites, one on the centre line and one on the setting out station. A flagman at each theodolite held up a flag so long as the cross wire on the theodolite was bearing on the pole. When both flags were up, the air was let out from the caisson which allowed it to ground. Several efforts were usually required, as in grounding the caisson it was often carried off by the current. Adjustments were made by the tackles shown in Fig. 7.

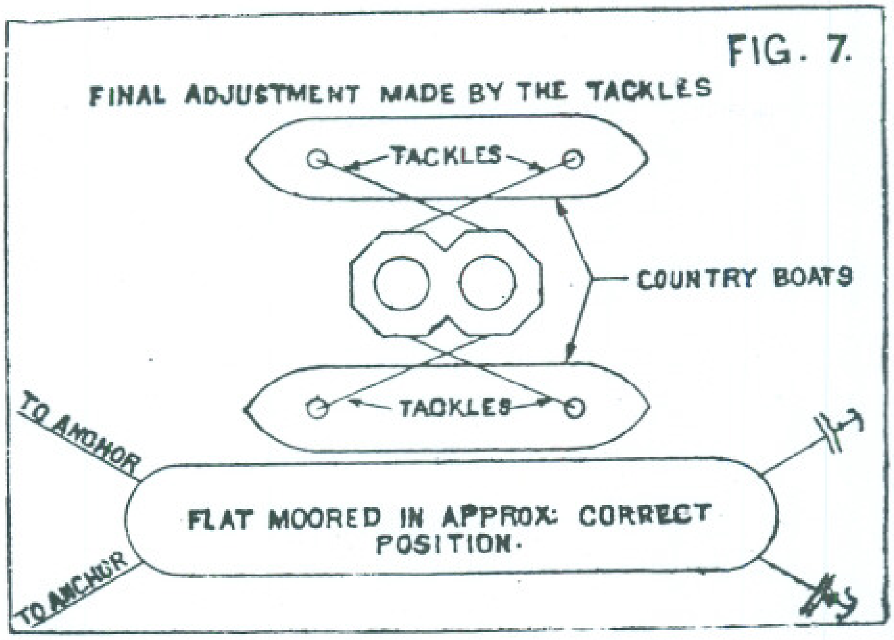


FIG. 7.

The operations of founding and concreting the caisson were completed by the 28th December.

Dredging was commenced on the 1st January 1929. The dredging plant consisted of a Scotch derrick erected on a 30-ton barge from which was worked a grab off a steam winch erected on the neighbouring bank. Progress was slow and a diver was employed intermittently for clearing the cutting edge. The average progress per working day till the 11th of March was about $3\frac{1}{2}$ inches by which time the well had gone down 12·3 feet.

Progress from now on averaged 3 inches per day. The kundi or hole dredged below the cutting edge was deepening at a greater rate than the sinking. By the end of April the kundi was 13 feet deep below the cutting edge but the sides would not cave in. By the aid of divers and a water jet fair progress was made till the 24th May, when the well stuck. The kundi had partially filled up in the last stage of sinking and was now only 2 to 3 feet deep.

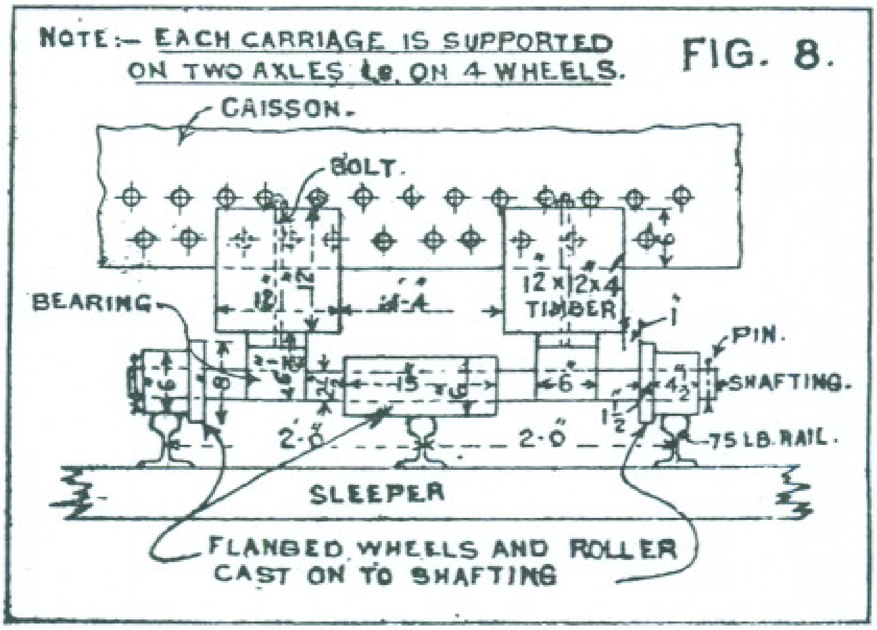
The cutting edge at this time had reached R. L. 645·62.

Well "F."—The caisson was floated out as described for the "I" caisson on the 18th January 1929 and the caisson as well as the two steining courses concreted by the 2nd of February.

For the dredging two Scotch derricks and steam hoists were erected on a 250 ton barge. The progress of sinking averaged 14 inches per dredging day till the 11th March by which time the well was embedded 16 feet. After concreting another four courses dredging was resumed on the 30th March and kept up till the 6th of April, the average progress being $4\frac{1}{2}$ inches per day. There was no progress during the rest of the month, in spite of 150 tons of kentledge on the well. Dredger after dredger came up empty. Ultimately more divers were used and 27 inches of progress was obtained from the 8th to 21st May when work was suspended for the season due to the rise in the river. The level of the cutting edge was at R. L. 650·28.

Well "H."—The caisson was floated out on the 18th February and taken to site, concreted and grounded by the 12th March. A modification was made in the slipway carriages, which were now supported on 4—6″ dia. flanged C. I. wheels on two 2½ inches axles, as shown in Fig. 8. This proved very satisfactory.

FIG. 8.



The dredging plant used was similar to that on well "F." Dredging was commenced on the 15th of March and progress was rapid, the average till the 15th of April being 13 inches per dredging day. At this stage it was 20 feet embedded. After concreting 4 courses dredging was resumed on the 27th April but the well refused to move. There was only 2 inches of progress from the 8th to the 14th of May. The well had stuck in a bed of tough clay with pockets of sand and boulders, and neither water jetting nor undercutting would help it to progress. The river was also rising and work was therefore stopped for the season on the 15th May. The cutting edge was at R. L. 644·84.

Well "K."—At the end of October this well had been sunk to R. L. 659. Work continued steadily and by the 23rd December it was sunk to R. L. 644·68, 13·68 feet above the designed depth. The abutment being strongly protected this depth was considered adequate. The average daily progress for the last 21 days was 6 inches. The well was then plugged and the reinforced concrete footing and 5′-6″ of pier masonry built.

Protection Works.—The construction of the protection bund on the Mari bank was taken in hand towards the end of November 1928. The excavation of the trench for the apron was commenced first and the spoil was dumped alongside to form the protection bund. The trench was excavated down to water level. The pitching of the apron was commenced towards the middle of December and all the pitching including the noses and slopes of the bund completed by the middle of June. The bund had also been carried to the right height by this time, though the slopes were left to be dressed off later.

About $9\frac{2}{3}$ lakhs cubic feet of pitching stone was used for $7\frac{2}{3}$ lakhs cubic feet of hand packed pitching. More than half the stone was obtained from Paikhel quarry—18 miles by rail from Mari Indus. The rest was brought from Sangjani, Usmankhattar and Wah. The supply of this stone was arranged for the contractors by the Railway.

Excavation for the Kalabagh Protection Works were commenced in February and pitching commenced in March 1929. The stone was obtained locally and was arranged for by the contractors. The work was completed by the middle of June except for a portion opposite the abutment which was only carried up to R. L. 702·00.

Position at the end of the Working Season 1928-29.

Well "*A.*"—Sunk to R. L. 655·72 the designed depth, plugged, R. C. pier footing and 5′-6″ of pier masonry built.

Well "*B.*"—Sunk to R. L. 647·85, the designed depth, plugged R. C. pier footing and 5′-6″ of pier masonry built.

Well "*C.*"—Sunk to R.L. 643·14 instead of R. L. 638, the designed depth, plugged, R. C. pier footing and 5′-6″ of pier masonry built.

Well "*D.*"—Sunk to R. L. 641·04 instead of R. L. 629, the designed depth, and plugged.

Well "*E.*"—Sunk to R. L. 645·84.
Well "*F.*"—Sunk to R. L. 650·28.
Well "*G.*"—Not commenced.
Well "*H.*"—Sunk to R. L. 644·84.
Well "*I.*"—Sunk to R. L. 645·62.

Well "*K.*"—Sunk to R. L. 644·68, 13·68 feet above the designed depth, plugged, and R. C. pier footing and 5′-6″ of pier masonry built.

The Mari protection bund was completed during the season as well as the Kalabagh abutment protection work to R. L. 702 instead of to R. L. 710, as additional work would have to be dismantled later when the abutment was being completed.

General remarks on the Working Season 1928-29.

The characteristic feature of the season's work was the realisation of the necessity for pneumatic sinking. It became evident to the contractor that open dredging in the compact boulder stratum gave very slow progress and was in fact impossible below a level of about R. L. 645. This fact was fully realised by the contractors as the season's work progressed and by March 1929 they had obtained a pneumatic sinking set consisting of 2 compressors, 2 boilers, 2 airlocks and all ancillary fittings. This plant was available from the B. B. & C. I. Railway and had arrived in India in 1911. It was still quite serviceable. There was little time to erect and operate the plant during the short remaining period of the working season and it was overhauled for use in the season 1929-30.

Floods of 1929.

During the month of August three large floods took place. Each was greater than the normal monsoon flood, while the last surpassed all records, having a discharge 50 per cent. greater than that estimated as a maximum. Plate XIV which marks the fluctuation in the river levels since 1927 shows the peaks of these floods, which have compelled a redesign of the waterway.

The first high flood took place on the 2nd August when the river rose to R. L. 700. This was higher than any level since 1889 and just higher than the flood of 1924.

The second big rise occurred on the 18th-19th August, as a result of the bursting of the Shyok Glacier dam. The river rose to R. L. 699.

The third and greatest flood occurred on the 28th and 29th August, the gauge at the bridge site being at R. L. 705·3.

A certain amount of damage had been done up to the time of the last flood, but not to any great extent. When the river was at R. L. 696 in July well "H" tilted 5·6 feet longitudinally and 1·6 feet transversely. Practically the whole tilt was taken then and the high floods had no further effect. Well "F" was submerged from early July, and from the shape of the waves it is believed to have tilted during the Shyok flood. Whether it took its full tilt then or whether the tilt that occurred was accentuated during the last flood is unknown. Well "E" withstood the first two floods.

The last flood of 29th August was unprecedented. It reached a level of R. L. 705·3, and it is estimated by the N.-W. Railway that it discharged 1,200,000 cusecs. An account of the flood, the estimate of its discharge and the damage done is given below as reported at the time by the Executive Engineer in charge of the bridge.

"There was a rapid rise of the river on the afternoon of the 27th August and large waves, which are a feature of the river in its angry moods here, began to form. The rise continued during the night of the 27th, and on the morning of the 28th had reached R. L. 699, which is above the normal high flood. The rise continued throughout the day and most of the night of the 28th-29th. After reaching a level of over R. L. 705 at the bridge site during the early hours of the 29th, the flood began to fall, and by the evening of the 31st the river had returned to a more or less normal level for the time of the year.

"By 11 hours on the 28th, Mari Ghat station was completely submerged, and during the afternoon the artificial spur upon which it was built was being washed away. By 21 hours it had ceased to deflect the river towards the centre of its channel, and a strong current was flowing through a deep breach which it had cut through the spur at the foot of the Mari bank. Thus the force of the current was directed on the still water pocket between the protection bund of the Mari abutment of the bridge and the bank, instead of striking tangentially on the heavily pitched river face of the protection bund. A strong breeze had sprung up, which increased the strength of the current, and the water in the stillwater pocket behind the bund rose and fell (at about five minutes intervals, which subsequently became shorter) in periodic affluxes. These periodic rises were about 4 feet, and reached a level of approximately R. L. 706. The level of the river running through the bridge channel was at this time (21 hours) about R. L. 702. At each periodic rise the water overtopped the protection bund at its junction with the approach bank. The successive rushes of water from the back to the front of the bund gradually ate away the sand core, and washed the facing of pitching stone into the river. Once the channel was made, it was only a matter of hours until the whole of the approach bank and the greater part of the protection bund downstream of it was washed away. Before the bund was breached here the stone pitching on the nose had begun to go. The current coming down from the breached Mari Ghat, and hugging the Mari bank as far as the bridge, was swirling past the nose to join the main stream rushing through the bridge channel, and carried away some of the pitching with it. Very shortly after this action had started, the approach bank was being cut away, as described above, and the current past the nose reversed its direction, *viz.*, water from the main channel ran past the nose to flow through the relief channel formed between the bund and the bank, and this current also was strong enough to sweep pitching from the nose towards the inner side of the bund.

"Beside the approach bank having been totally washed away, and one-third to one-half of the protection bund having been carried away, serious damage has been done to the wells. A 200-ton wagon flat broke loose from Mari Ghat, and was wrecked on well "E." The top of this well was standing some 4 feet above the flood level and two of the contractors' gantries and electric dredging winches were in place on it. The flat struck it fairly, broke its back and enveloped the well, with half hanging down on each side. The halves of the flat acted as scoops or deflectors, and greatly aggravated the scour round the well, so that it is now tilted some 8 feet, although it had been sunk some 30 feet into the bed. This was a most remarkable misfortune. All the other wells were submerged, and the flat could have passed over any of them unharmed. Even in striking well "E" the probabilities were that it would strike it a glancing blow and be carried on, but it happened to strike it so fairly that the two halves of the flat were bent round the well. Had it not remained in position, and thereby greatly increased the local scour, it is possible that well "E" would not have been tilted. Well "F" has been tilted some 12 feet, and its righting will be a difficult and costly business.

"Well "H," which was tilted earlier in the season fortunately appeared to be no worse.

"Well "I" and the Kalabagh protection works withstood the flood successfully.

"As soon as possible after the flood went down soundings were taken and a cross section of the river bed plotted. Similarly, levels were taken on both banks of the river both above and below the bridge site from which to obtain the slope of the water surface.

"The maximum height of the flood at Kalabagh gauge is found to be R. L. 707·2, compared with R. L. 706 for the 1878 flood.

"At the bridge site, the mean of the marks on the upstream and downstream sides of the Kalabagh approach bank is R. L. 705·3; on the Mari side R. L. 705·2 was measured on the morning of the 29th, just after the flood had begun to go down. Before the Mari approach bank went, and before the flood reached its highest, an afflux of about 1½ feet was observed, *viz.*, R. L. 701 on the upstream side and R. L. 699·5 on the downstream side of the Mari approach bank. Observations of surface slopes also show a distinct afflux at the bridge site.

"No measurements of surface velocity were made, as all hands were too busily occupied in trying to save the bund and approach bank. The Irrigation Department reported a maximum surface velocity of 23 feet per second opposite Kalabagh. I have measured a velocity of 18 feet per second in an ordinary flood of R. L. 696. Using the formula that increase of velocity is proportional to the square roots of the depths, and allowing for the extra scour found after this flood, I computed a maximum surface velocity of 21·3 feet per second at the bridge site (See Plate XV), which agrees very well with the Irrigation Department figure of 23 feet per second at Kalabagh, where the river is narrower and swifter.

"The discharge was calculated in three ways, and was found to be:

1. By Kutter's formula	.. 10,55,000
2. By Bazin's formula	.. 12,74,000
3. By velocity curve and cross section	.. 11,99,000
Total	.. 35,28,000

Mean of three methods = 11,76,000 cusecs.

"Although this result seems extraordinarily high, there are strong grounds for accepting it as correct.

"The Discharge Division of the Punjab Irrigation Department sent a Sub-Divisional Officer to Attock, to measure the discharge there. He calculated it by surface velocities, by Kutter's formula and by afflux through the bridge piers, and the mean of his three results is about 10½ lakhs of cusecs. Between Attock and Kalabagh the Haro and Sohan rivers and a number of un-named nalas add their contribution to the Indus. It is known that the Haro was in extraordinarily high flood, as it badly damaged two bridges, and there was general local rain which would cause the Sohan and local nalas to flow. The addition of a little over a lakh of cusecs between Attock and Kalabagh is therefore most probable. The two independent observations and calculations therefore agree.

"The Irrigation Department afterwards reduced their figure of the discharge at Attock to 8·17 lakhs. On the other hand, the figure of 1 lakh of cusecs for the water coming in between Attock and Kalabagh has to be increased several times. After the submission of the report, the discharges of the Haro and Sohan rivers were measured, and these were found to total 3·10 lakhs.

"On this evidence there appears every reason to conclude that the discharge was not far short of 1,200,000 cusecs.

Effect of 1929 Floods on Design of Waterway.

The discharge of approximately 1,200,000 cusecs in the flood of August 28th-29th made it imperative to reconsider the amount of waterway to be provided. As designed the bridge could discharge 800,000 cusecs with safety. Actually during the big flood, no less than 1,068,000 cusecs was estimated to have passed between the abutments. The possibility of the recurrence of a 1,200,000 cusecs discharge could not be ignored, and it was decided that the bridge should be extended to bridge the full width of the river between the Mari and Kalabagh banks. This entailed an extension of the bridge at the Mari end by 4 spans of 175′-4″ centre to centre of piers. It was also decided to increase the depths of wells still to be sunk. Plate IX shows the altered design, with old and new depths of wells.

With the revised depth of wells the maximum intensity of pressure on the foundations allowing for buoyancy but excluding frictional resistances works out to :

5·3 tons per square foot for the shallowest well.

8·8 tons per square foot for the deepest well.

Assuming the lowest scour level to be R. L. 638 the maximum intensity of pressure on the well masonry is 8·1 tons per square foot at that level.

Working Season, 1929-30.

Well "I."—Well "I" had been sunk down to R. L. 645·62 during the 1928-29 working season. It had been scoured down to R. L. 653, during the August 1929 flood, but was otherwise undamaged. Preparations to commence pneumatic sinking on it were taken in hand on the 7th of September. Air was first let in on the 23rd of September. By the 13th October the work had got under way and after a week of work the average sinking was 7″ to 8″ per day. No special difficulties were encountered and the well was sunk to the right depth, *i.e.*, R. L. 619·15, by the 11th December. Leaving out the period prior to the 13th of October it took 47 sinking days to sink 26·03′, *i.e.*, an average progress of ·55 feet per day.

It was proposed to concrete the bottom plug on well "I" under pressure. The work was done in 4 hour shifts instead of the usual time of six hours. This prevented the occurrence of any case of 'bends,' as the working pressure was now 30lbs. per square inch. The concreting was commenced on the 14th and was carried on without a break till the morning of the 17th by which time the top of the concrete was one foot below the dome door. This was the utmost that could be done under pressure without getting the door embedded in the concrete. The concreting was rather slow. The only trouble experienced was due to water blowing in from the outside. The first foot of concrete was done without mishap but after the cutting edge had been sealed there was no outlet for the air except through the discharge valve controlled from the outside. If this was insufficiently open the excess air would blow through the annular space between the concrete and the sides of the working chamber. The consequent fall of pressure would cause an inrush of water which when driven out would wash away the mortar from the concrete adjacent to the sides of the working chamber. A similar inrush of water with identical results would take place if the discharge valve was too much open. It was not possible for the man outside to know what was happening inside at any given moment and consequently the discharge valve could never be adjusted correctly. The consequence of these recurrent blows was the formation of fog inside the caisson which hampered work. As a result of this experience therefore it was decided to do away with plugging under pressure on the other wells.

The remainder of the bottom plug and the top plugs were both done under water and completed by the 14th of January.

Well "H."—This well which had been sunk to R. L. 644·84 in the 1928-29 working season had acquired a longitudinal tilt of 5·57 feet and a cross tilt of 1·64 feet during the hot weather floods. The upstream cutting edge was at R. L. 639·96.

Preliminary operations were commenced as soon as the river had gone down. The electric dredging hoist was fitted up on a gantry and all auxiliary work completed by the 15th of November. Outside dredging was commenced on the 16th November and completed on the 9th of December. The downstream cutting edge was exposed and dredging carried all round the downstream half of the well. The air domes were lowered without any great difficulty on the 9th and 10th November.

One airlock was erected on the downstream well on the 22nd and 23rd December. Air was let in on the 24th. No shaft and air lock were provided over the upstream well as it was not thought necessary, one lock being sufficient for ingress and egress to both chambers. Two 40 feet girders were placed cantilevered out across on the 27th and about 200 tons of pig iron loaded on the girders by the 7th January. Meanwhile work had been going on inside without any appreciable results. By the 8th January the longitudinal tilt had only been reduced from 5·57 feet to 5·29 feet and the cross tilt from 1·64 to ·97 feet. It was therefore thought advisable to close the manhole between the chambers and have a slight excess of pressure in the upstream chamber to enable undercutting of the centre bar, as this offers the most resistance to righting. Work was therefore stopped on the 8th January and resumed on the 13th, by which time an airlock had been fitted over the upstream well. The manhole plate was fitted on the 14th and undercutting of the centre bar commenced. The well started moving slowly by the 18th on which date the longitudinal tilt was 5·15 feet, being an improvement of ·11 feet for the last 24 hours; the cross tilt was reduced to ·78 foot on that date. The progess increased gradually up to the 23rd January by which time the longitudinal tilt had been reduced to 3·83 feet and the cross tilt to ·89 foot. Improvement was rapid and the well was righted to within specified limits by the 29th of January. At this stage the well was embedded only about 4 feet on the downstream side and about 13 feet on the upstream side. The progress in sinking was good, averaging almost a foot per working day till the end of February, by which time the well had been sunk to R. L. 623·21, and it was embedded on an average about 28 feet into the ground. Progress now dwindled to 3 inches per day. The last 8·7 feet of sinking to R. L. 614·53 feet took 24 days to finish giving an average progress of about 4·3 inches per day. The delay was due to the increased depth and to the very compact nature of the sand and boulders.

The bottom plug was put in immediately after removal of the pneumatic plant. An inordinate rise in the river however prevented the putting in of the top plug.

Well "E."—This well, which had been sunk to R. L. 645·81 in the 1928-29 working season, was found to have tilted 6·72 feet longitudinally and 1·1 feet transversely during the August 1929 flood, the upstream cutting edge having settled down to R. L. 638·08.

This damage was caused by a wagon flat being wrecked on the well during the floods. Photo No. 5 shows the wrecked flat enveloping the well. The Bridge Department of the N.-W. Railway was entrusted with the work of removing it. This took from the 25th October to the 7th of February, on which date the well was definitely handed over to the All-India Construction Company for commencement of righting operations. The exceedingly difficult nature of the work accounted for the long time taken in the removal of the flat.

To right the well the method adopted was to dredge outside the downstream end down to the cutting edge, and apply cantilevered kentledge in conjunction with excavation under pneumatic pressure inside the well. Photo No. 6 shows the well loaded and air locks in position.

Outside dredging was carried out up to the 22nd March, when the downstream cutting edge was clear.

The removal of silt deposited from freshets in March impeded progress. The air domes were lowered and fitted in position from the 28th to the 30th March. The shafts were fitted on the 1st and 2nd April and the airlocks on the 5th, four 40-feet girders cantilevered out on the downstream face having been placed in position on the 3rd and 4th. 250 tons of kentledge was then loaded on the girders.

Air was let in on the 9th and an accumulation of silt was found, which had to be cleared.

The practice had been to let the water in at the end of the 3rd shift *i.e.*, at 3·00 hours and restart the compressors at 7·00 hours, but the inrush of water was bringing in silt; hence from the 21st April onwards the compressor was run continuously.

After the removal of the silt, undercutting of the centre bar and re-entrant angles in the upstream chamber commenced. Two inches of movement was obtained reducing the longitudinal tilt to 6·44 feet. The tilt was reduced to 5·32 feet on the 27th April. There was again an inrush of silt which took till the morning of the 30th to clear. From this date steady and increasing progress was obtained. The tilt was 2·14 feet on the 5th. 70 tons of kent edge were removed on this date, resulting in a slowing down of the movement of the well. Further removal of kentledge was therefore stopped. The longitudinal tilt was reduced to ·08 foot by the 9th morning and to 0·00 on the 9th evening, the side tilt having been reduced to ·54 foot from the original tilt of 1·06 feet.

Work was stopped for the season on this date due to the strong current in the river, and all the plant removed from the well by the 14th of May. The cutting edge was at R. L. 641·3.

Well "*F*"—This well had been sunk to R. L. 650·28 in the 1928-29 working season. It had thus been left embedded about 22 feet. After the floods of August 1929 however it was found to have acquired a longitudinal tilt of 11·5 feet and a cross tilt of 2·8 inches, the upstream cutting edge having gone down to R. L. 639·7.

Special methods were adopted for this well owing to the excessive tilt. As a preliminary, dredging outside the downstream face was carried out as vigorously as possible. This face was embedded 16 feet. This was all dredged and cleared to 3 feet below the cutting edge, so that a diver could pass into the working chamber under the cutting edge from the outsid . In order to overcome the resisting moment about the centre bar righting moments were obtained by—

(*a*) application of cantilevered kentledge ;
(*b*) suspension of crates containing pig iron from the downstream faces ;
(*c*) application of 100 ton jacks inside the upstream working chamber.

The diagram on Plate XVI shows a graph of the moments. Plate XVII shows the design and method of application of the crates. Photo No. 7 gives a view of the well loaded and airlocks in position.

Outside dredging was done with an electric hoist and gantry reinforced later by two Scotch derricks fitted up on a 150-ton barge. Dredging was carried on till the 17th March. By the 1st April the pneumatic plant was erected, girders placed and loaded and crates slung in position. The crates were loaded to 80 tons each and the girder kentledge was 150 tons.

By the 11th April the jacks were brought into action, and removal of silt and undercutting of the centre bar commenced. Between the 27th March and the 3rd April the tilt had been reduced from 11·54 feet to 11·1 feet and from the 12th to 15th April further progress to 10·5 feet was obtained. Progress was then held up for three days by a large boulder under the Mari cutting edge in the downstream well. After this was removed steady but slow progress was made till the 27th when the tilt had been bought down to 9·3 feet.

During April there had been three freshets which had brought down a large quantity of silt into the excavation which had been dredged out round the well. This silt blew into the working chamber, and its continuous removal retarded progress. After the third freshet on the night of the 26th-27th April, the excavation at the downstream end of the well, which had been made to R. L. 648 was found to be filled up to R. L. 660. The crates were therefore more than half buried and ceased to function. Unavailing efforts to get further movement were continued till the 3rd May, when work was stopped for the season, the level of the cutting edge being R. L. 649·50 downstream and R. L. 640·20 upstream.

Protection of Wells.—Additional precaution against scour was taken by protecting the wells with carefully laid pitching :—

Well "A" 1,31,000. cubic feet pitching stone. This large quantity is due to the fact that surplus stone was available from the abandoned protection bund.

,, "B" 16,000 cubic feet.

,, "C" 24,000 cubic feet.

,, "D" 17,000 cubic feet.

,, "E" 15,000 cubic feet.

,, "F" 7,000 cubic feet.

,, "H" 12,000 cubic feet in addition to 47 7-ton broken concrete blocks.

,, "I" 11,000 cubic feet.

The pitching stone on the slopes of the protection bund was removed and as much stone from the apron as could be taken out easily. The earth in the protection bank was left to be removed by the floods.

Position at end of Season.—The position of the works at the end of the 1929-30 working season was as follows :—

Well "A."—Sunk and plugged at R. L. 655·72 (1928-29 working season).

„ "B."—Sunk and plugged at R. L. 647·75 (1928-29 working season).

„ "C."—Sunk and plugged at R. L. 643·14 (1928-29 working season).

„ "D."—Sunk and plugged at R. L. 641·04 (1928-29 working season).

„ "E."—Completely righted and sunk to R. L. 641·3.

„ "F."—Was righted 2·2 feet—Tilt remaining 9·3 feet. Cutting edge downstream R. L. 649·50 upstream R. L. 640·20.

„ "G."—Not commenced.

„ "H."—Completely righted and sunk to R. L. 614·53 and the botton plug put in.

„ "I."—Sunk and plugged at R. L. 619·15.

„ "K."—Sunk and plugged at R. L. 644·68.

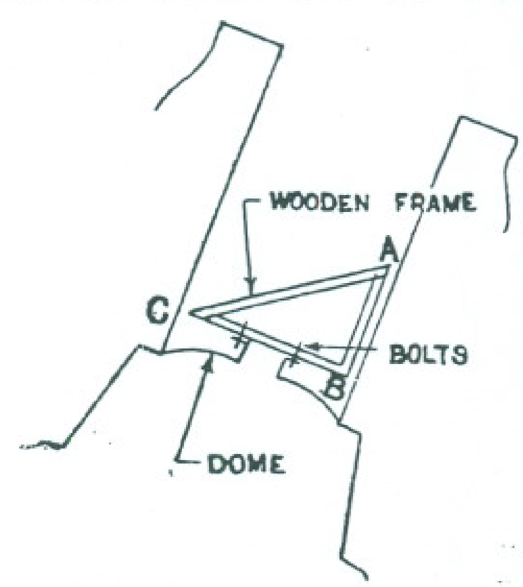
It was unfortunate that the season was one of high river levels. During the last two months the level was on an average about 4 feet higher than normal with a very strong current. An endeavour was made to right all three wells in one season, though it was realised that there was an element of doubt about well "F." But sufficient movement was obtained on the latter to make it reasonably certain that the remaining tilt could be removed.

Notes of Special Devices.

Lowering domes in Tilted Wells.—Slight trouble was experienced with these on "H" as the dome seatings were inclined due to the tilt and the diver had difficulty in getting the domes to sit properly.

A wooden triangular frame was therefore devised (Fig. No. 9).

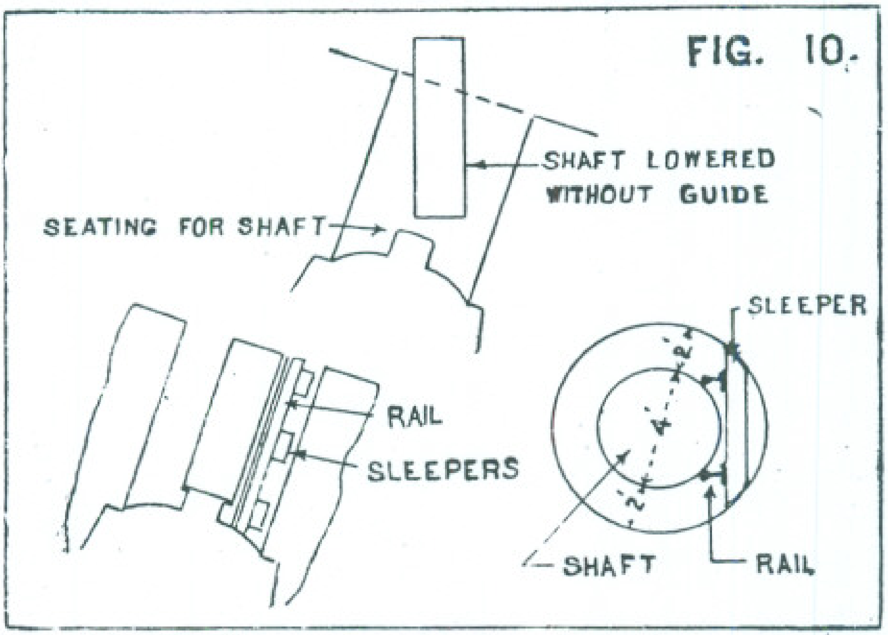
FIG. 9.



This fitted on to the dome as shown in the sketch and was attached to it by two bolts. When lowered the side AB slides along the face of the well, BC being at right angles to it and parallel to the dome seating, the dome is automatically guided on to its seat. A little manipulation by the diver would get it right. The device enabled the dome to be lowered into position very expeditiously.

Lowering Shafts in Titled Wells.—The well being tilted the shaft when lowered would not have got a true seating on the dome but would have gone down as shown in the sketch, Fig. 10.

FIG. 10.

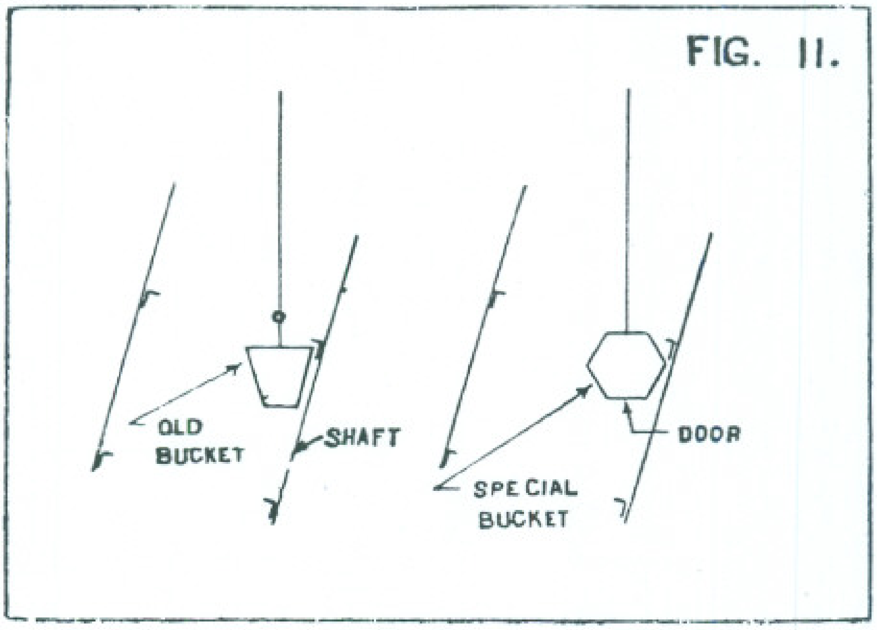


A special rail slipway was therefore devised, to ensure the shaft being guided to its seating on the dome (See Fig. 10).

Any slight error was corrected by the diver.

Hoisting in inclined Shafts.—It was out of the question to use ordinary buckets for hoisting as they would catch against the angle rings on the inclined shaft. A bucket as sketched below (Fig. 11, was devised and used.

FIG. 11.



The bulge in the middle and the sloping sides ensured an unobstructed path for the bucket. It was a success for shingle. It did not work well with silt however, as there was a tendency for the silt to consolidate by the shaking while being hoisted and it would refuse to come out through the small door at the bottom. In such conditions therefore the silt was hoisted up in bags, eight or nine bags containing about 5 cubic feet being carried up at a time, a trip taking 4 to 5 minutes.

Material for Concrete Work.

Sand.—The sand used for concrete work was obtained from the Nihal Shah Nullah adjacent to the bridge site. It is a well graded sand and gave excellent results. The mechanical analysis is shown below :—

	Per cent.
Passed through 16 meshes to the sq. in. but retained on 64 meshes per sq. in.	29·2
Passed through 64 meshes to the sq. in. but retained on 144 meshes per sq. in.	7·8
Passed through 144 meshes to the sq. in. but retained on 196 meshes per sq. in.	5·0
Passed through 196 meshes to the sq. in. but retained on 625 meshes per sq. in.	6·4
Passed through 625 meshes to the sq. in. but retained on 900 meshes per sq. in.	5·6
Passed through 900 meshes to the sq. in. but retained on 2,500 meshes per sq. in.	14·4
Passed through 2,500 meshes to the sq. in. but retained on 6,400 meshes per sq. in.	17·1
Passed through 6,400 meshes per sq. in.	14·5
	100·0

Void tests showed an average of 24 per cent.

Cement.—All cement used was from the Punjab Portland Cement Factory at Wah.

Mortar.—This was tested daily and hundreds of tests made. The following are average results with 1 : 3 mortar :—

Strength after 7 days with sand thoroughly washed	350—440	.. Lbs. per sq. inch.
,, ,, 28 ,, ,, ,, ,,	450—550	

This was very satisfactory, the B. S. S. minimum strength of 1 : 3 mortar being 325 lbs. per square inch after 7 days and 356 lbs. per square inch after 28 days.

Concrete.—The stone used for concrete was broken from lime stone boulders obtained from the adjacent hills.

Dredgers.

The dredgers used for open sinking and for dredging round the wells were 25 cubic feet. Priestman "Hook On" Foundry Type for sand and 25 cubic feet Priestman Whole Tine Type for the boulder stratum. As is indicated in the paper open dredging was slow and unsatisfactory, and the efficiency low. In the initial stages dredgers would come up full, but later on in the boulder stratum would bring up only three or four cubic feet of material and sometimes only a handful or nothing at all. This emphasises the necessity of pneumatic sinking for a work of this nature.

Working of Pneumatic Plant, 1929-30.

As stated before a pneumatic sinking set was obtained towards the end of the 1928-29 working season. This was erected on a 150-ton barge between the 10th June and 15th August 1929. A second set was obtained in December and similarly erected by the 8th April 1930.

Each set consists of two boilers having a working pressure of 150 lbs. per square inch, two Murray Workman air compressors each having a capacity of 1,250 cubic feet of free air per minute, two air receivers each capable of storing 2,000 cubic feet of air and two airlocks and two air domes with the necessary lengths of 4 feet dia. shafting. The layout of the plant on the barge is shown in Fig. 12 below and Photo No. 8.

LAYOUT OF PNEUMATIC PLANT ON A 150-TON BARGE.

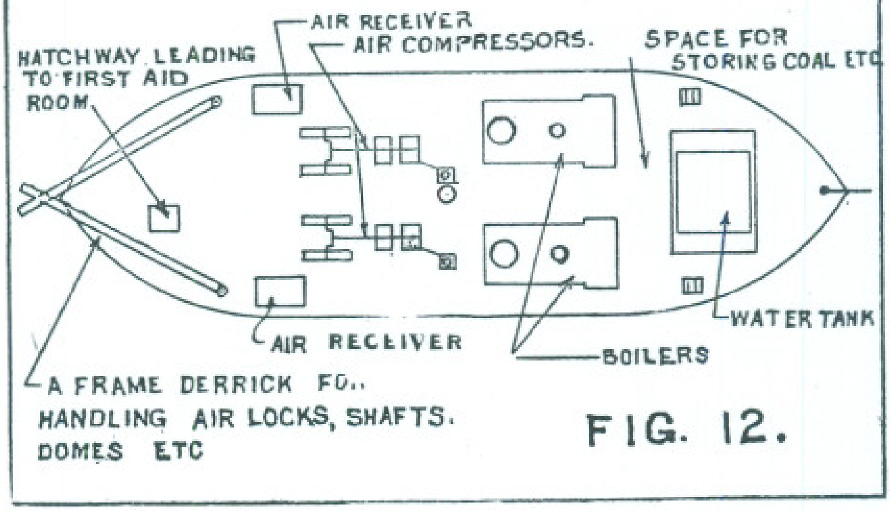


FIG. 12.

The steam from the two boilers is led to a common pipe from which branch off the steam pipes to the two compressors. Each compressor can therefore be run from either of the boilers. Ordinarily only one boiler and one compressor is kept working, the other set being a standby, which would come into use in case of a breakdown or to enable minor repairs or boiler washouts to be carried out.

The air receivers are also connected to the discharge pipes from both the air compressors so that both are in commission simultaneously with either compressor working. 4 inches pipes lead from the receivers to a 5″ main pipe from which again 4 inch armoured flexible rubber hoses lead to the inlet valve in each airlock.

The quantity of air going into the working chamber and slight variations of pressure are regulated by an inlet and a discharge valve on each airlock. These are located outside the lock instead of inside as designed by the Consulting Engineers, as the latter method would require the presence of an intelligent man in each airlock in each shift whereas with outside controls only two intelligent men working in alternate day and night shifts are required. It also enables the engineer-in-charge who spends most of his time outside to keep an eye on the valves and to cope with any emergency himself.

The air from the receivers is at a higher temperature than the atmosphere. An arrangement had therefore been made to keep a constant stream of water dripping on both receivers and also to keep a jet of water playing on the air pipes leading to the airlocks.

In the hot weather water was also kept dripping on to the airlocks from a perforated pipe ring. This kept the temperature of the walls of the airlocks down and prevented them getting unbearably hot.

Work was usually done in 3 shifts of 6 hours each, inclusive of the periods of compression and decompression. The interval between the end of the third shift and the beginning of the first was utilised for minor repairs. The periods allowed for compression, work and decompression followed the chart shown in Plate XVIII as far as practicable.

The labour in each shift consisted of :—

1 Hoister (working the electric hoist), in each airlock.

2 coolies for tipping bucket into spoil chute.

12 coolies for excavation in each working chamber.

1 Jamadar.

1 Supervisor or mistry.

The spoil was hoisted up from each shaft in a bucket of 5 cubic feet capacity by means of an electric winch fixed at the top of the airlock. On reaching the top the door of the spoil chute would be opened and the contents of the bucket tipped into it. The bucket would then be lowered, then filled up with spoil by the men in the working chamber. The average period for a whole shift for a bucket-trip was about 6 minutes. Valuable time, however, never less than 1 minute was spent in filling up the bucket after being lowered. This time could have been cut down to not more than 20 seconds, by providing a spring hook for the bucket and having a spare bucket in each working chamber which would be filled while the other one was going up and thus the delay caused in filling the bucket would be eliminated, the amount of sinking depending on the quantity of stuff taken away, *i.e.*, on the rapidity of the hoisting. Any time saved under this head means a considerable economy in the expenses per foot of sinking.

The soil encountered was almost wholly sand, shingle and boulders. These latter when too big to be taken out through the spoil chute were blasted usually at the end of the shift after letting the air out, but occasionally even with the air on, the men all going up to the airlock during the operation. With this latter method, however, the air inside the working chamber would be very smoky for a few minutes after the explosion. The fumes would be got rid of by opening the discharge valve for a while.

There would generally be little or no movement of the well while the air was on. It would sink only when the air was let out and occasionally charges of Gelignite would be necessary to cause the well to sink.

Progress on fair working days ranged between 4″ and 9″, the maximum being 2′-0″.

The minimum pressure worked at was 15 lbs. per square inch and the maximum $31\frac{1}{2}$ lbs. per square inch corresponding to a depth of 72 feet of water. The revolutions per minute of the compressor at these pressures were about 40 r. p. m. and 70 r. p. m. respectively.

When blasting of large boulders was necessary it was done invariably in water when the air had been let off. On only three occasions did blasting take place under pressure, when the men were removed to the airlock. They were able to return to the working chamber within a few minutes.

It was customary to fire a charge of 1 or 2 lbs. of gelignite after the end of the third shift. The charge would be placed where considered most necessary and the men brought out, decompressed and removed from the well. Air would be let out and the charge detonated electrically in water. The effect of the day's work was generally obtained after these charges, the well settling down with the shock.

As previously mentioned only one boiler was kept working ordinarily. It was however kept lit up for the whole of the 24 hours and the coal consumption was therefore practically independent of the number of shifts working.

Up to 20 lbs. per square inch pressure, about 5 tons of coal was used daily. At pressure of 30 lbs. per square inch the coal consumption rose to between 7 and 8 tons per day.

Work would have been speeded up had the pneumatic plant been of more modern design, which provides separate locks for men and material. With the plant in use work had to stop for a considerable period during the change of shifts.

This paper is accompanied by eighteen Plates and eight photographs. An appendix is added giving a list of plant used on the construction.

APPENDIX.

List of Plant used during Construction.

General Plant.

Locomotive	.. 1 No. six coupled goods type, 5′-6″ gauge.
Trucks	.. 10 low sided, 5 open rail carrying.
Motor Launch	.. 1 No. 30′ long by 6′ beam by 3′-6″ draft.
Country Boats	.. 15 No. average 25 tons burden.
Cranes	.. 2 No. steam travelling, slewing and derricking, 5′-6″ gauge, 4 ton capacity at 35′ radius.
	2 No. steam travelling, slewing and derricking 5′-6″ gauge, 7 ton capacity at 20′ radius.
	1 No. steam travelling, slewing and derricking 4′-8½″ gauge, 5 ton capacity (approx.).
Stone Crushers	.. 2 No. 16″ by 10″ jaw.
Concrete Mixers	.. 2 No. Milwaukee mixers, 6 c.ft. capacity with kerosene engine on same base.
	1 No. Milwaukee mixer, 12 c. ft. capacity.
	2 No. Rex 7-S mixers, ¼ c. yd. capacity, with petrol motor on same base.
	2 No. small Jaeger mixers.
	1 No. Stothert & Pitt mixer, about ¼ c. yd. capacity, belt driven.
Pumping Set	.. 1 No. 5 H. P. Petter engine driving centrifugal pump, 2″ delivery. (For sand and ballast washing).
Pumping Set	.. 1 No. 5 H. P. Petter engine driving geared double acting pump. (For general water supply).
Worthington Pumps	.. 6 No. Size $3'' \times 1\frac{3}{4}'' \times 3,''$ $1\frac{1}{4}''$ suction, 1″ delivery.
Hand Pumps	.. 2 No. " Contractors " pattern.
Crab Winches	.. 3 No. 50 cwt. capacity.
Differential Pullies	.. 2 No. 15 ton.
	5 No. 10 ton.
Pulley Blocks	.. 25 No. of sizes.
Screw Jacks	.. 5 No. 15 ton.
Oxy-Acetylene Welding Set	1 No.
⅞″ Wire Rope	.. 5,000 l. ft.
Steam Portable Engines	.. 3 No. 12 N. H. P. (=about 30 B. H. P.)

Well Sinking Plant.

Grabs	.. 9 No. Priestman whole tine, single chain, ring discharge type 20 c. ft.
	3 No. Priestman Foundry type, 15 c. ft.
Steam Hoists	.. 1 No. Double cylinder, double drum, dia. 3′-6″ with boiler 14 N.H.P. W.P. 105 lb. per sq. in.
	1 No. Double cylinder, single drum, dia. 4′-0″.
	1 No. Double cylinder, single drum, dia. 3′-0″.
Electric Winches	.. 4 No. single drum, 20″ dia., 24″ width, mounted on trolly for moving along gantry. Driven by 220 volt. D. C. motor, 6¼ B.H.P., 440 r.p.m., with suitable gantries for straddling wells.
Pulsometers	.. 3 No. Size 7, 5″ suction, 4″ delivery. 3 No. Size 8, 6″ suction, 5″ delivery.
Diving Sets	.. 4 No. (Helmets, dresses, pipes and double cylinder pumps).

Caisson Erection Plant.

Air Compressors	.. 2 No. Ingersoll Rand portable petrol driven compressors. Capacity 250 c. ft. of free air per minute compressed to 100 lb.
Rivetting Hammers	.. 6 No. Ingersoll Rand, size 8A.
Caulking Hammer	.. 1 No. do. do. size 2-S.
Rivet Cutter	.. 1 No. Consolidated Pneumatic Tool Co. Size 80-B.
Drilling Machines	.. 2 No. Capacity 1¼″ holes.
Camber Jacks	.. 12 No.

Pneumatic Sinking Plant.

Two sets as detailed below, each mounted on a 150 ton steel barge.

Air Locks	.. 2 No. 7′-0″ dia. by 7′-0″ mean height.
Air Compressors	.. 2 No. Steam driven, slow speed straight line type, capacity 1,250 c. ft. per min. to 40 lbs. per sq. in.

Pneumatic Sinking Plant.—*concld.*

Boilers	.. 2 No. Old Locomotive boilers.
Air Receivers	.. 2 No. approx. 300 c. ft. capacity each.
Water Tanks	.. 3 No. 4′×4′×4′. (For feed and cooling water).
Lighting Set	.. 1 No. 5 B.H.P. Petter engine and dynamo. (For use as emergency lighting set when main supply fails).
Worthington Pumps	.. 2 No. $1\frac{1}{4}''$ suction, 1″ delivery. (For pumping feed and cooling water).
Shear Legs	.. 1 No. Of two spars 50 ft. long by 14″—18″ dia. (For erecting and dismantling the air locks, etc).
Crab Winches	.. 3 No. 50 cwt. capacity. (For use with above, and for warping the barges).

Power House.

One Robey Crude Oil Engine 40/44, B.H.P.
One D.C. Generator, $22\frac{1}{2}$ k.w. 220/230 volt. 102 amps.

Workshop.

Motor, electric	.. 1 No. 6 B.H.P.
Engine	.. 1 No. 5 B.H.P. Petter. (Used to drive workshop when current not available).
Lathes	.. 1 No. 10″ centre, 12′ gap bed, sliding, surfacing and screw cutting.
	1 No. 6″ centre, 4′ bed, sliding, surfacing, and screw cutting.
Drilling Machines	.. 2 No. Vertical spindle, swinging table, belt driven, capacity $1\frac{1}{4}''$ and $1\frac{1}{2}''$ holes.
Shaping Machine	.. 1 No. Power driven.
Hack Saw Machine	.. 1 No. Power driven.
Grinder	.. 1 No. for two wheels 12″ dia.
Blower	.. 1 No. 8″ dia. outlet (for forges).
Shearing machine	.. 1 No. Hand Power, to cut $\frac{5}{8}''$ plate and punch $\frac{5}{8}''$ holes.
Circular Saw	.. 1 No. Capacity up to 2′ dia. saws.

List of Plates accompanying Paper.

List of Photos accompanying Paper.

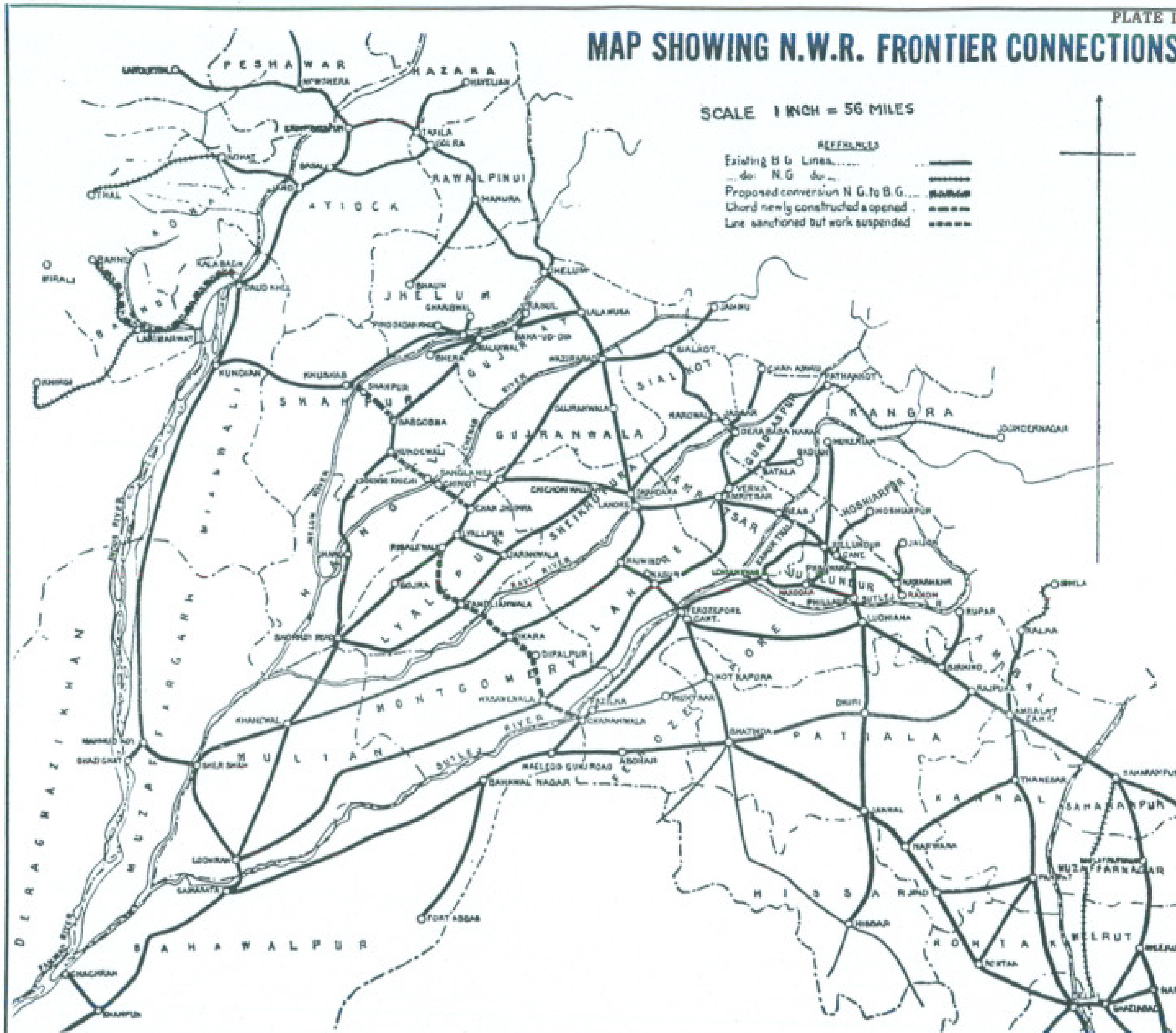
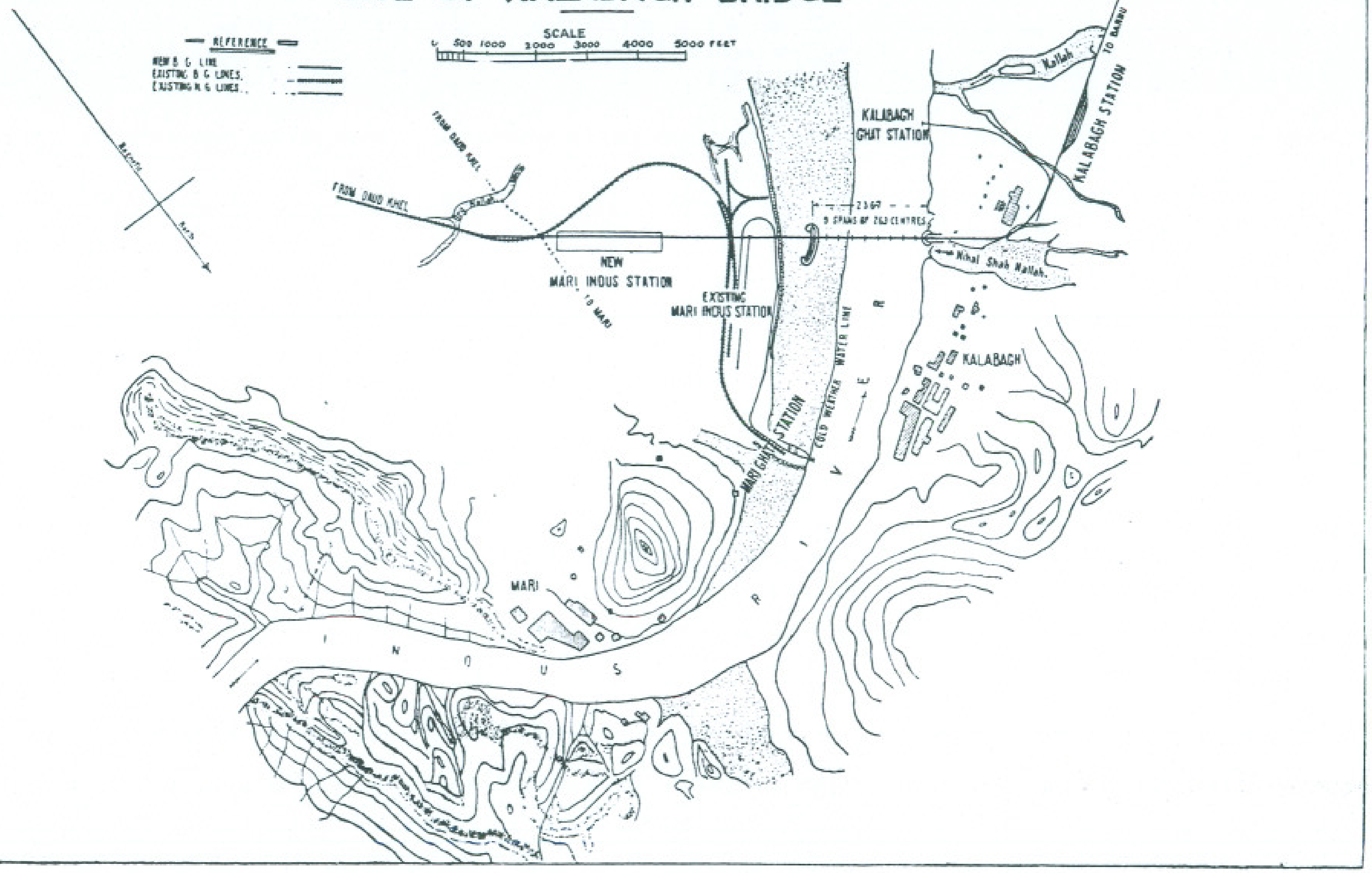
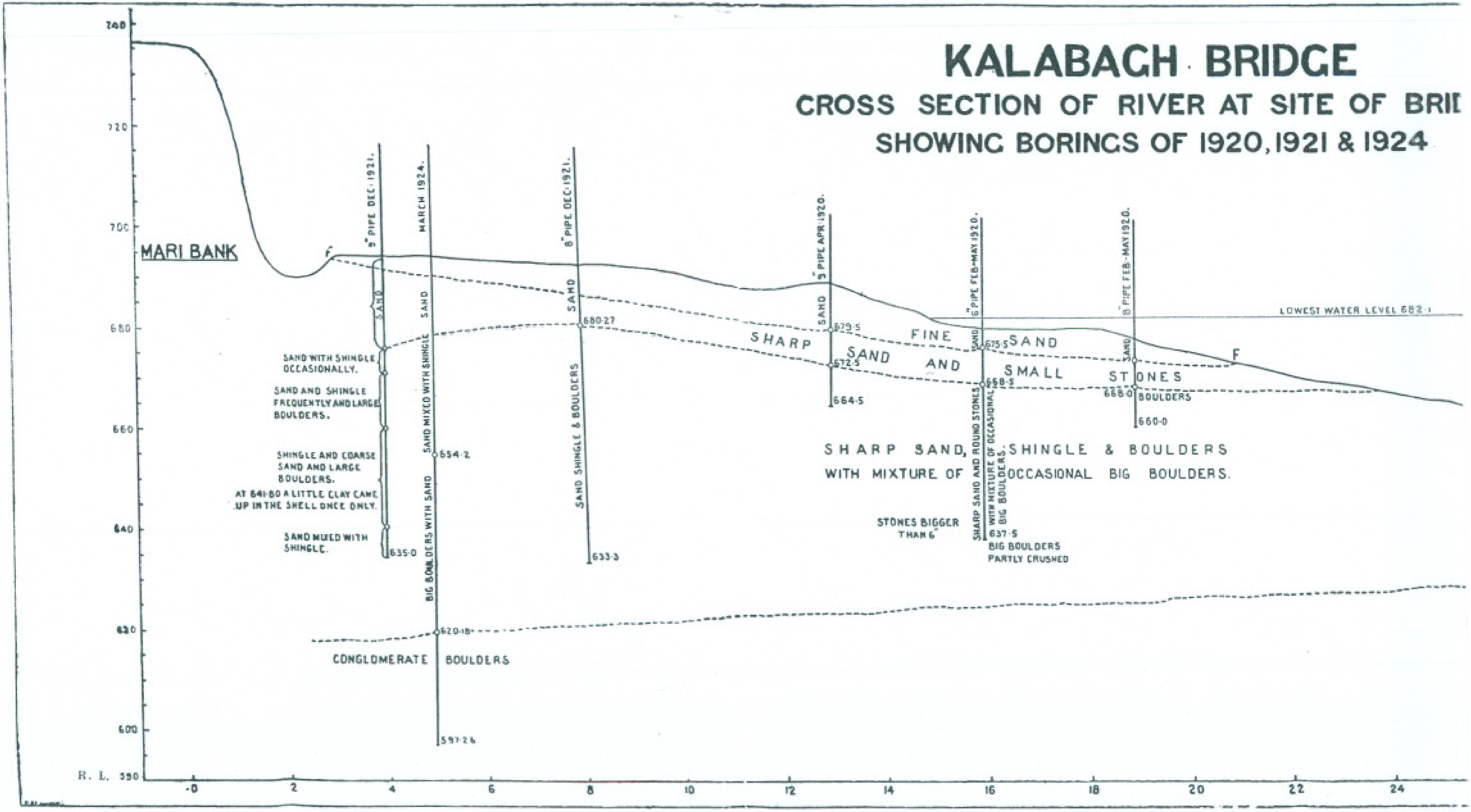


PLATE I.
MAP SHOWING N.W.R. FRONTIER CONNECTIONS
SCALE 1 INCH = 56 MILES
REFERENCES
Existing B G Lines
do N.G do
Proposed conversion N.G. to B.G.
Chord newly constructed & opened
Line sanctioned but work suspended
PESHAWAR
HAZARA
RAWALPINDI
ATTOCK
JHELUM
SHAHPUR
GUJRAT
SIALKOT
GUJRANWALA
KANGRA
GURDASPUR
HOSHIARPUR
AMRITSAR
LAHORE
JULLUNDUR
LYALLPUR
MONTGOMERY
MULTAN
MUZAFFARGARH
DERA GHAZI KHAN
BAHAWALPUR
FEROZEPORE
PATIALA
AMBALA
KARNAL
HISSAR
ROHTAK
SAHARANPUR
MUZAFFARNAGAR
MEERUT
SUTLEJ RIVER
RAVI RIVER
INDUS RIVER
JHELUM RIVER
CHENAB RIVER

PLATE II

SITE OF KALABAGH BRIDGE




KALABAGH BRIDGE
CROSS SECTION OF RIVER AT SITE OF BRI[D]
SHOWING BORINGS OF 1920, 1921 & 1924
MARI BANK
9" PIPE DEC: 1921.
MARCH 1924.
8" PIPE DEC: 1921.
9" PIPE APR: 1920.
6" PIPE FEB.-MAY 1920.
8" PIPE FEB.-MAY 1920.
LOWEST WATER LEVEL 682·1
SAND
SAND WITH SHINGLE OCCASIONALLY.
SAND AND SHINGLE FREQUENTLY AND LARGE BOULDERS.
SHINGLE AND COARSE SAND AND LARGE BOULDERS.
AT 641·80 A LITTLE CLAY CAME UP IN THE SHELL ONCE ONLY.
SAND MIXED WITH SHINGLE.
635·0
SAND MIXED WITH SHINGLE
654·2
BIG BOULDERS WITH SAND
620·18
597·26
680·27
SAND SHINGLE & BOULDERS
633·3
679·5
672·5
664·5
675·5
668·5
637·5
668·0
660·0
SHARP SAND AND SMALL STONES
FINE SAND
BOULDERS
SHARP SAND, SHINGLE & BOULDERS WITH MIXTURE OF OCCASIONAL BIG BOULDERS.
SHARP SAND AND ROUND STONES WITH MIXTURE OF OCCASIONAL BIG BOULDERS.
STONES BIGGER THAN 6"
BIG BOULDERS PARTLY CRUSHED
CONGLOMERATE BOULDERS
F
R. L.