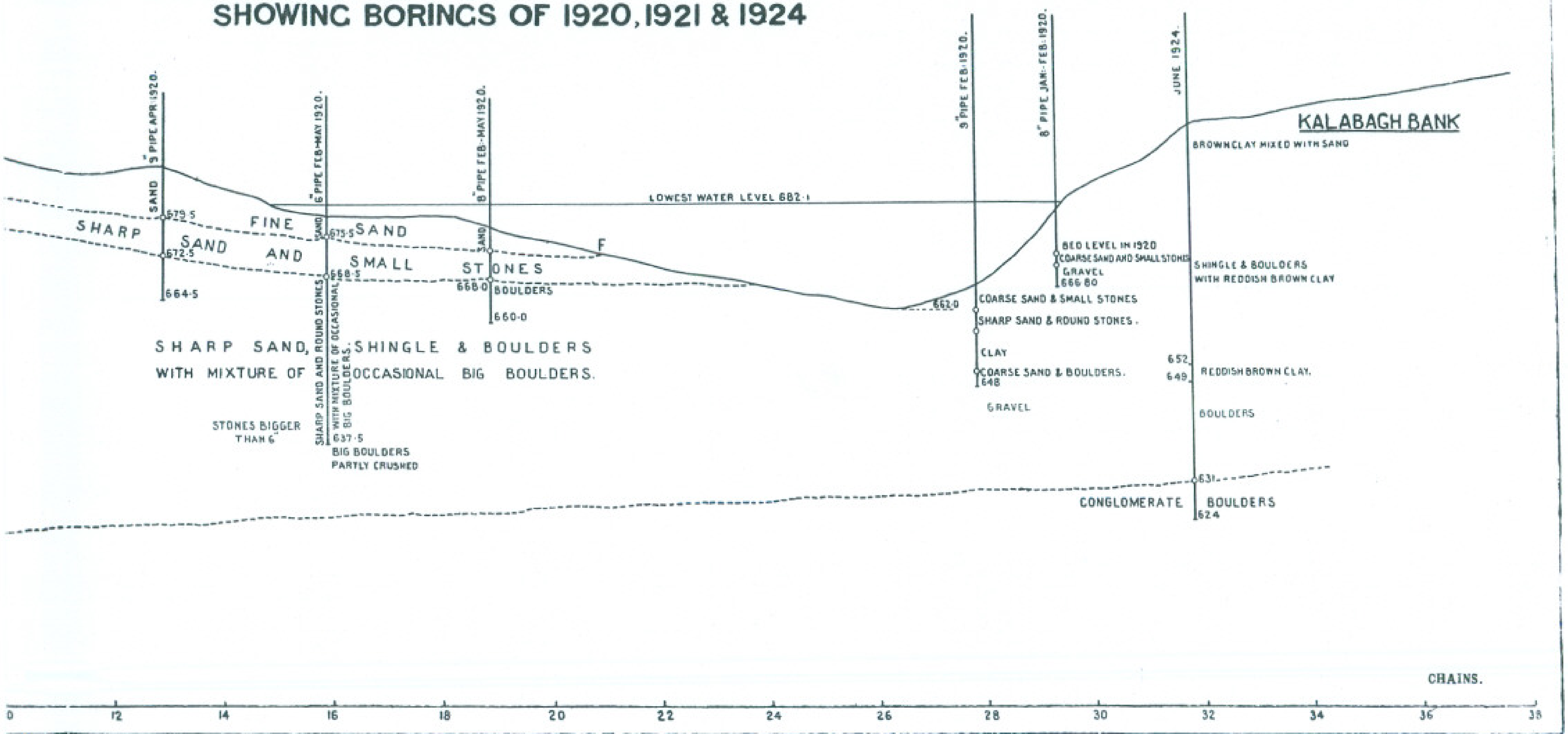
PLATE III.

KALABAGH BRIDGE

CROSS SECTION OF RIVER AT SITE OF BRIDGE

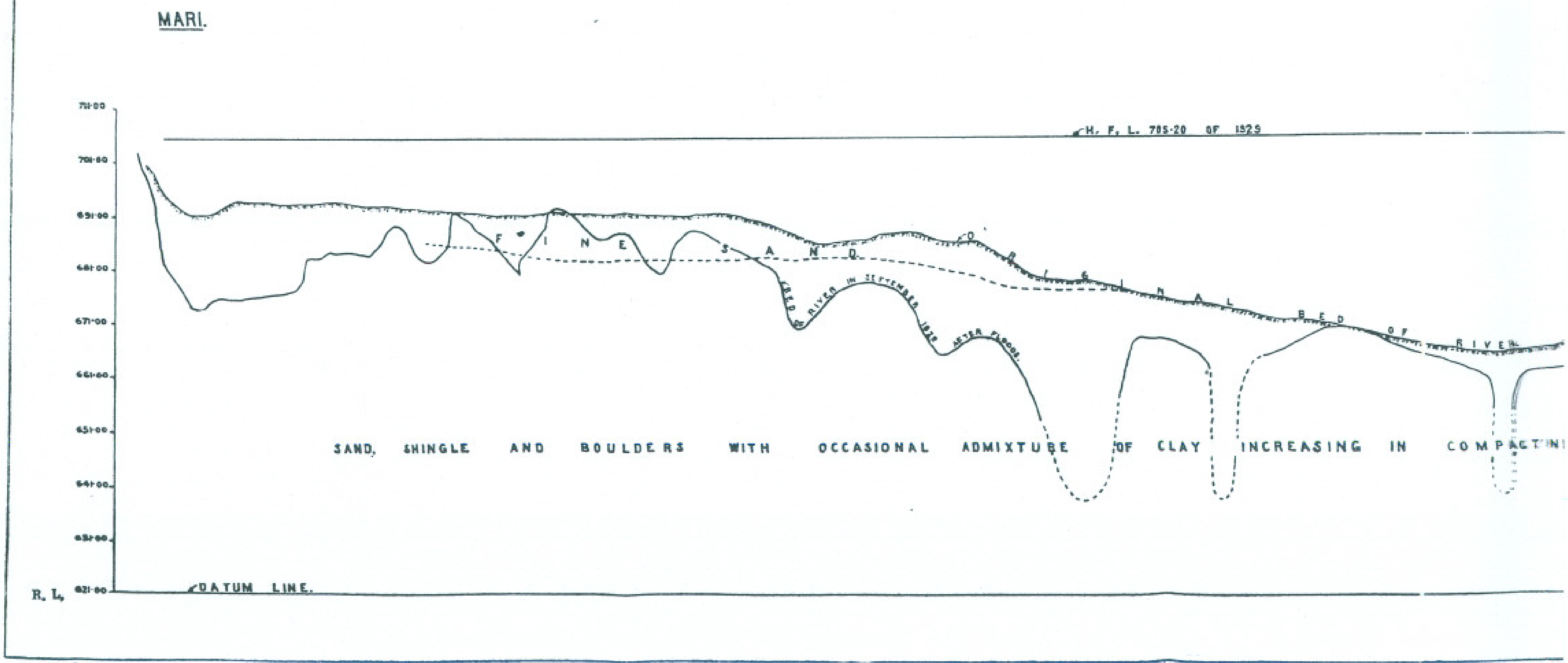
SHOWING BORINGS OF 1920, 1921 & 1924



KALABACH BRIDGE

DIAGRAM SHOWING ACTUAL SUBSOIL STRATA.

HORIZONTAL SCALE 228·57 FEET TO ONE INCH



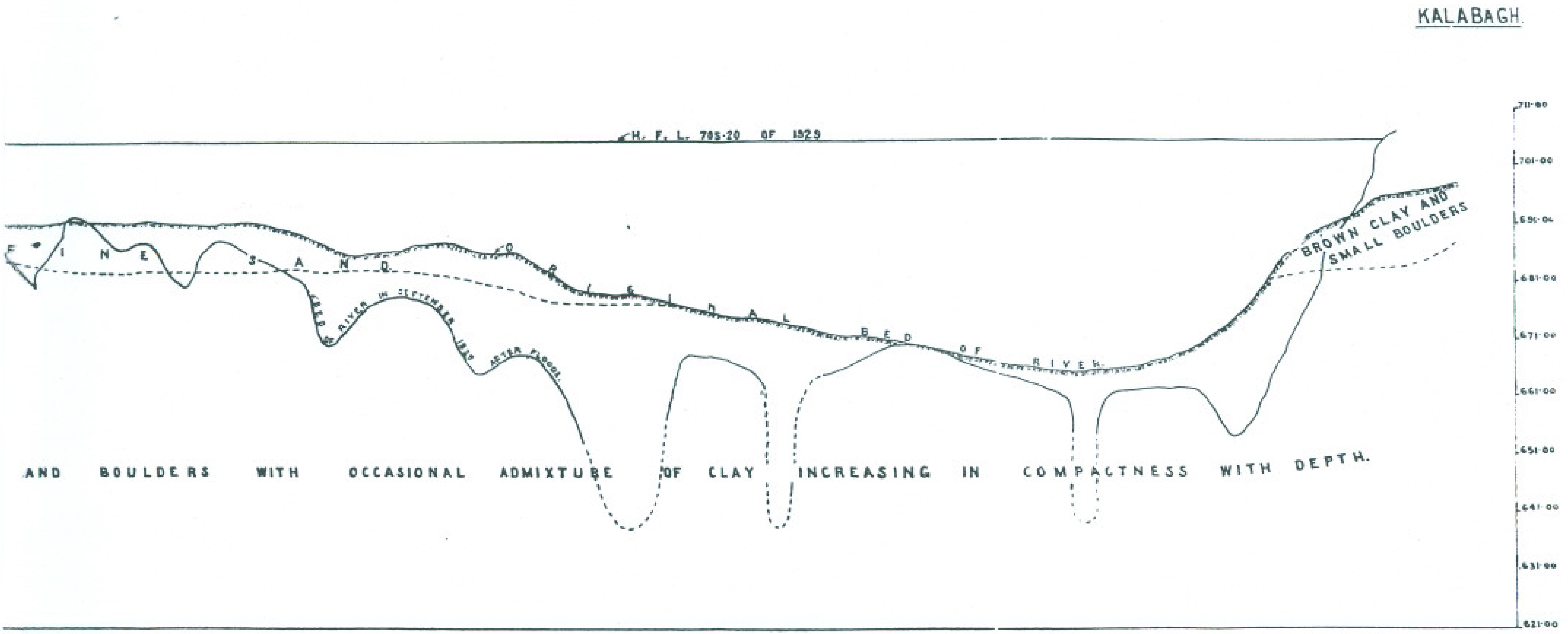
Traced by Ali Gohar

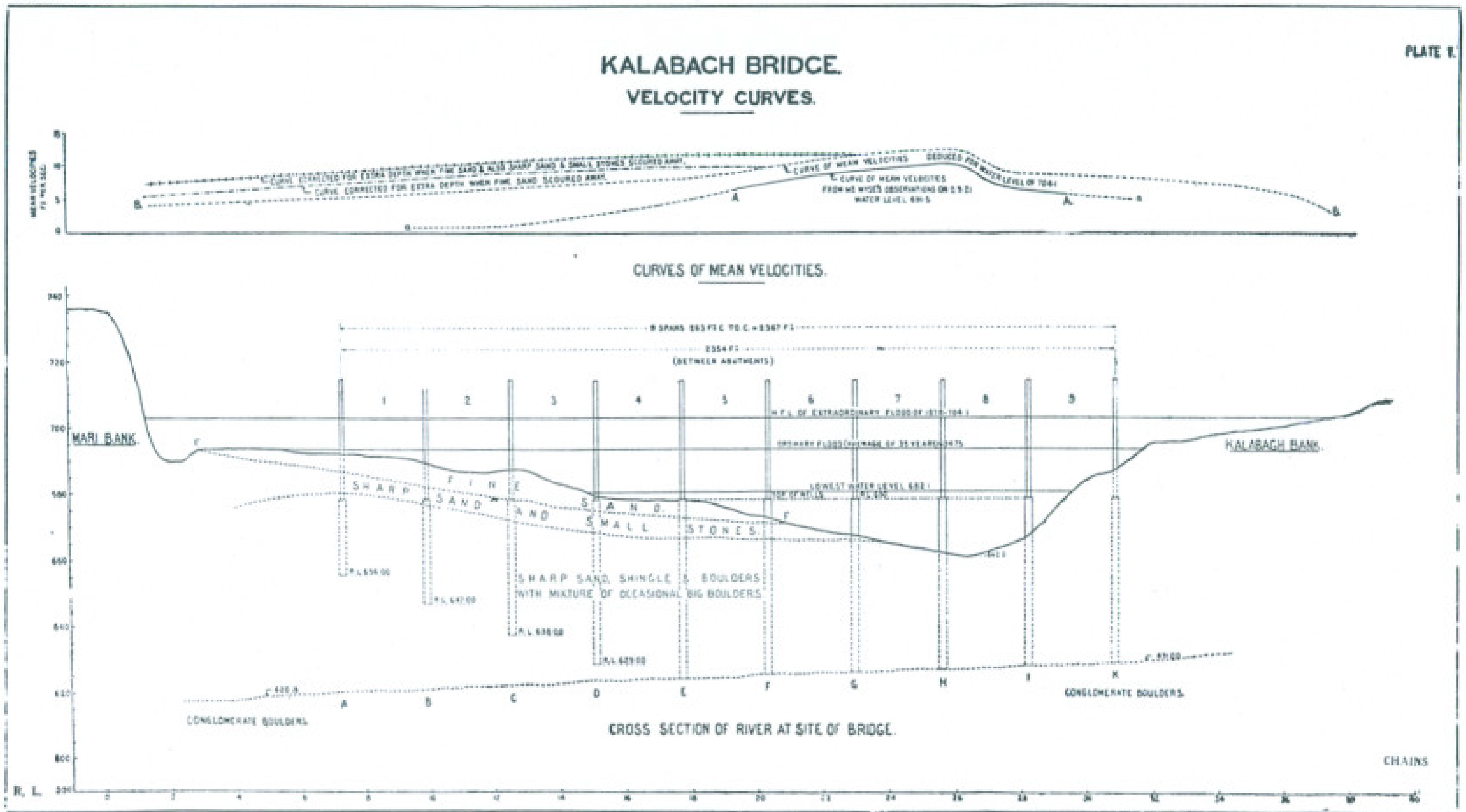
PLATE IV.

KALABACH BRIDCE

DIAGRAM SHOWING ACTUAL SUBSOIL STRATA.

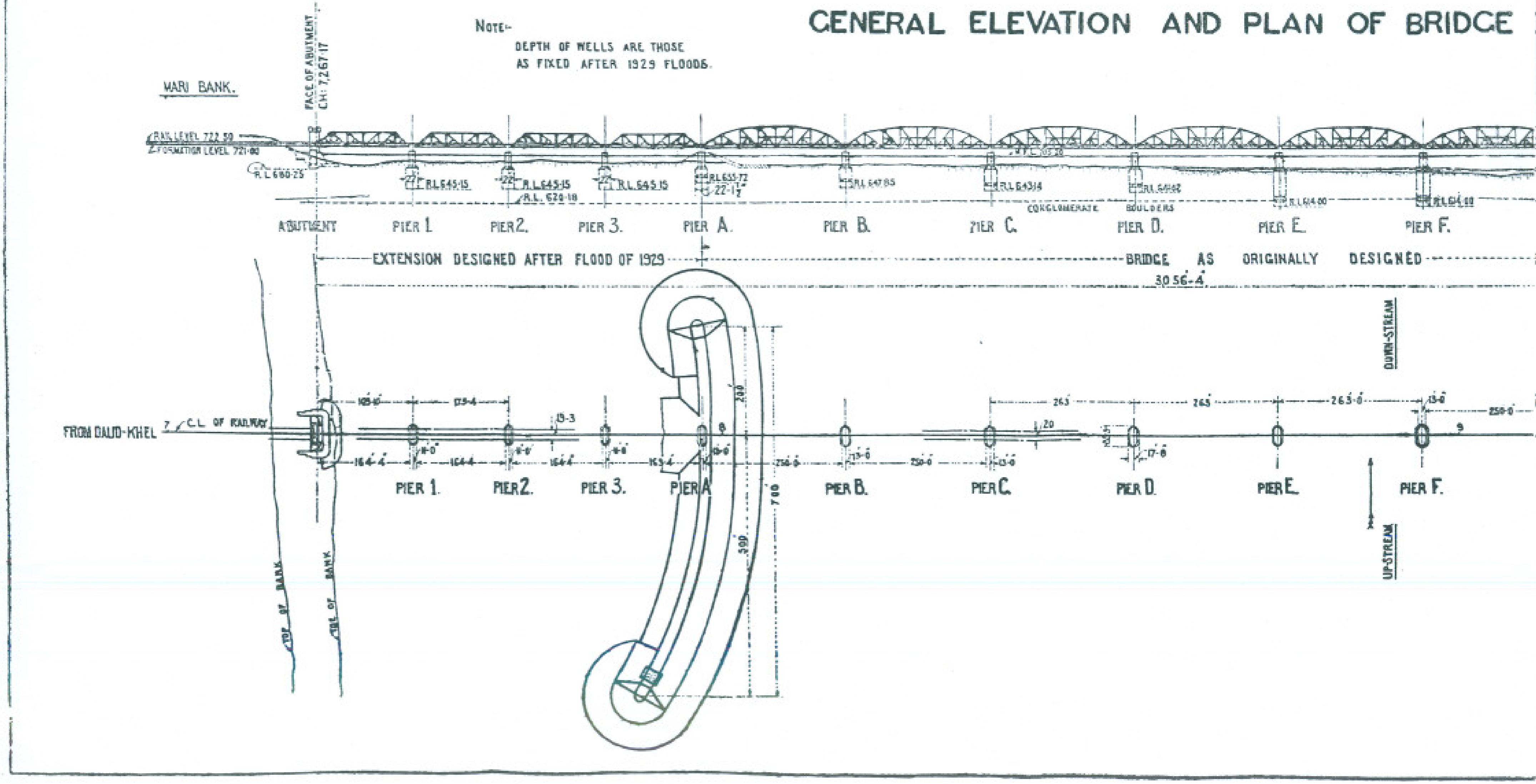
·ORIZONTAL SCALE 228·57 FEET TO ONE INCH




KALABACH BRIDGE.
VELOCITY CURVES.
MEAN VELOCITIES FT PER SEC.
CURVE CORRECTED FOR EXTRA DEPTH WHEN FINE SAND & ALSO SHARP SAND & SMALL STONES SCOURED AWAY.
CURVE CORRECTED FOR EXTRA DEPTH WHEN FINE SAND SCOURED AWAY.
CURVE OF MEAN VELOCITIES DEDUCED FOR WATER LEVEL OF 704·1
CURVE OF MEAN VELOCITIES FROM MR HYDE'S OBSERVATIONS ON 2.9.21 WATER LEVEL 691·5
CURVES OF MEAN VELOCITIES.
(BETWEEN ABUTMENTS)
H.F.L. OF EXTRAORDINARY FLOOD OF 1878 704·1
ORDINARY FLOODS (AVERAGE OF 35 YEARS)
LOWEST WATER LEVEL 682·1
MARI BANK.
KALABACH BANK.
SHARP FINE SAND
SHARP SAND AND SMALL STONES.
SHARP SAND, SHINGLE & BOULDERS WITH MIXTURE OF OCCASIONAL BIG BOULDERS
CONGLOMERATE BOULDERS.
CROSS SECTION OF RIVER AT SITE OF BRIDGE.
CHAINS
R. L.

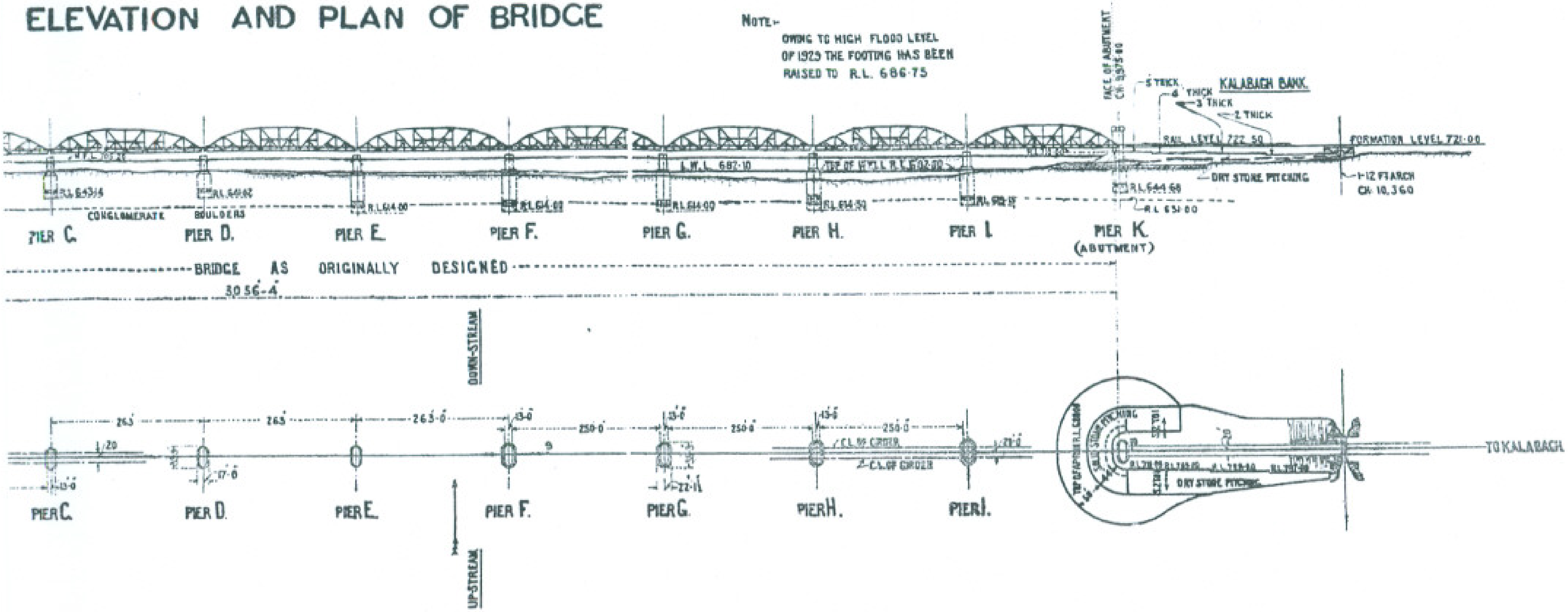
KALABACH BRIDGE

GENERAL ELEVATION AND PLAN OF BRIDGE



KALABACH BRIDGE

ELEVATION AND PLAN OF BRIDGE



KALABACH BRIDGE

PROTECTION BUND MARI ABUTMENT

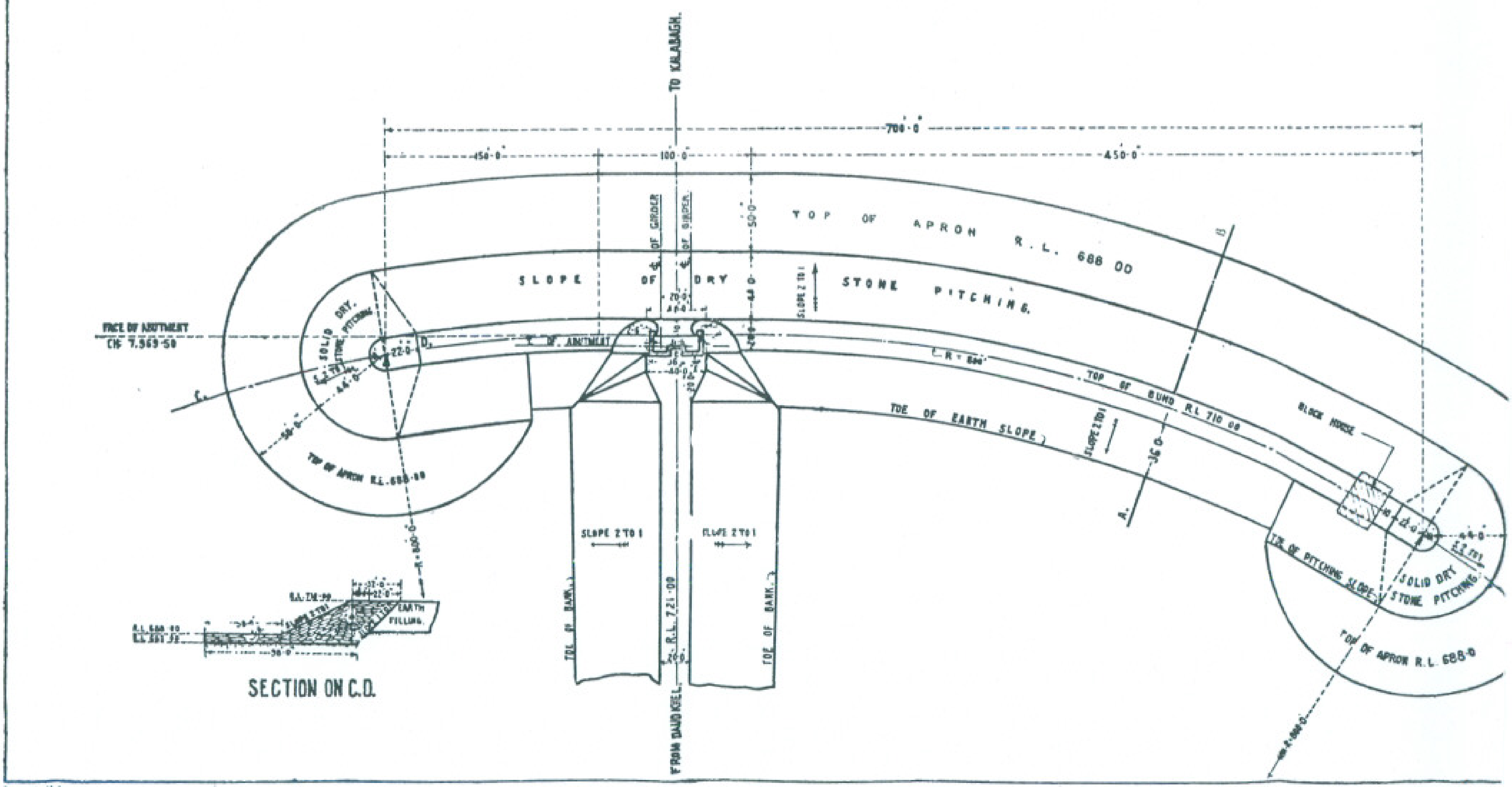
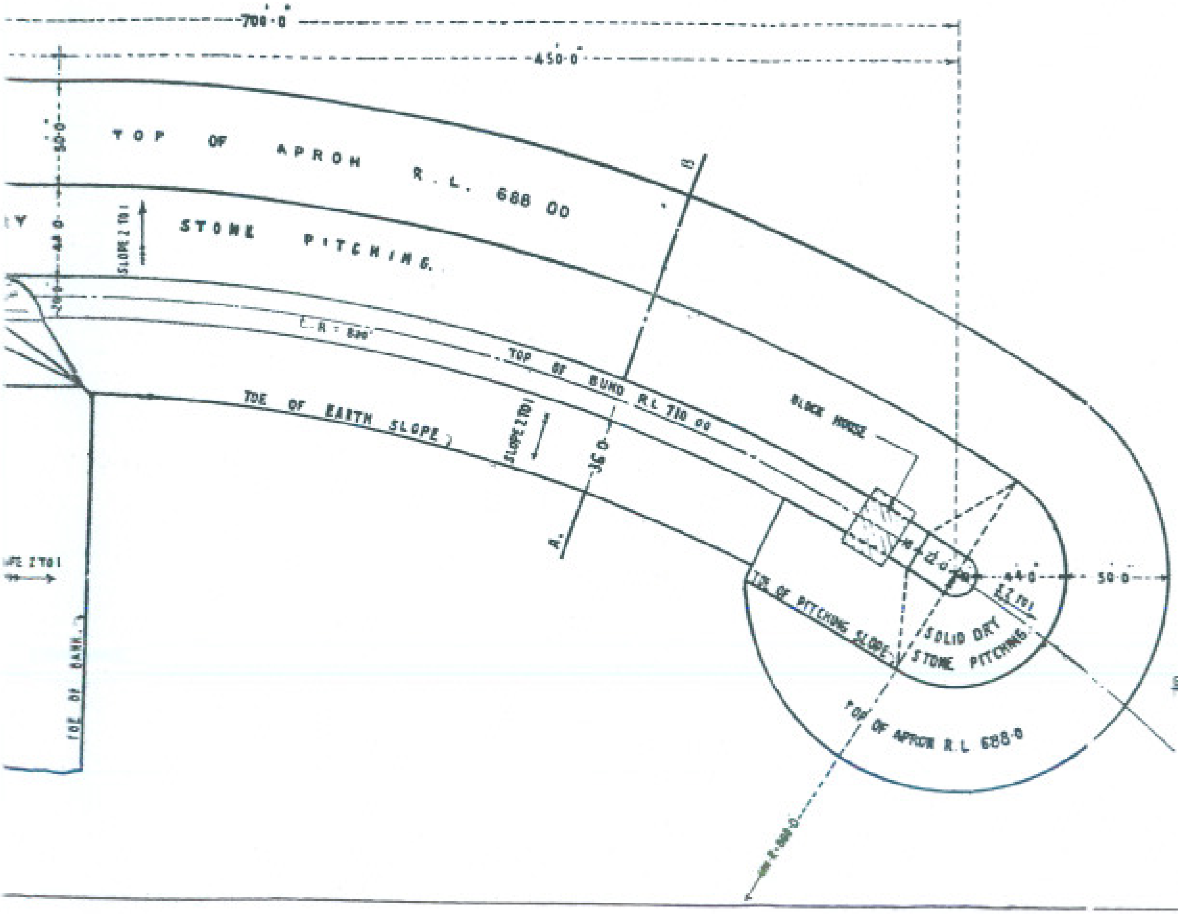


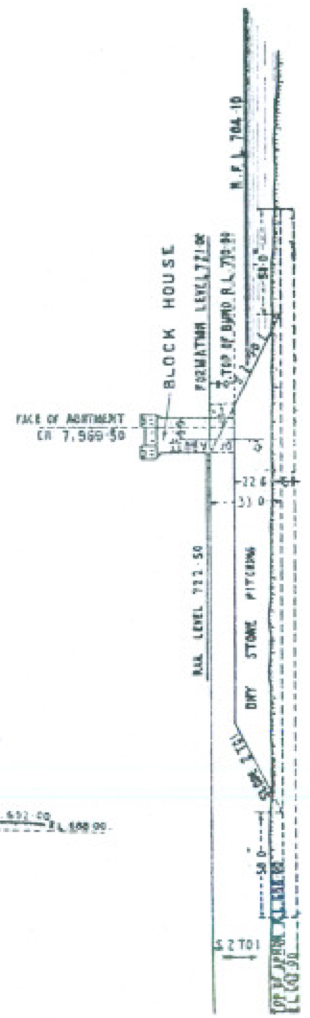
PLATE VII

KALABACH BRIDGE

PROTECTION BUND MARI ABUTMENT



SECTION ON A.B.

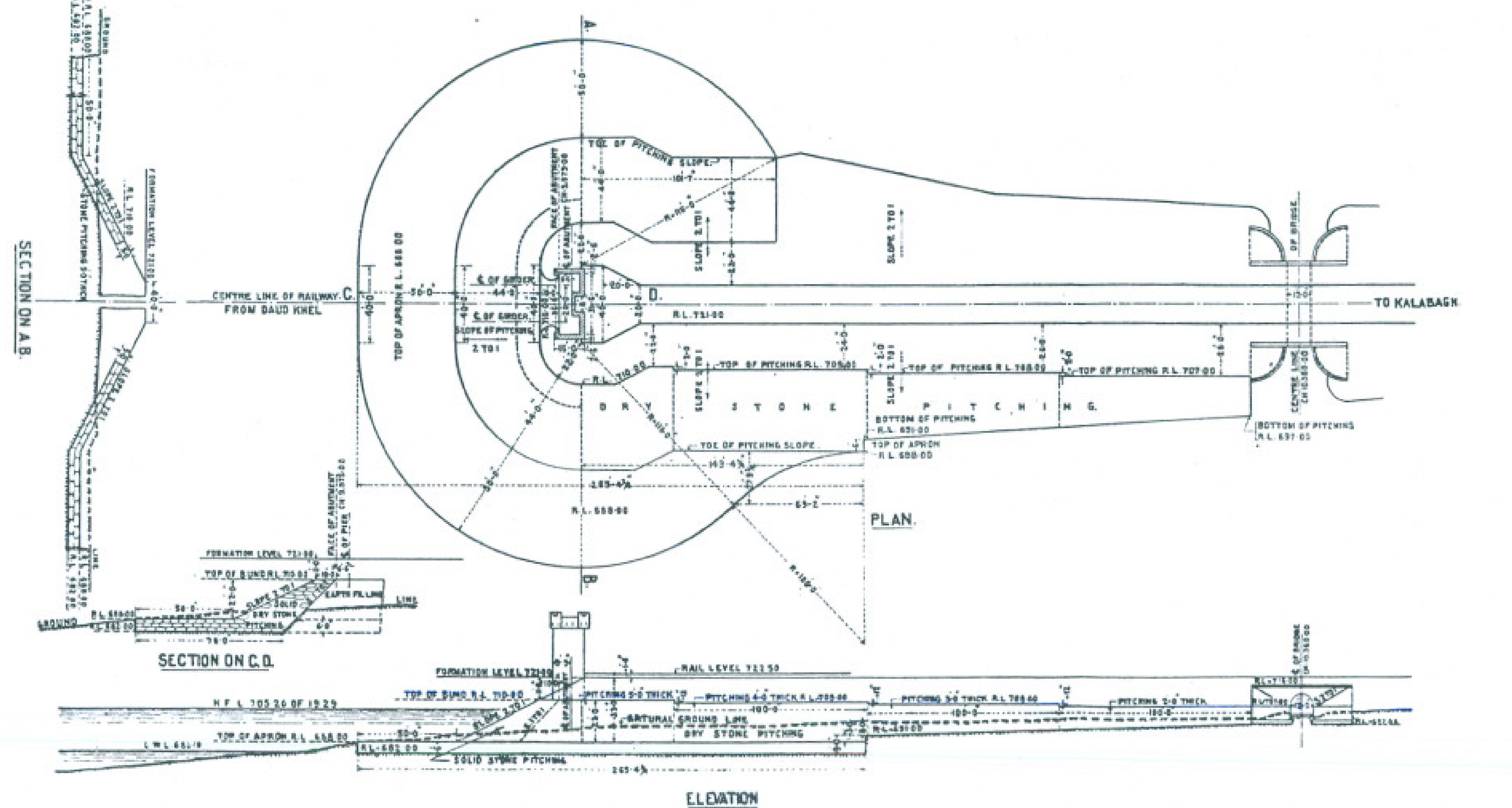


SIDE ELEVATION

PLATE VIII

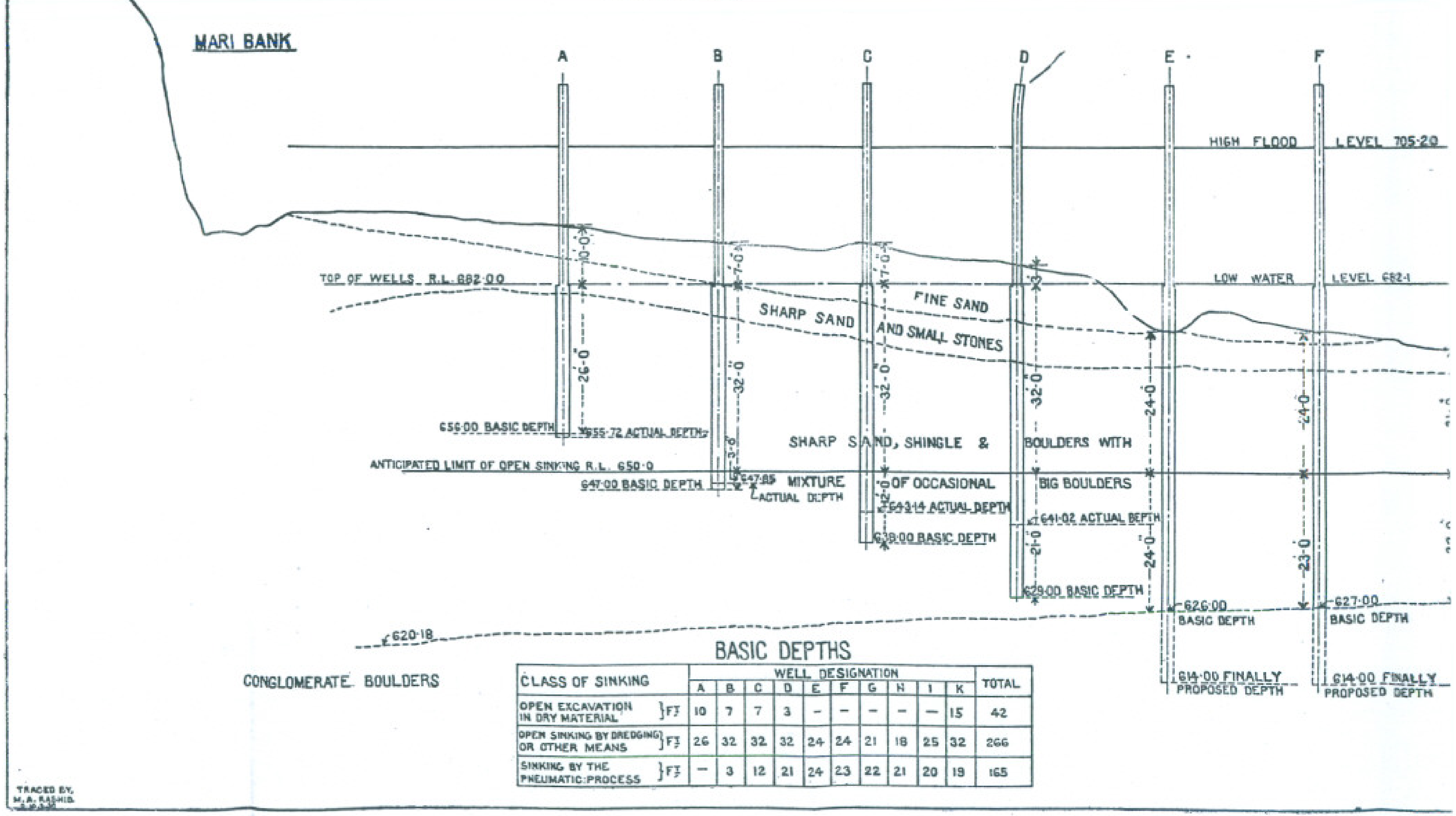
KALABACH BRIDGE.

PROTECTION WORK KALABACH ABUTMENT.



KALABACH BRIDGE

DIAGRAM SHOWING DEPTHS OF WELLS, DESIGN



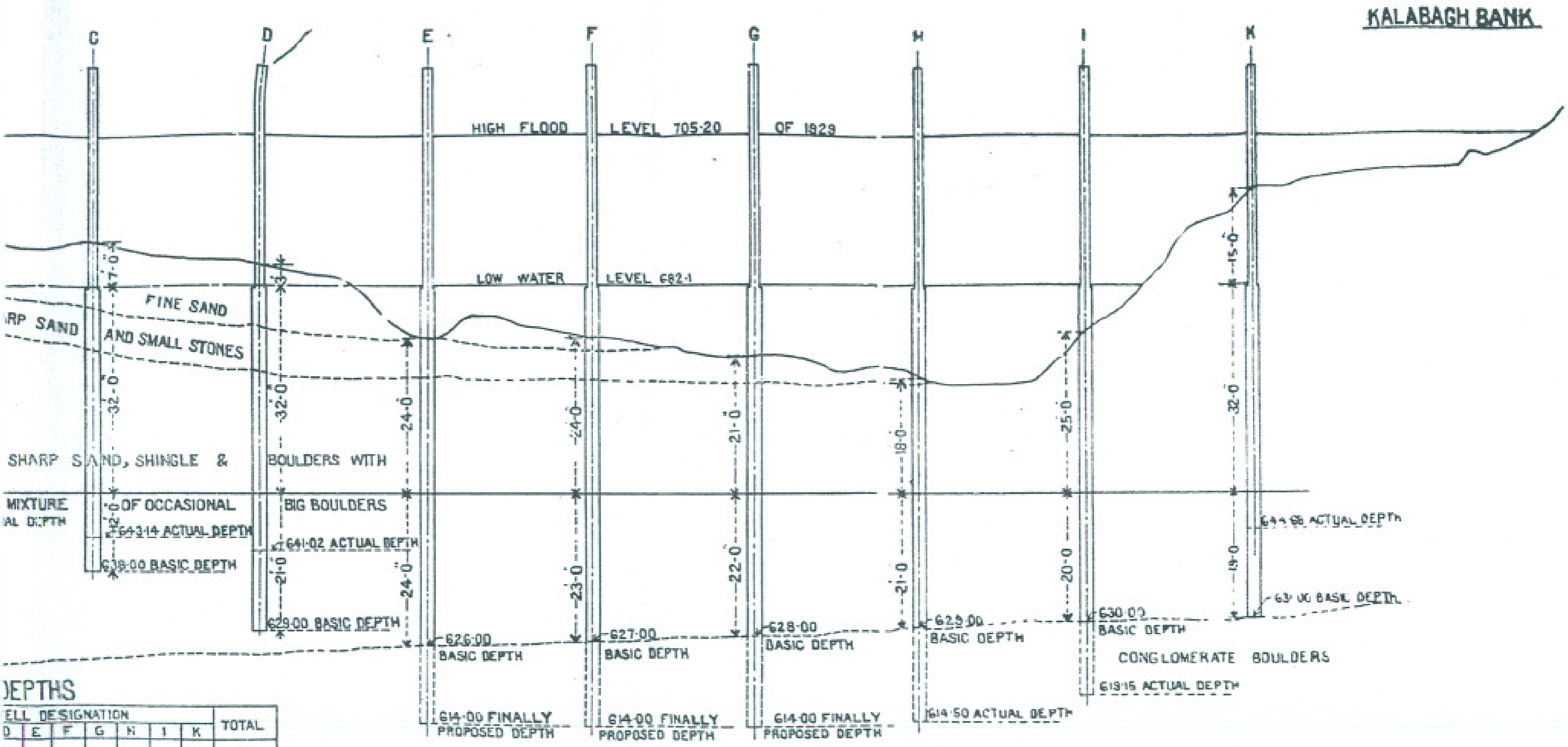
BASIC DEPTHS

CLASS OF SINKING	WELL DESIGNATION A	B	C	D	E	F	G	H	I	K	TOTAL
OPEN EXCAVATION IN DRY MATERIAL } FT.	10	7	7	3	–	–	–	–	–	15	42
OPEN SINKING BY DREDGING OR OTHER MEANS } FT.	26	32	32	32	24	24	21	18	25	32	266
SINKING BY THE PNEUMATIC PROCESS } FT.	–	3	12	21	24	23	22	21	20	19	165

KALABACH BRIDGE

PLATE IX

DIAGRAM SHOWING DEPTHS OF WELLS, DESIGNED & ACTUAL



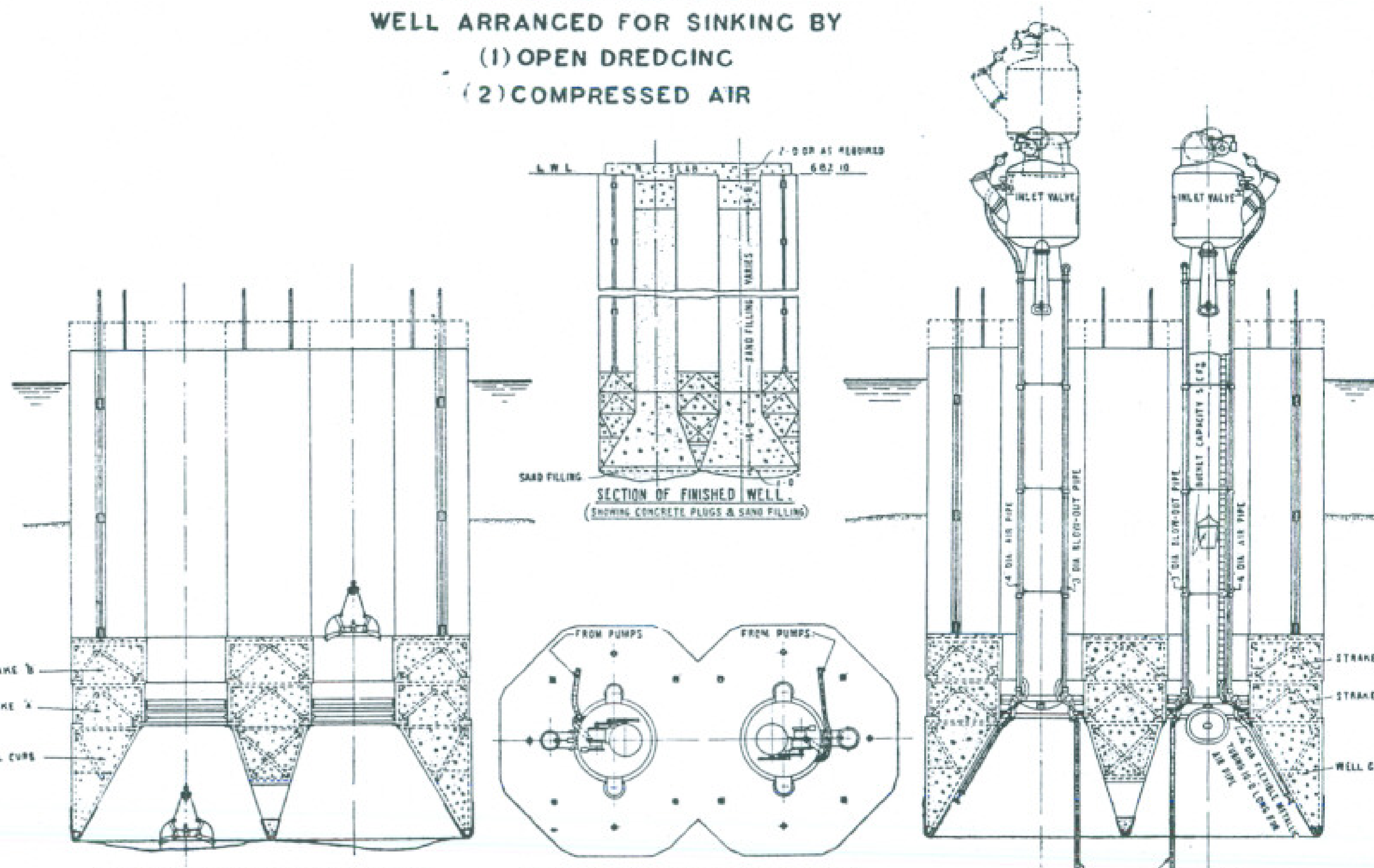
EPTHS

ELL DESIGNATION							
D	E	F	G	H	I	K	TOTAL
3	–	–	–	–	—	15	42
2	24	24	21	18	25	32	266
21	24	23	22	21	20	19	165

PLATE X

KALABACH BRIDGE

WELL ARRANGED FOR SINKING BY (1) OPEN DREDGING (2) COMPRESSED AIR



SHOWING METHOD OF SINKING BY OPEN DREDGING.

PLAN OF WELL SHOWING AIR LOCKS IN POSITION.

SHOWING TEMPORARY APPLICATION OF COMPRESSED AIR WHEN REQUIRED

SCALE $\frac{1}{156}$

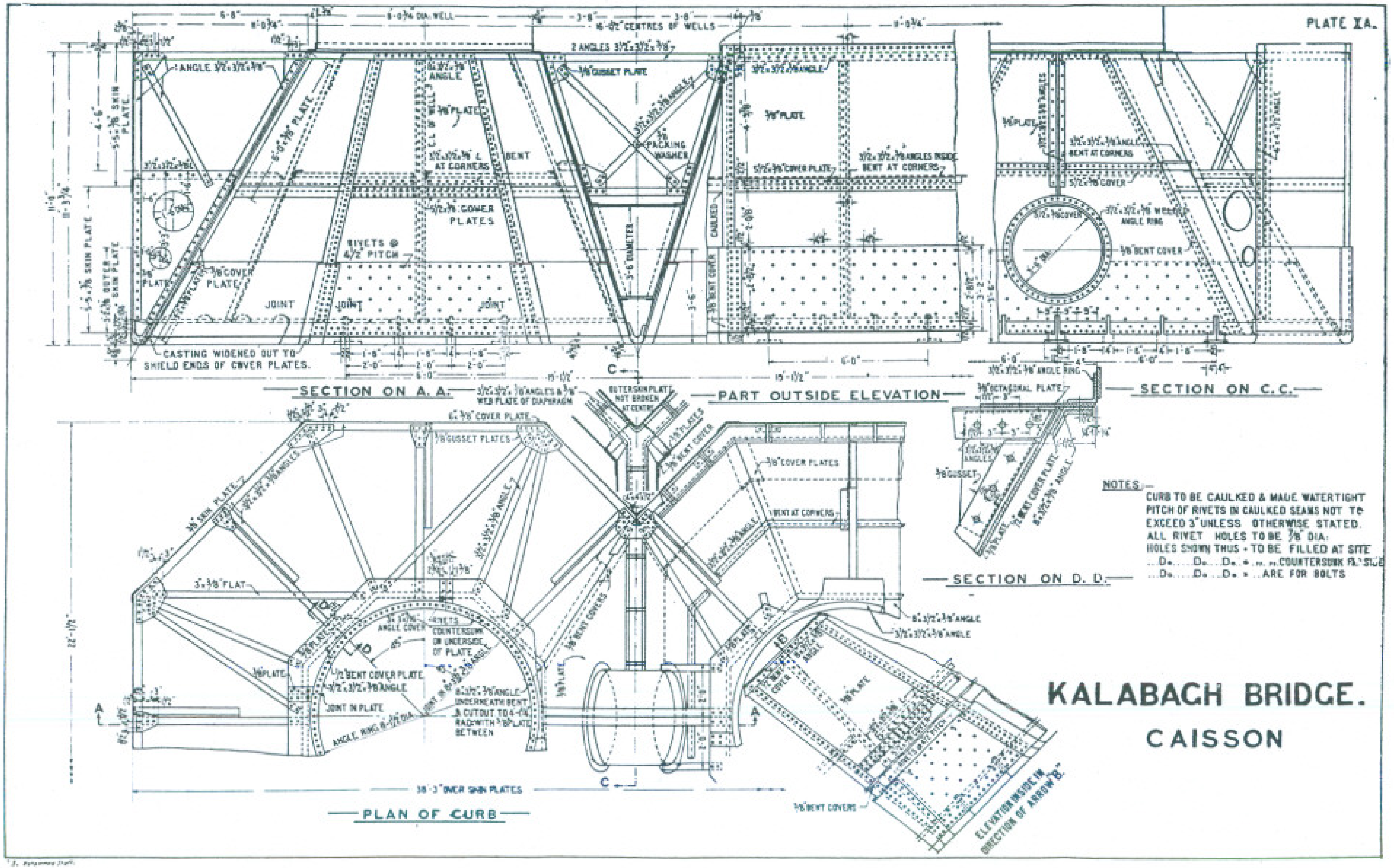
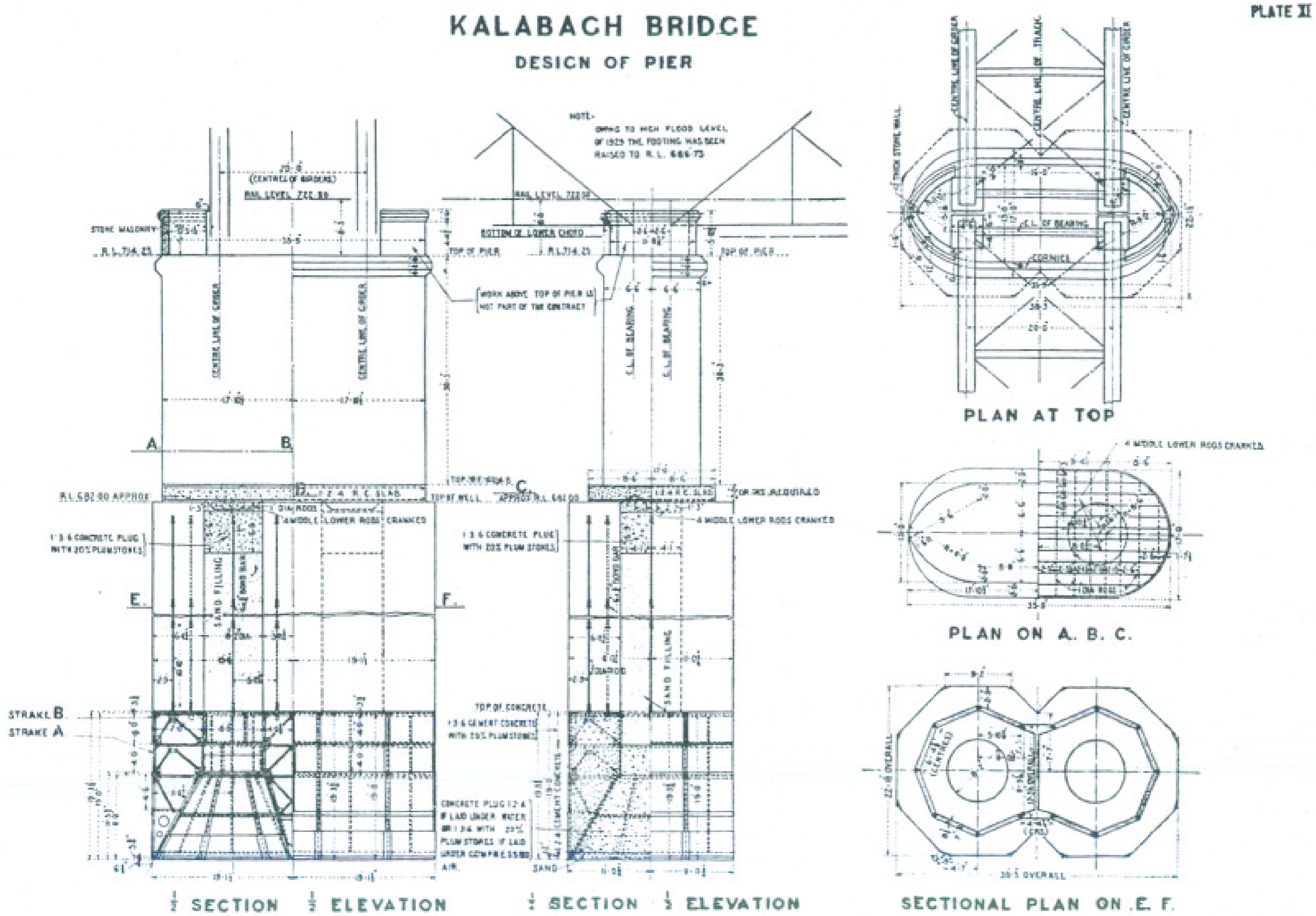


PLATE XA.
SECTION ON A. A.
PART OUTSIDE ELEVATION
SECTION ON C. C.
SECTION ON D. D.
PLAN OF CURB
ELEVATION INSIDE IN DIRECTION OF ARROW "B".
16'-0½" CENTRES OF WELLS
38'-3" OVER SKIN PLATES
NOTES.
CURB TO BE CAULKED & MADE WATERTIGHT
PITCH OF RIVETS IN CAULKED SEAMS NOT TO EXCEED 3" UNLESS OTHERWISE STATED.
ALL RIVET HOLES TO BE ⅞" DIA.
KALABACH BRIDGE.
CAISSON

PLATE II


KALABACH BRIDGE
DESIGN OF PIER
NOTE- OWING TO HIGH FLOOD LEVEL OF 1929 THE FOOTING HAS BEEN RAISED TO R.L. 686·75
WORK ABOVE TOP OF PIER IS NOT PART OF THE CONTRACT
STONE MASONRY
RAIL LEVEL
BOTTOM OF LOWER CHORD
TOP OF PIER
CENTRE LINE OF GIRDER
C.L. OF BEARING
R.C. SLAB
TOP OF WELL
R.L. 682·80 APPROX.
4 MIDDLE LOWER RODS CRANKED
1:3:6 CONCRETE PLUG WITH 20% PLUM STONES
SAND FILLING
STRAKE B
STRAKE A
TOP OF CONCRETE
1:3:6 CEMENT CONCRETE WITH 20% PLUM STONES
CONCRETE PLUG 1:2:4 IF LAID UNDER WATER OR 1:3:6 WITH 20% PLUM STONES IF LAID UNDER COMPRESSED AIR.
SAND
½ SECTION ½ ELEVATION
½ SECTION ½ ELEVATION
THICK STONE WALL
CENTRE LINE OF TRACK
CORNICE
PLAN AT TOP
PLAN ON A. B. C.
30·5 OVERALL
22·10 OVERALL
SECTIONAL PLAN ON E. F.

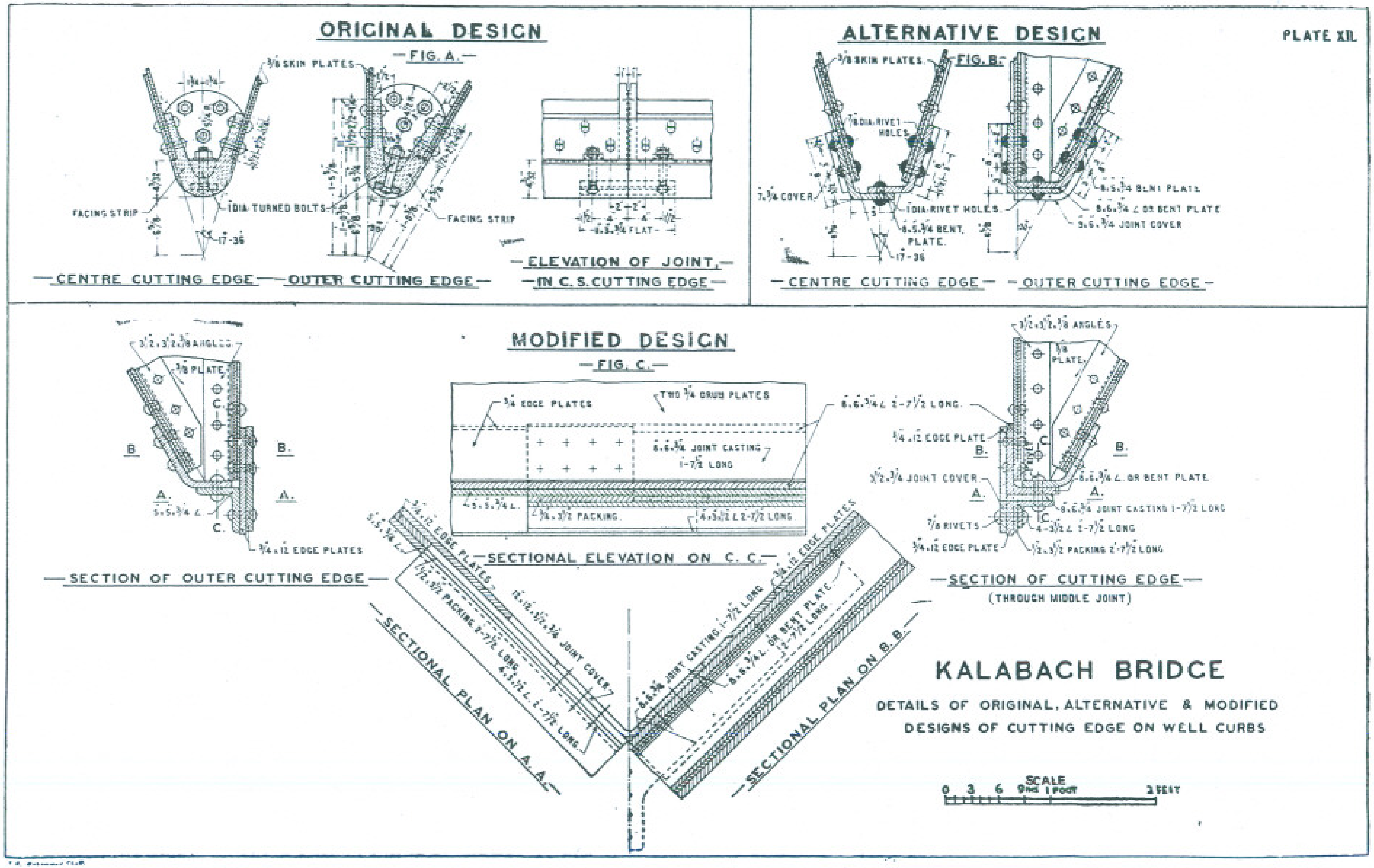


PLATE XII.
ORIGINAL DESIGN
—FIG. A.—
3/8 SKIN PLATES
FACING STRIP
1 DIA. TURNED BOLTS
FACING STRIP
—CENTRE CUTTING EDGE—
—OUTER CUTTING EDGE—
—ELEVATION OF JOINT,—
—IN C. S. CUTTING EDGE—
ALTERNATIVE DESIGN
FIG. B.
3/8 SKIN PLATES
7/8 DIA. RIVET HOLES
1 DIA. RIVET HOLES
6.6.3/4 BENT PLATE.
6.6.3/4 BENT PLATE
6.6.3/4 ∠ OR BENT PLATE
3.6.3/4 JOINT COVER
—CENTRE CUTTING EDGE—
—OUTER CUTTING EDGE—
MODIFIED DESIGN
—FIG. C.—
3/8 PLATE.
B.
A.
C.
3/4 x 12 EDGE PLATES
—SECTION OF OUTER CUTTING EDGE—
3/4 EDGE PLATES
TWO 3/4 DRUM PLATES
6.6.3/4 JOINT CASTING 1-7 1/2 LONG
1/2 x 3 1/2 PACKING.
—SECTIONAL ELEVATION ON C. C.—
3/4 x 12 EDGE PLATES
1/2 x 3 1/2 PACKING 2-7 1/2 LONG
4.3 1/2 ∠ 2-7 1/2 LONG
JOINT COVER
SECTIONAL PLAN ON A. A.
6.6.3/4 JOINT CASTING 1-7 1/2 LONG
6.6.3/4 ∠ OR BENT PLATE 2-7 1/2 LONG
SECTIONAL PLAN ON B. B.
3 1/2 x 3 1/2 x 3/8 ANGLES
3/8 PLATE.
6.6.3/4 ∠ 2-7 1/2 LONG.
3/4 x 12 EDGE PLATE
3 1/2 x 3/4 JOINT COVER
6.6.3/4 ∠ OR BENT PLATE
6.6.3/4 JOINT CASTING 1-7 1/2 LONG
7/8 RIVETS
4-3 1/2 ∠ 1-7 1/2 LONG
3/4 x 12 EDGE PLATE
1/2 x 3 1/2 PACKING 2-7 1/2 LONG
—SECTION OF CUTTING EDGE—
(THROUGH MIDDLE JOINT)
KALABACH BRIDGE
DETAILS OF ORIGINAL, ALTERNATIVE & MODIFIED
DESIGNS OF CUTTING EDGE ON WELL CURBS
SCALE
0 3 6 9 INS 1 FOOT 2 FEET

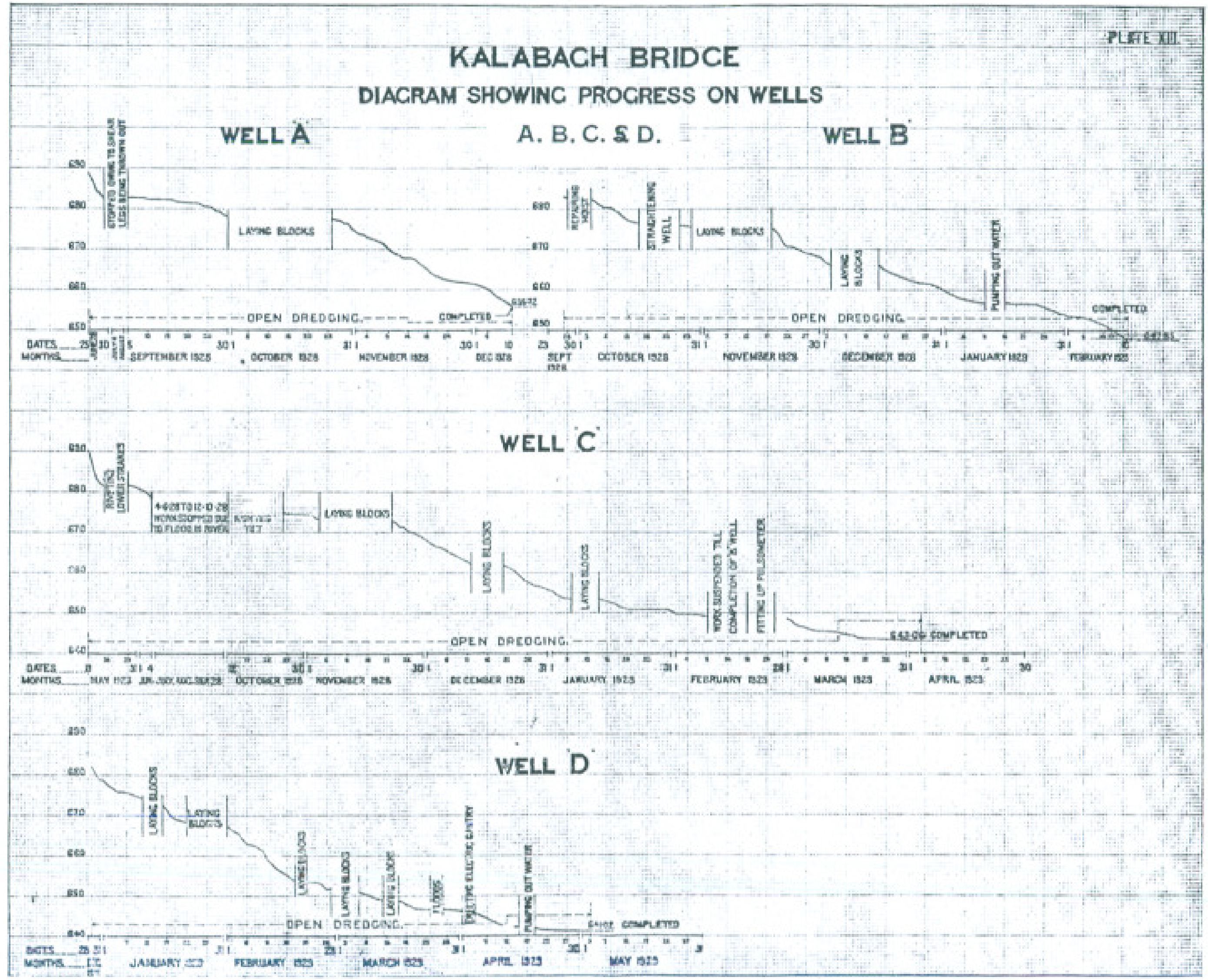


PLATE XIII.
KALABACH BRIDGE
DIAGRAM SHOWING PROGRESS ON WELLS
A. B. C. & D.
WELL A
WELL B
WELL C
WELL D
STOPPED OWING TO SHEAR LEGS BEING THROWN OUT
LAYING BLOCKS
REPAIRING HOIST
STRAIGHTENING WELL
PUMPING OUT WATER
COMPLETED
OPEN DREDGING
WORK SUSPENDED TILL COMPLETION OF 'B' WELL
FITTING UP PULSOMETER
642·00 COMPLETED
FITTING ELECTRIC GANTRY
FLOODS
DATES
MONTHS
SEPTEMBER 1928
OCTOBER 1928
NOVEMBER 1928
DECEMBER 1928
JANUARY 1929
FEBRUARY 1929
MARCH 1929
APRIL 1929
MAY 1929

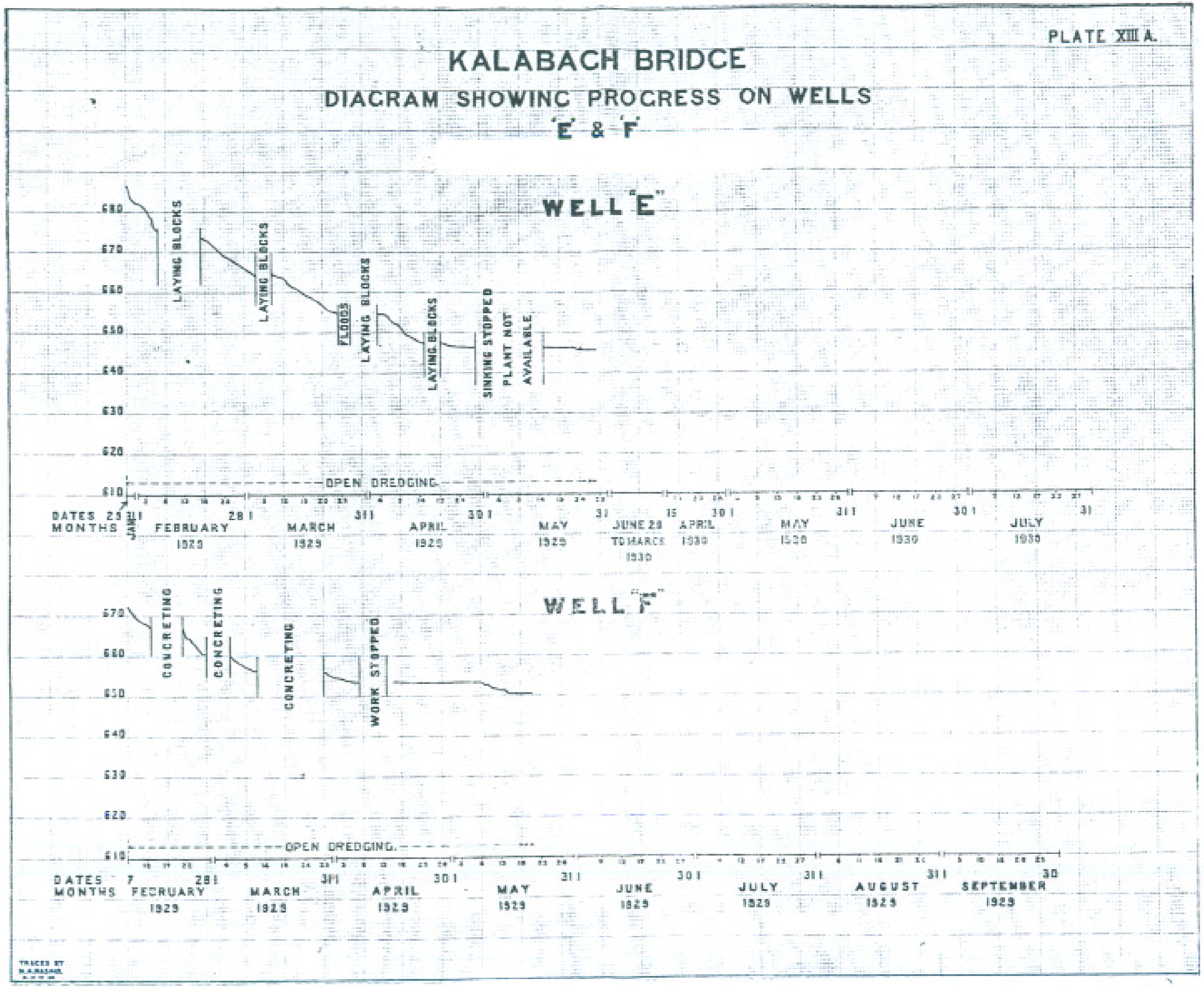


PLATE XIII A.
KALABACH BRIDGE
DIAGRAM SHOWING PROGRESS ON WELLS
'E' & 'F'
WELL "E"
LAYING BLOCKS
LAYING BLOCKS
FLOODS
LAYING BLOCKS
LAYING BLOCKS
SINKING STOPPED
PLANT NOT AVAILABLE
OPEN DREDGING
DATES
MONTHS
FEBRUARY 1929
MARCH 1929
APRIL 1929
MAY 1929
JUNE 29 TO MARCH 1930
APRIL 1930
MAY 1930
JUNE 1930
JULY 1930
WELL "F"
CONCRETING
CONCRETING
CONCRETING
WORK STOPPED
OPEN DREDGING
DATES
MONTHS
FEBRUARY 1929
MARCH 1929
APRIL 1929
MAY 1929
JUNE 1929
JULY 1929
AUGUST 1929
SEPTEMBER 1929

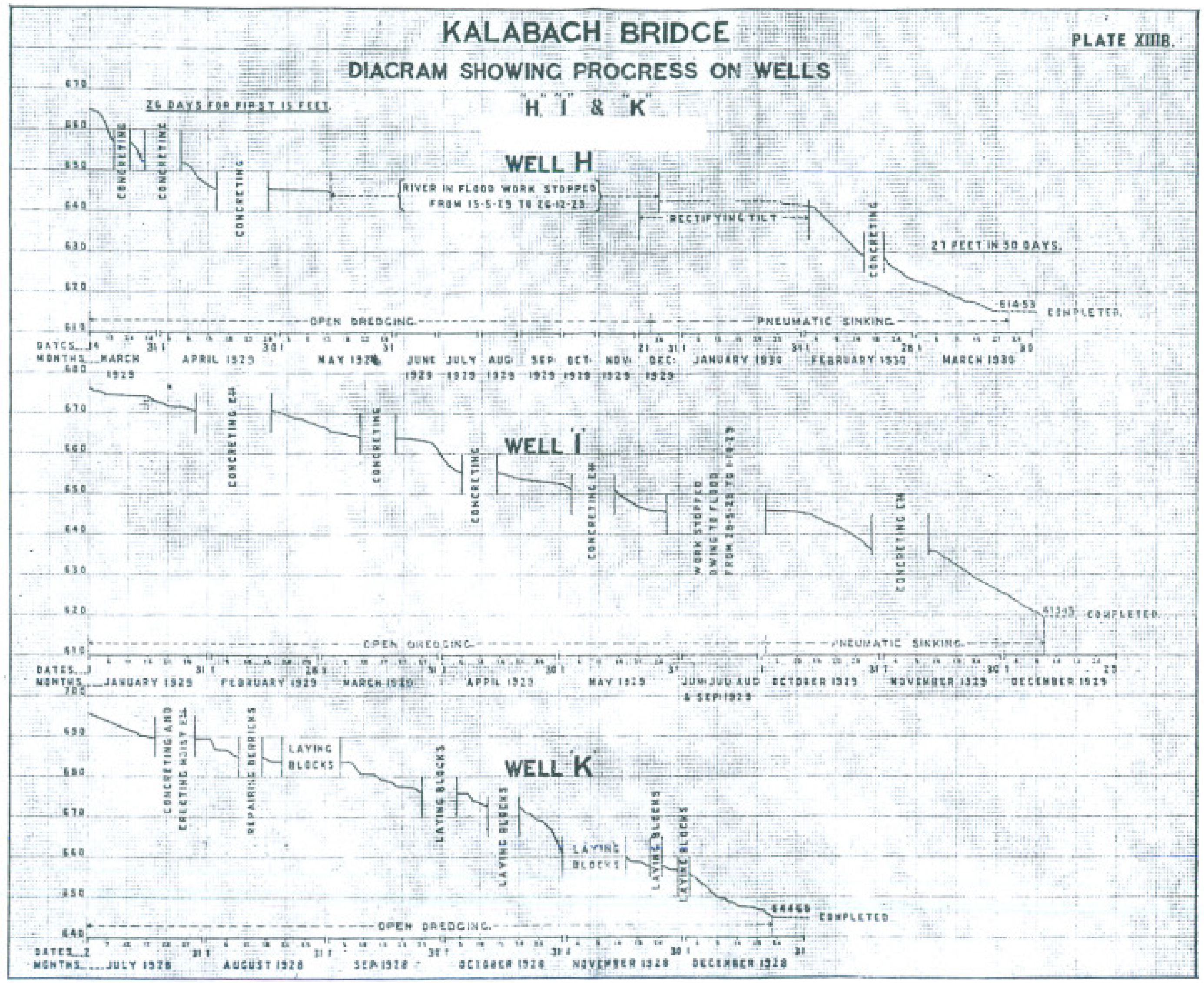


PLATE XIIIB.
KALABACH BRIDGE
DIAGRAM SHOWING PROGRESS ON WELLS
"H" "I" & "K"
WELL H
26 DAYS FOR FIRST 15 FEET.
CONCRETING
RIVER IN FLOOD WORK STOPPED
FROM 15-5-29 TO 26-12-29
RECTIFYING TILT
27 FEET IN 50 DAYS.
614·53 COMPLETED.
OPEN DREDGING
PNEUMATIC SINKING
DATES
MONTHS
MARCH 1929
APRIL 1929
MAY 1929
JUNE 1929
JULY 1929
AUG 1929
SEP 1929
OCT 1929
NOV 1929
DEC 1929
JANUARY 1930
FEBRUARY 1930
MARCH 1930
WELL I
CONCRETING EM
WORK STOPPED
OWING TO FLOOD
FROM 26-5-29 TO 1-10-29
613·5 COMPLETED.
JANUARY 1929
FEBRUARY 1929
MARCH 1929
APRIL 1929
MAY 1929
JUN JUL AUG & SEP 1929
OCTOBER 1929
NOVEMBER 1929
DECEMBER 1929
WELL K
CONCRETING AND ERECTING HOIST E.M.
REPAIRING DERRICKS
LAYING BLOCKS
644·60 COMPLETED
JULY 1928
AUGUST 1928
SEP 1928
OCTOBER 1928
NOVEMBER 1928
DECEMBER 1928

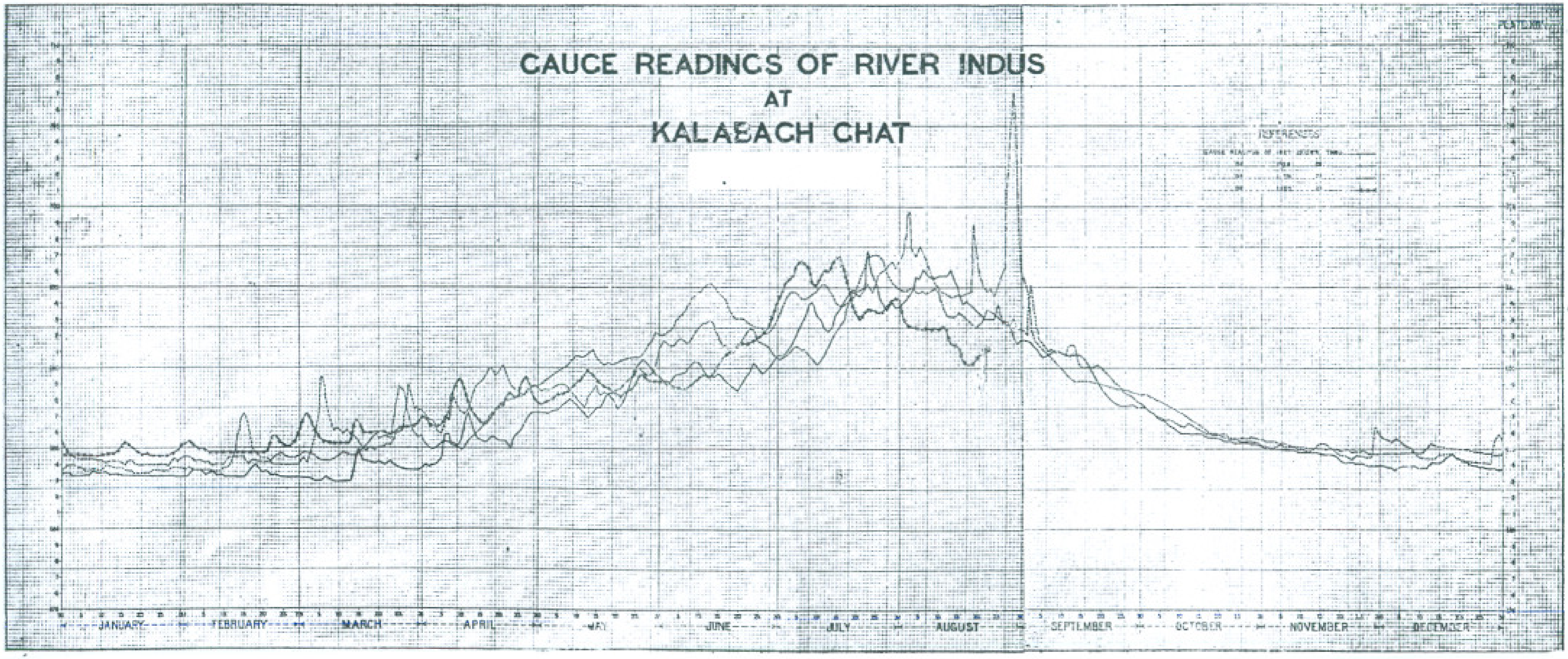

CAUCE READINCS OF RIVER INDUS
AT
KALABACH CHAT
REFERENCES
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

PLATE XV.

KALABACH BRIDGE

CROSS SECTION & VELOCITY CURVE 1929 FLOODS.

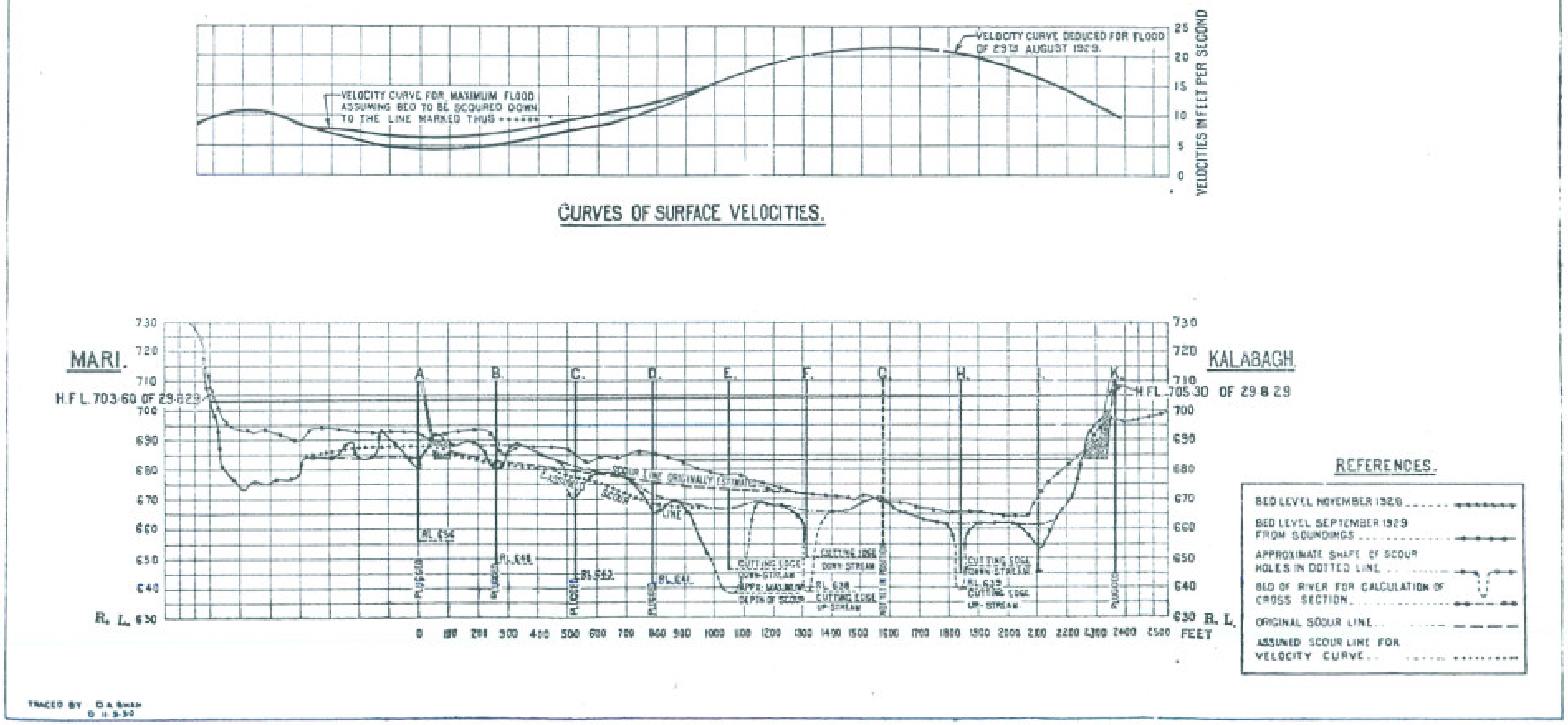
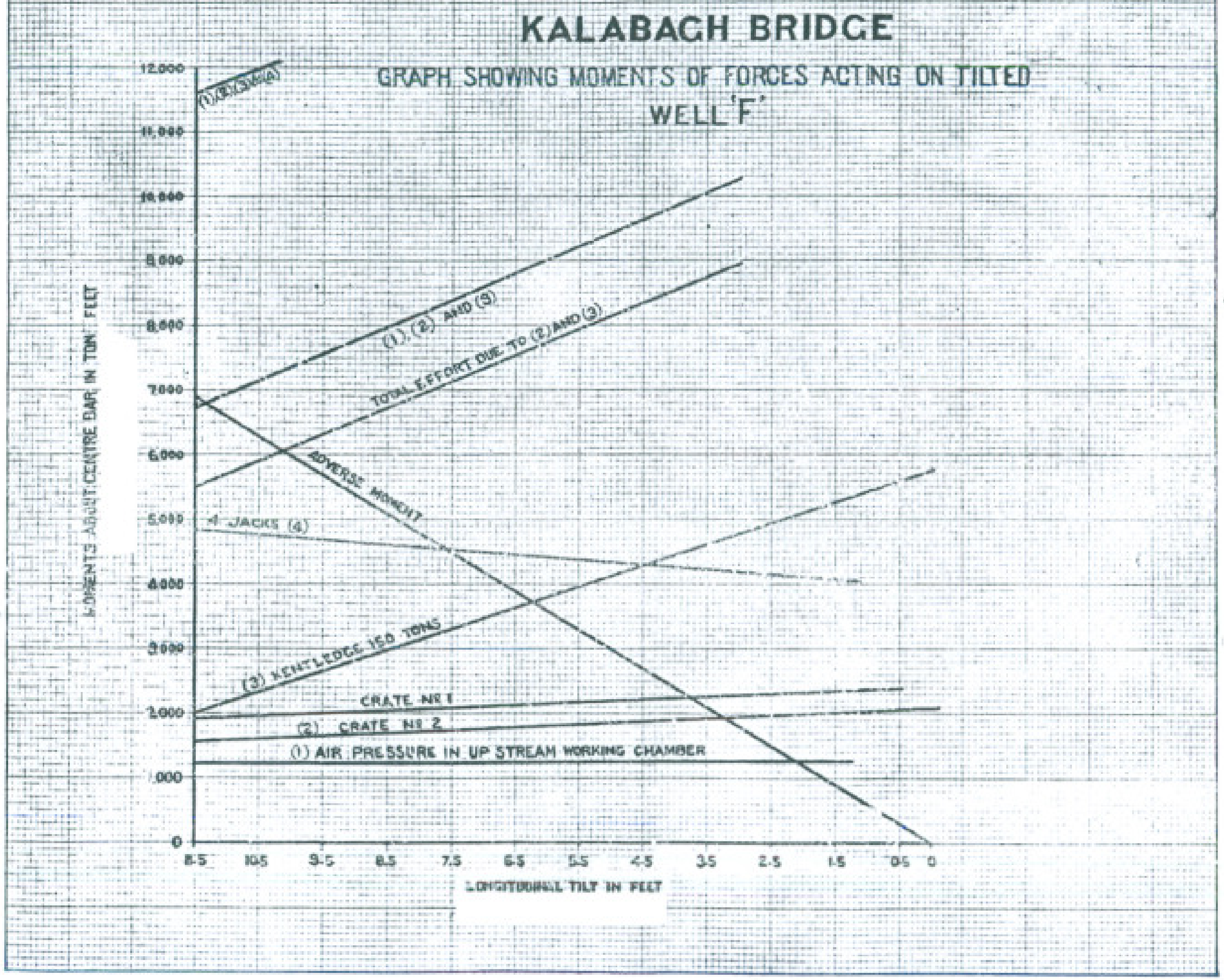


PLATE XVI.


KALABACH BRIDGE
GRAPH SHOWING MOMENTS OF FORCES ACTING ON TILTED WELL 'F'
MOMENTS ABOUT CENTRE BAR IN TON FEET
LONGITUDINAL TILT IN FEET
(1), (2) AND (5)
TOTAL EFFORT DUE TO (2) AND (3)
ADVERSE MOMENT
4 JACKS (4)
(3) KENTLEDGE 150 TONS
CRATE Nº 1
(2) CRATE Nº 2
(1) AIR PRESSURE IN UP STREAM WORKING CHAMBER

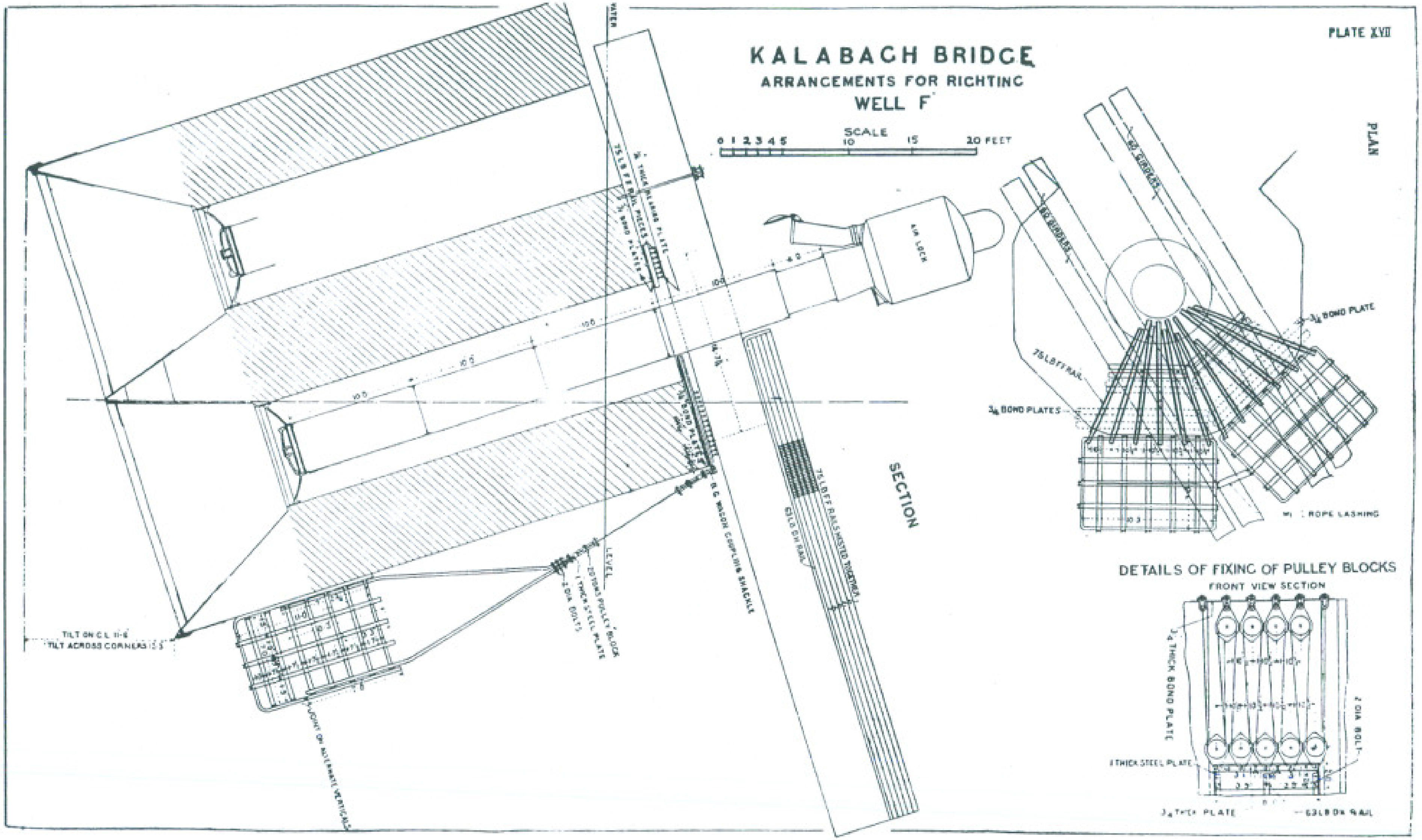
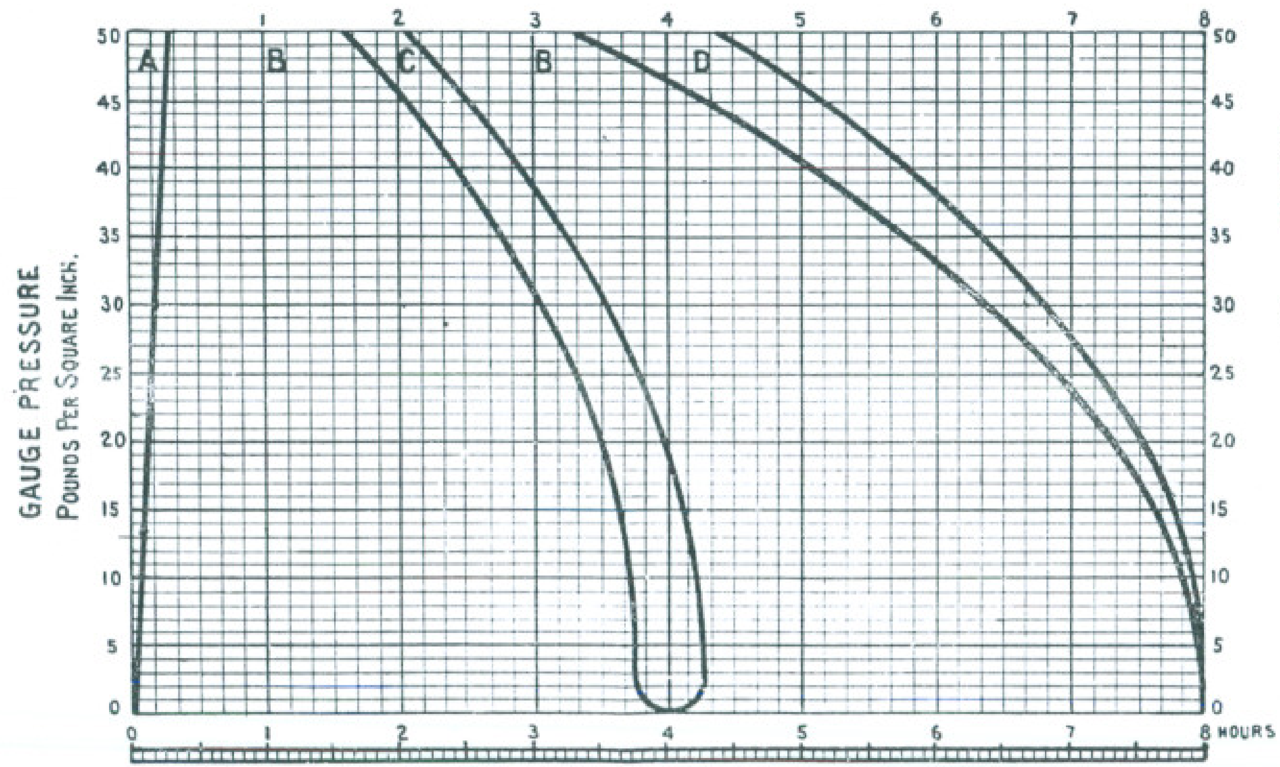


PLATE XVII
KALABACH BRIDGE
ARRANGEMENTS FOR RIGHTING
WELL F
SCALE
0 1 2 3 4 5 10 15 20 FEET
PLAN
SECTION
AIR LOCK
WATER
LEVEL
¾ THICK BEARING PLATE
75 LB F.F. RAIL PIECES
¾ BOND PLATES
¾ BOND PLATES
¾ BOND PLATE
B. G. WAGON COUPLING SHACKLE
75 LB F.F. RAILS NESTED TOGETHER
63 LB D.H. RAIL
20 TONS PULLEY BLOCK
1 THICK STEEL PLATE
2 DIA BOLTS
TILT ON C.L. 11-6
TILT ACROSS CORNERS 15.5
JOINT ON ALTERNATE VERTICALS
75 LB F.F. RAIL
ROPE LASHING
DETAILS OF FIXING OF PULLEY BLOCKS
FRONT VIEW SECTION
¾ THICK BOND PLATE
2 DIA BOLT
1 THICK STEEL PLATE
¾ THICK PLATE
63 LB D.H. RAIL

PLATE XVIII

KALABAGH BRIDGE

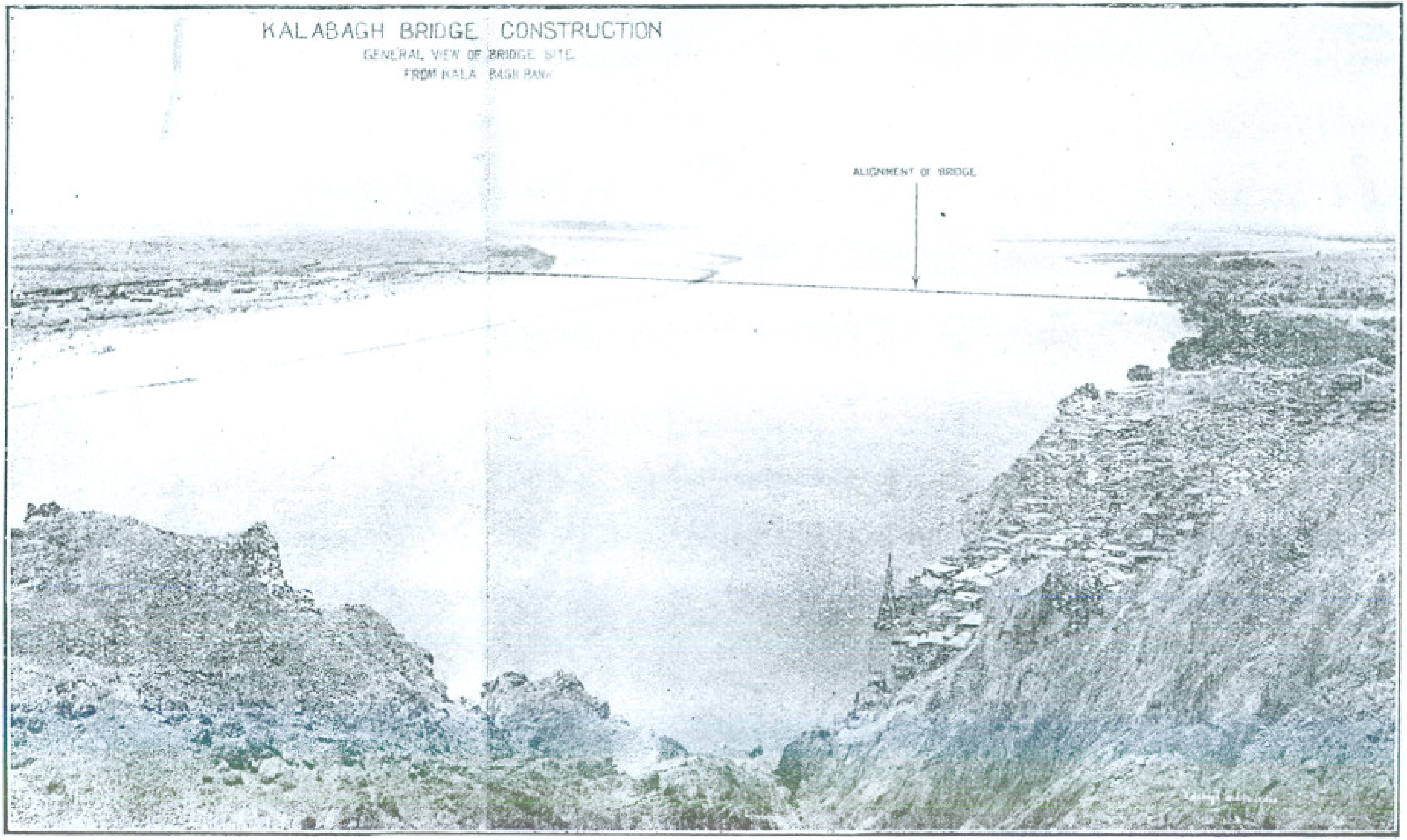
DIAGRAM FOR WORK IN COMPRESSED AIR.

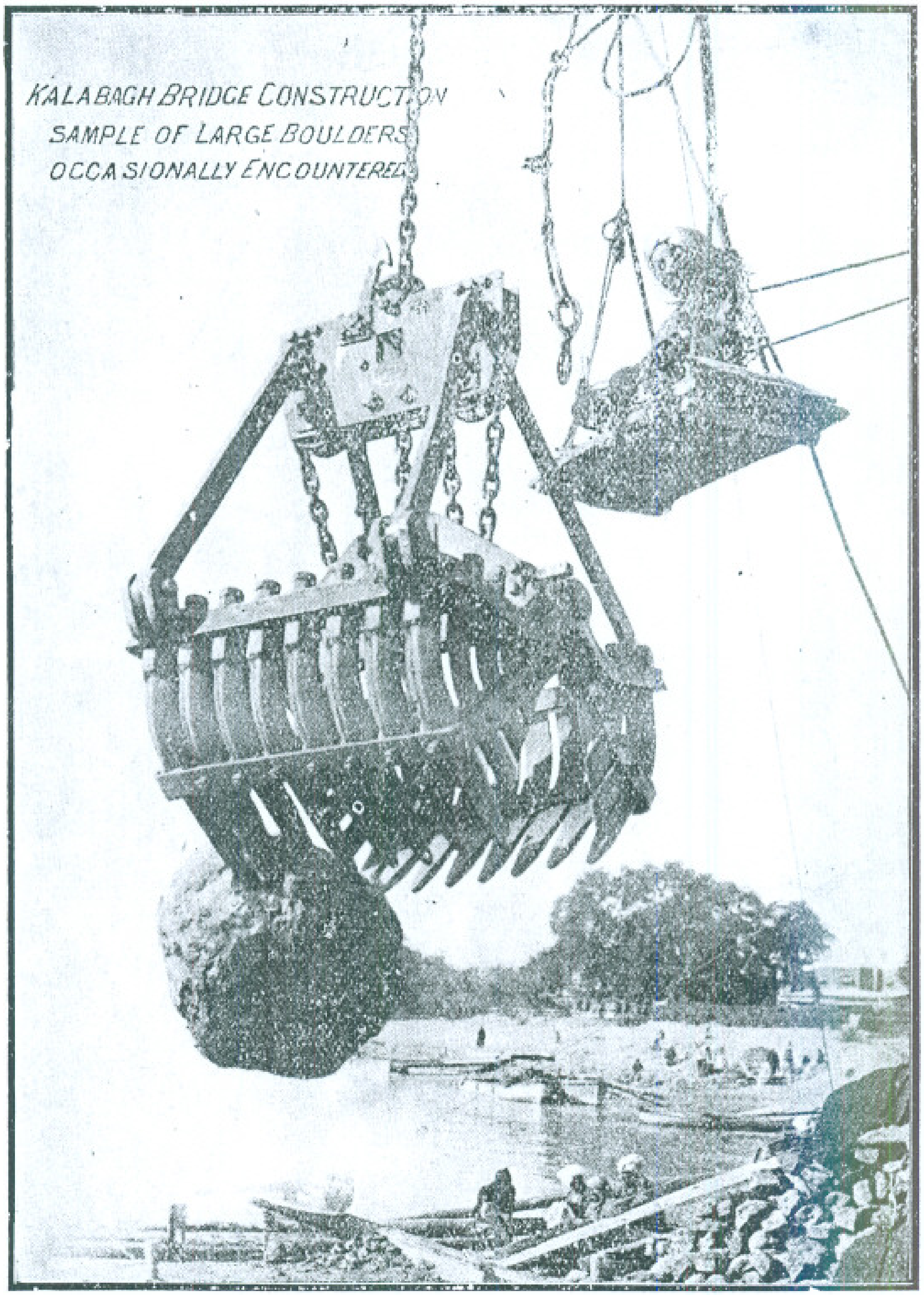


A. Period of Compression
B. Period of Work
C. Period of Rest
D. Period of Decompression

Note:-

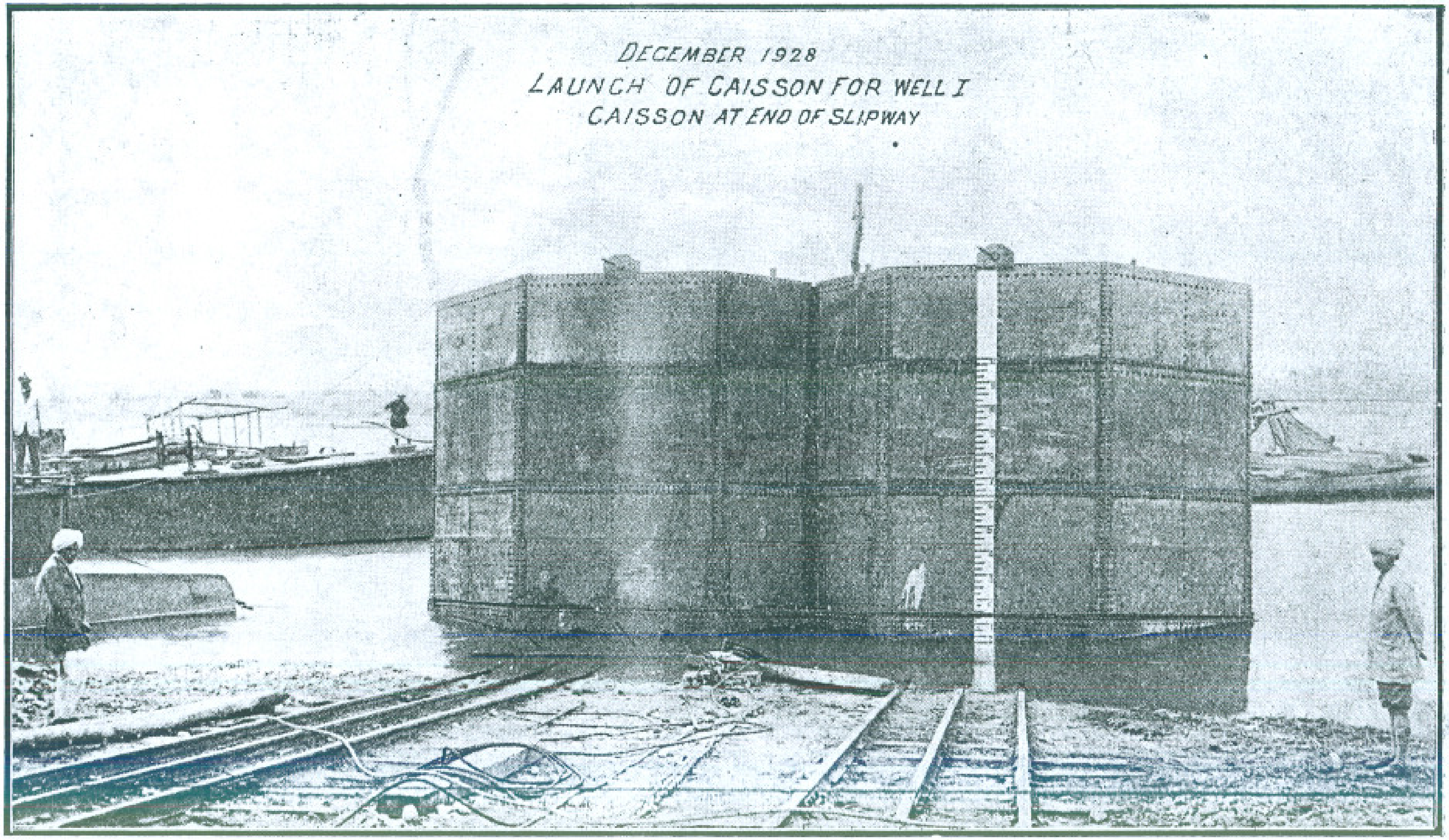
The first half of the decompression shall be effected at a uniform rate of 15 lbs per square inch in 3 minutes the second half shall be reduced at such uniform rate that the total time of decompression will equal that given in the diagram

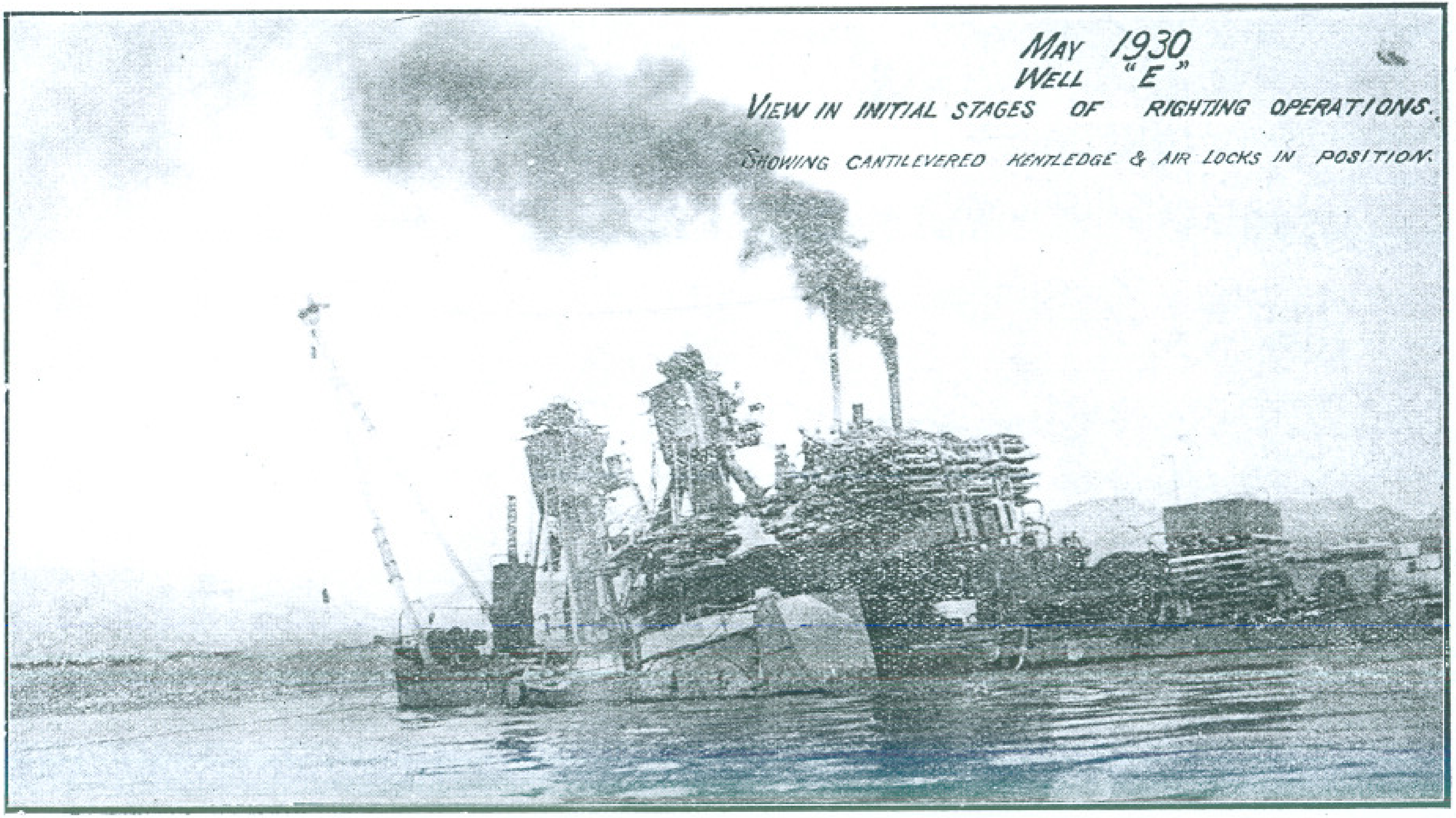

KALABAGH BRIDGE CONSTRUCTION
GENERAL VIEW OF BRIDGE SITE
FROM KALA BAGH BANK
ALIGNMENT OF BRIDGE

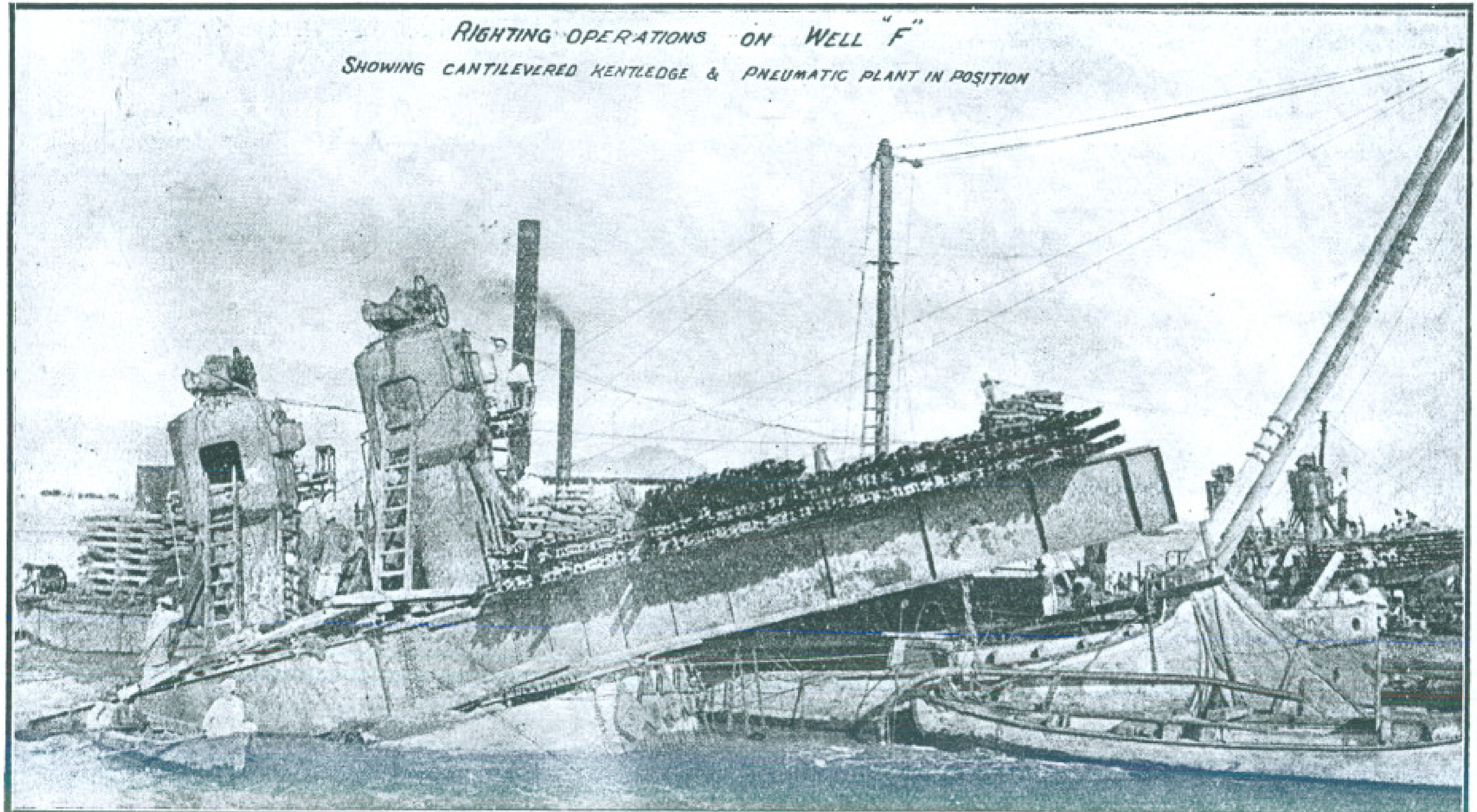

KALABAGH BRIDGE CONSTRUCTION
SAMPLE OF LARGE BOULDERS
OCCASIONALLY ENCOUNTERED

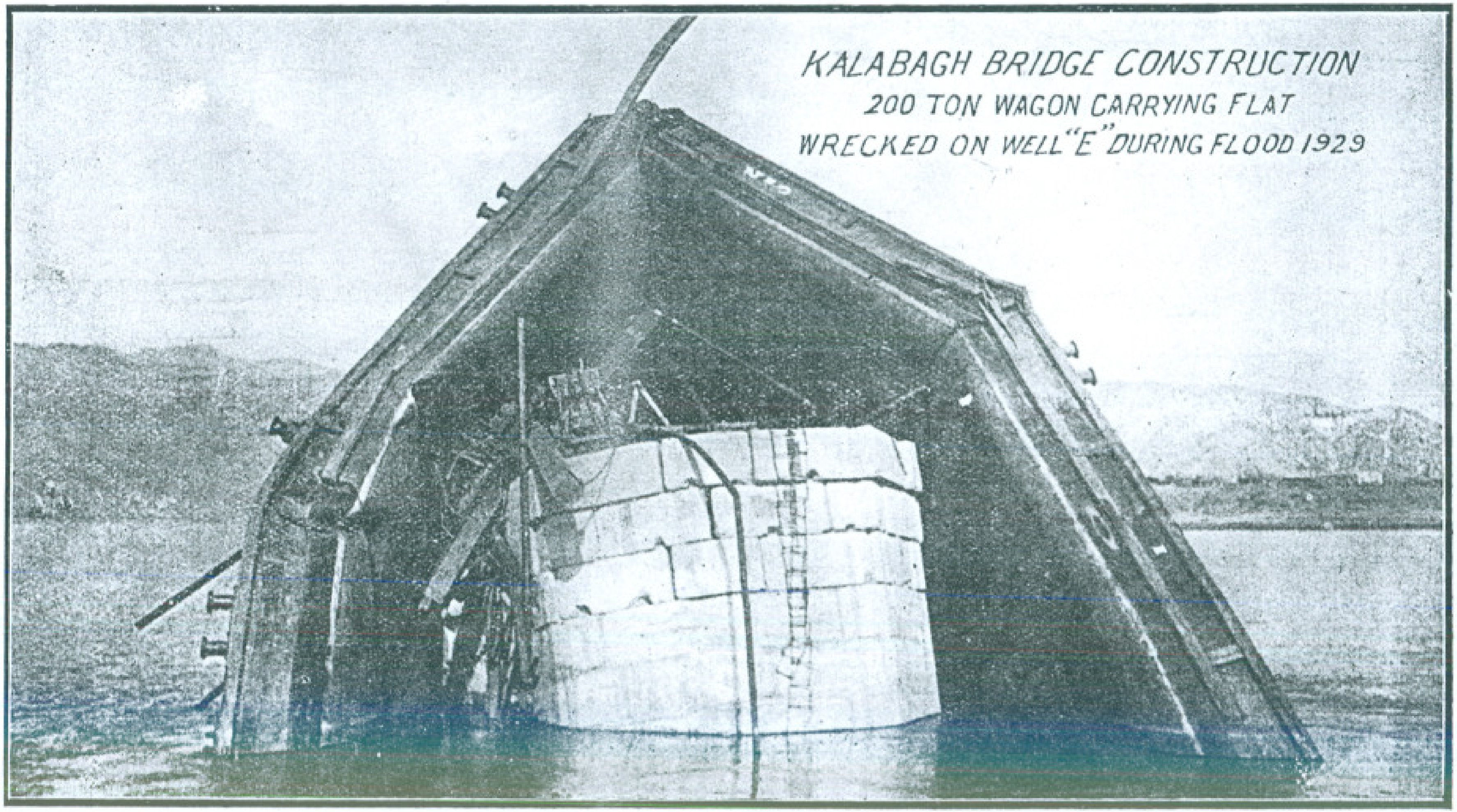

KALABAGH BRIDGE CONSTRUCTION
BOULDER FACE MARI CLIFF

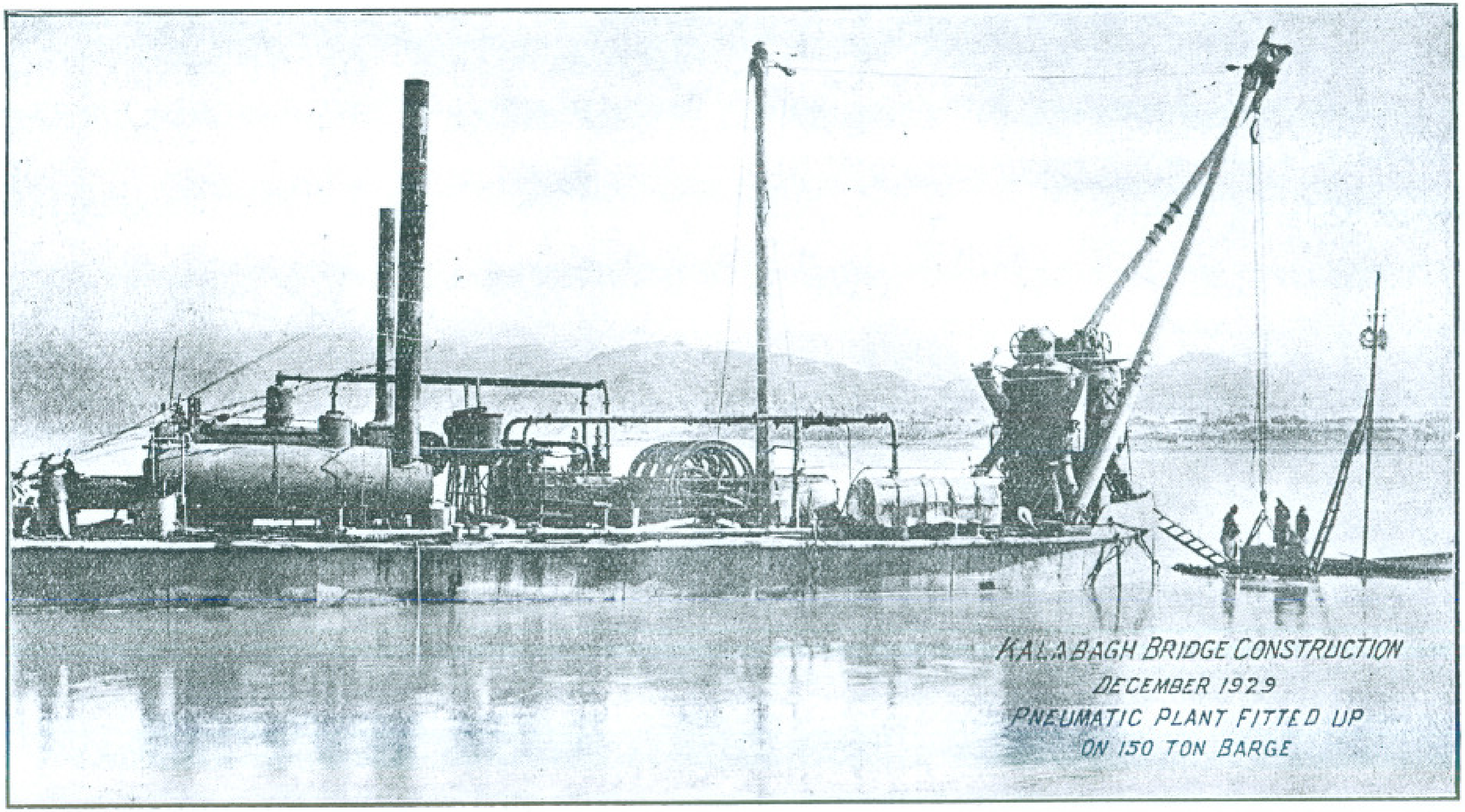
KALABAGH BRIDGE CONSTRUCTION. PHOTO 4.




MAY 1930
WELL "E"
VIEW IN INITIAL STAGES OF RIGHTING OPERATIONS.
SHOWING CANTILEVERED KENTLEDGE & AIR LOCKS IN POSITION.


RIGHTING OPERATIONS ON WELL "F"
SHOWING CANTILEVERED KENTLEDGE & PNEUMATIC PLANT IN POSITION


KALABAGH BRIDGE CONSTRUCTION
200 TON WAGON CARRYING FLAT
WRECKED ON WELL "E" DURING FLOOD 1929


KALABAGH BRIDGE CONSTRUCTION
DECEMBER 1929
PNEUMATIC PLANT FITTED UP
ON 150 TON BARGE

DISCUSSION.

MR. F. C. JUDGES stated that he was introducing the Paper owing to the indisposition of the Author.

He remarked that the Paper on the Kalabagh Bridge Construction dealt with the history, design and progress of construction to the end of the working season 1929-30.

The problems that arose were different from those encountered in bridging a river in the alluvial plains of India. The characteristic feature at Kalabagh was that the bed was composed mainly of shingle and boulders and not of sand. Observations taken up to the time of the construction showed little or no scour in the unobstructed river, and it was thought that excessive scour round the wells in this hard bed of shingle and boulders would not occur. It was found, however, that scour up to 35 ft. actually took place, where the river was obstructed by wells, in the severe floods of 1929. This was a remarkable depth when the fact was taken into consideration that experience on this construction had proved very clearly that beyond a depth of about 40 ft., pneumatic sinking was essential with the type of well originally used. After a lapse of many years, this was the first bridge on the North Western Railway where the pneumatic process had been employed, the previous instance being the Kotri bridge in 1898.

Those who had read the paper would have seen that at the close of the 1929-30 working season, work on righting the tilt on well 'F' was not then complete, only 2 ft. out of the $11\frac{1}{2}$ ft. of longitudinal tilt having been removed when the season ended. During the present season the whole tilt has been removed and the sinking of the well to its full depth was nearly finished. The remainder of the substructure work, including the extension wells, would be completed by April 1931. Girder erection had commenced and it was anticipated that the bridge would be opened for traffic in about a year's time.

MR. J. VARDON remarked that there were two points that he would like to make a few remarks on. They were :—

(1) The Author had referred to borings carried out in 1921 and 1924. These were done by the speaker, together with soundings and river velocities, and on page 67, para. 2, it was written that it had never been clear what was meant by the term "conglomerate boulders" but it was probable that it was intended to convey the idea of a stratum of boulders and sand rendered compact under pressure. The term conglomerate was rather a misnomer. The geological definition of the word "Conglomerate," the speaker said, was—

"A rock composed of pebbles cemented together."

Nothing more accurately described this stratum than the word used, as the boulders or round rock pieces were actually composed of pebbles cemented together, with as good a mortar as Mr. Vardon had seen on engineering works. These "conglomerate boulders" were examined by

Colonel Cowie, Colonel Anderson and Mr. Hallidy as specimens of interest.

It was never the speaker's intention to convey by the term "conglomerate boulders" a stratum of boulders and sand rendered compact under pressure.

(2) The second point he would like to mention was in connection with the sinking of piers. Very soon after the first wells had reached the boulder stratum, it was obvious to the contractor's engineers that open dredging was going to be a slow and expensive process and dewatering was tried, presumably with the object of allowing men to get to the bottom of the well and pick out or somehow displace the compact bed of boulders that the Priestman Grabs could not bite into.

When the speaker visited the bridge during the 1928-29 working season, one of the wells was being pumped, but it was obvious that the pumps and the pulsometers being used were far too small and not of a suitable type.

The speaker was able, a few years ago, to inspect well sinking operations in progress by complete dewatering in a river where the strata conditions were similar to those at Kalabagh. Had these methods been adopted at the Indus Bridge, it might have avoided pneumatic sinking, speeded up the work considerably and consequently lowered the cost. The method of dewatering witnessed was outlined as follows :—

The infiltration area of the Kalabagh Bridge well curbs was approximately 700 sq. ft. and the infiltration head from low water level (682·00) to the bottom of the deepest wells (614·00) was 68.00 feet.

From his experience of wells in the Punjab, the speaker calculated that the total quantity of water which would flow into the wells at Kalabagh when the bottom of the curbs was at 614·00 ft. would be 550,000 gallons per hour or roughly 10,000 gallons per minute. This quantity would have to be pumped out by two pumps, one being used in each hole. The delivery of each pump would therefore be 5,000 gallons per minute.

The pumps used for this purpose were of the vertical spindle type, direct coupled to an electric motor and suspended by a chain from a gantry or shear legs mounted on the well and which could be raised or lowered by a winch. A pump of this type would be about 23″ to 24″ over the pump bowls and about 3′-0″ over the electric motor, leaving ample room in the hole for other operations.

These pumps could be constructed of the "Sponge Type" so that they could dewater up to about six inches from the bed of the well and they could be designed to handle sand and small pebbles without any injury to the impellers or pump casing.

The speaker had seen a very large pump of this type discharging boulders up to about five inches in diameter, in deepening a shallow river, and recovering gravel and sand for constructional purposes. This special type of pump was a fairly recent development, and the engineer-in-charge of the work referred to, found them invaluable for this purpose.

The initial cost of the Power House with cables and pumps would be high; very roughly say Rs. 1,50,000 as each pump would require 150 H.P. Two pumps should be sufficient for the work.

The operating costs per hour for a pair of pumps under worst conditions, assuming the cost of generating current at -/1/- per B.H.P. delivered at the well, would be Rs. 18.

The pumps were portable and could be moved from pier to pier as required, and would be used on those piers passing through boulder formation. They would be available for use on other piers when the one they were working on was being concreted. It could be appreciated that if the wells could be kept dewatered in this way, several means could be adopted for speedy removal of pebbles and boulders from the bottom of the well, *e.g.*, half a dozen pneumatic paving breakers could be used by men to dislodge compacted boulders in the well and under the curb, leaving the pumps to deal with the sand and gravel.

The speaker discussed this with the contractor's manager some months ago and understood from him that he intended trying out this method on the Sagaing Bridge in Burma which his Company were building.

MR. G. LACEY said that the Author was to be congratulated on the presentation of a valuable paper which was of great interest, not merely to bridge builders, but to canal engineers, who were also intimately concerned with the behaviour of great rivers.

A study of the paper showed how important a part the anticipated maximum discharge played in the design of a large bridge such as this, and also how necessary it was to know the material of which the river bed was composed in order that the scour during a maximum flood could be predetermined. He would confine himself in what he had to say to these two aspects of the paper.

The photograph showing the boulder face of the Mari cliff gave an excellent idea of the material which was probably encountered when the river bed was deeply scoured. The Author had stated in the paper that the boulders in the river bed varied from small boulders about three inches in diameter to bigger ones as large as eighteen inches in diameter. That meant that the large boulder in Photo 3 was of the order of eighteen inches. He suggested that photographs of this character were enhanced in value if a foot rule, or any object which lent scale, such as a rupee, were placed in the same vertical plane as the subject of the picture.

The problem of the railway engineer was that of designing a bridge of sufficient waterway to accommodate the maximum discharge without dangerous afflux or scour. The early practice in railway bridge design, as the Alexandra Bridge across the River Chenab demonstrated, was that of bridging everything that had semblance of a river bed. Modern practice was based on designing the waterway in such a manner that it could accommodate the reduced width of a river, trained and contracted so that it could flow in one well defined deep waterway. There was, it was clear, a limit to that contraction, and railway engineers were steadily approaching that limit.

In a paper recently published by the Institution of Civil Engineers* he had shown that, when due allowance had been made for the obstruction offered to the passage of water by railway bridge piers in alluvial rivers, the effective width of waterway of a number of modern railway bridges was given by the formula

$$W_s = 2{\cdot}67\,Q^{\frac{1}{2}}$$

in which expression W_s was the minimum width of waterway and Q the discharge in cusecs.

It was of interest to check the results obtained from that formula with the actual waterway provided. He did not challenge in any way the accuracy of the various discharges quoted in the paper, but he considered that the value of the paper would be enhanced, if the Author could supplement in his reply, the various hydraulic data which he had quoted. He fully appreciated that the observations were necessarily approximate.

On page 89, the maximum discharge of the Indus was stated to have been calculated in three ways ; by Kutter's formula, by Bazin's formula, and by velocity curve and cross section. If the value of Kutter's N, and of Bazin's co-efficient, could be quoted, these figures would be of more value. It was also necessary to know the cross sectional area in each case, the wetted perimeter, the hydraulic mean depth, and the slope of the water surface.

The discharges of the Haro and Sohan rivers had been measured, or calculated, and if, for these also, the hydraulic data could be quoted he would be indebted to the Author.

Flood discharge observations were rare, and if they were to be co-ordinated and full advantage obtained from them, the full data, slope, hydraulic mean depth, etc., were essential.

He had said that the modern tendency was to approach the limit in the contraction of railway bridge waterways. A glance at Plate II showed that the Kalabagh Bridge was very differently sited from bridges in alluvial plains. The river issued from a gorge in a clearly defined curved expansion. There was no wide trough in which the river flowed, and the banks at the bridge site did not necessarily indicate, as they might elsewhere, the limits of the vagaries of the river from one big flood to another but more probably showed, as the discharge and also the scoured cross section suggested, that in this instance Nature had provided her own training works, and the banks had possibly been generated, not one at one time, and the other at another, but simultaneously at some previous very high flood.

The width between those banks was 3,100 ft. and since the river was curved, the active width owing to the retarded velocity on the inner flank was slightly less. If the width was taken as 2,900 ft. the formula showed that before the construction of the bridge the river could accommodate a flood of 11·8 lakhs cusecs.

* Procs. Inst. C. E., Vol. 229 "Stable Channels in Alluvium."

The effective waterway of the completed bridge was determined from the following approximate calculations :—

Gross waterway—		
9 spans of 263 ft. centres ..	.. 2367·00 ft.	
4 spans of 175·33 ft. ,, ..	.. 701·33 ft.	
		3068·33 ft.
Deduct.—		
Twice width of 8 piers of 22·125 ft.	.. 354·00 ft.	
Add for two end slopes to centres abutment piers ..	.. 60·00 ft.	
Twice width of 3 piers of 22·0 ft.	.. 132·00 ft.	
Add for end slopes ..	.. 60·00 ft.	
		606·00 ft.
Effective waterway ..	..	2462·33 ft.

According to the formula, that waterway would in ordinary circumstances accommodate a flood of about 8·5 lakhs without contraction of the waterway beyond its normal stable minimum width. The precise value of the maximum discharge was in doubt, but the siting of the bridge with reference to the gorge made it possible for a natural contracted section to exist, although possibly it was inadvisable to contract further, as had been done before the flood of 1929.

The point on which he desired to lay emphasis was that bridge engineers were not always presented with so favourable a site as this, and that they were now working right up to what might be regarded as the safe contraction of waterways. There was in his opinion a fixed minimum stable waterway beyond which no river in a khadir could be safely trained. If a less width than this was provided, the natural minimum width upstream during high flood was of necessity greater than that at the bridge, however skilful the training. There was thus a genuine bottle-neck immediately upstream of the training works with the possibility of reverse curves on each flank. This led to the formation of an island upstream, as had actually occurred at the railway bridge across the Jumna between Kalanour and Sarsawa. It was however correct to state that this condition was observable only after the catastrophic flood of about four lakhs in 1924, which vastly exceeded the previous records of irrigation and railway engineers alike. The previous record flood had been estimated at 2·5 lakhs and for this flood the bridge had been allotted a waterway which was sufficient, and in close agreement with that which the formula he had quoted would indicate.

KHAN SAHIB MIAN IQBAL HUSSAIN, Executive Engineer, Discharge Division, remarked that the Author had to lay great stress on the question of discharge, for he felt that all the damage done to the works was due to the wrong estimation of highest flood figure, and he had quoted the Thal Project Report in support of his fixing 8 lakhs discharge as the maximum possible one, for the original design of the bridge.

If he would please read the contents of para. 101, Part. VI of the actual report, he would find the calculations made therein by the Chief Engineer for the Headworks were arranged to pass safely more than one million cusecs. And therefore, when the Chief Engineer, Irrigation, could stretch his 8 lakhs figure to 10 lakhs, the Railway authorities could also have done just the same thing, especially when the Railway authorities had made independent enquiries. They could comfortably swell the figure as much as they liked as they were doing now.

The Author had asserted that during the record flood of 1929, no less than 12 lakhs of cusecs passed at Kalabagh. This figure was 50 per cent. more than the one fixed by the Irrigation authorities.

It was only in 1878 that the Kalabagh gauge recorded 706·0 and for that gauge the late Mr. Middleton had fixed a discharge of about 8 lakhs and this figure he considered to be the maximum possible. And now the Author asserted that because in 1929, the Kalabagh gauge recorded 708·7, the discharge evidently must be higher and he fixed a figure of 12 lakhs accordingly.

The Author might know that this gauge figure of 708·7 was not the actual representation of the gauge, which it would have registered had the stream been unobstructed as was the case in 1878. This time, below the gauge site, more than ⅓rd of the river section was blocked by the embankment and the piers and caissons. The Author, on page 89, had mentioned the maximum Kalabagh gauge as 707·2. This was wrong. It should be 708·7. Possibly he deducted 1·5 from this figure for his alleged afflux.

The Author was surprised to know that a figure of about 8 lakhs had been given by the Irrigation Department for the 1929 maximum record flood, but much as he might doubt this figure, he had not put forward anything solid in support of his own version.

There was a divergence of 20 per cent. in his Kutter's and Bazin's figures, and his own system of co-relation of velocities for different section under different conditions was undoubtedly defective.

The officers of the Discharge Division were present both at Kalabagh and Attock when the maximum flood passed and actual observations were made, and the figure arrived at from actual observation was 8,17,000 cusecs. Surface velocities were measured by surface floats (sleepers coming down the river) and their positions fixed by theodolite and plane tables. The same data collected and used in Kutter's formula with N= 0·03, would give 8,94,000 cusecs.

Now it was asserted that the gauge at Kalabagh was too much inflated or to put it differently, the afflux above the bridge was undoubtedly much higher than 1·5 ft. and certainly about 3 ft. or more.

The speaker possessed relative gauges of Attock (Khairabad) and Kalabagh for different periods when the gauges at both sites had been steady for more than 2 days and from this data one could easily establish a relation between the two.

Dates.	15-16 $\frac{7}{28}$.	6-7 $\frac{7}{28}$.	11-12 $\frac{6}{28}$.	28-30* $\frac{7}{24}$.
Khairabad (Attock). Zero R. L. of Gauge 871·32 ..	23·0	28·0	35·0	56
Kalabagh. Zero R. L. of Gauge 679·7 .	13·6	14·1	15·2	19

*During the maximum flood of July 1924 the Attock and Kalabagh gauges remained steady for more than 3 days.

Now if one gauge was plotted against the other, the value for 66·0 gauge which was recorded at Attock during the 1929 flood, could be easily worked out. This was found to be about 21·0 by the speaker.

In 1924, the Author mentioned on page 68, that the gauge had gone to R. L. 699·6, *viz.*, 19·9 gauge at Kalabagh and if that figure was an authoritative one, then the effect of an 86·0 gauge at Attock would possibly be about 21·9 at Kalabagh.

But because there had been an inflow of serious nature between Attock and Kalabagh increasing the discharge to the extent of about 3 lakhs at different times and different places, the gauge might have increased by 2 or 3·0, say 3·0 ft. maximum. Thus the ultimate gauge at Kalabagh again would be about 25·0, which had been obtained in 1878 and for which the late Mr. Middleton had correctly fixed an approximate discharge figure of about 8 lakhs.

On sheet No. II the behaviour of the gauges at both the sites was shown. The gauges were recorded hourly.

Immediately the Railway embankment gave way, the water surface dropped by about three feet.

Further, the peak period at Attock was only about 4 hours, while at Kalabagh the gauge remained steady for a full eleven hours, till the embankment gave way.

The speaker considered the only possible conclusion one could arrive at would be that the 1929 flood *did* only pass about 8 lakhs cusecs at Kalabagh and this could furthermore be verified by gauges below Kalabagh, where the 1929 gauges had remained at or below the levels of previously maximum recorded floods.

Finally he was of opinion that the real cause of the damage at Kalabagh was not actually the maximum discharge figure of 8 lakhs, but the

rigid policy of the Railway Department of shortening the waterways, and too much interference with the adapted section of the river and the earlier they relaxed that policy, the better it would be for all concerned.

MR. ISHAR DAS said he wanted to say something about discharges as he had been in charge of discharges at Kalabagh and Indus. He pointed out that the co-efficient of ·89 to be fixed with the surface velocity was not a correct co-efficient for all discharges. As one who had got the discharges of over thirty years or more for the Kalabagh and Indus gauges, his impression was that when the discharge went above five lakhs (he was only speaking from his memory) the co-efficient should be about ·91 and when the discharge went above six lakhs, the co-efficient should be about ·92. This could be borne out by examining the cross sections of the river and the relation of hydraulic mean depth with the discharge. Taking into account these different co-efficients, it would be found that the discharges would be different and as the assumed discharge was about seven lakhs, he thought that with a higher co-efficient the discharge would be more than that, and would be something between 7 and 8 lakhs.

MR. A. MUSTO, congratulated the Author on an extremely interesting and useful paper and said he had only a few remarks to make on practical points.

On page 80, the Author had discussed the form of the cutting edge. The speaker remarked that the cutting edge should always be as sharp as possible, and that the outer plate should be the lowest and the thickest. He considered that the blunt or rounded edge of the caisson was a hopeless design. The effect of the blunt edge was simply to support the caisson and increase the difficulty of sinking and of excavation. The rounded edge pushed material *outside* the caisson, thereby compacting all the soil as the caisson sank and increasing the skin friction throughout.

With reference to the concrete blocks referred to on page 73, the speaker asked what forms were used for making the recess in the underside of the concrete blocks for taking the T headed bolts. He explained that at Sukkur, wooden forms were, in the first instance, used, but it was found that in spite of thorough greasing and soaking before use, these wooden forms swelled in the concrete and were extremely difficult to remove, the bottoms in particular nearly always remaining stuck to the concrete. This necessitated making fresh forms for almost every recess; moreover when the block was lifted with the T bolt, the portion of the wooden form remaining in the hole became crushed and splintered, and this made it difficult to withdraw the T bolt after lifting. To overcome this difficulty, a special form made of concrete, in the shape of a small box, with the slot for the T head cast into it and the necessary recess below was made as a separate unit, and these concrete forms or boxes were spaced on the moulding floor, inside the form of the main block, before the latter was cast. The concrete form being heavy, kept its position on the moulded floor, without any holding arrangements, while concrete was being poured for the main block; and it also served as a guide and support for the taper plug used to form the slot for the T headed bolt right

S.E.L.B.C. Dg. No. $\frac{250}{1931}$.

C. C. CORE BOX FOR 10 TON BLOCKS

SCALE $\frac{1}{4}$ SIZE.

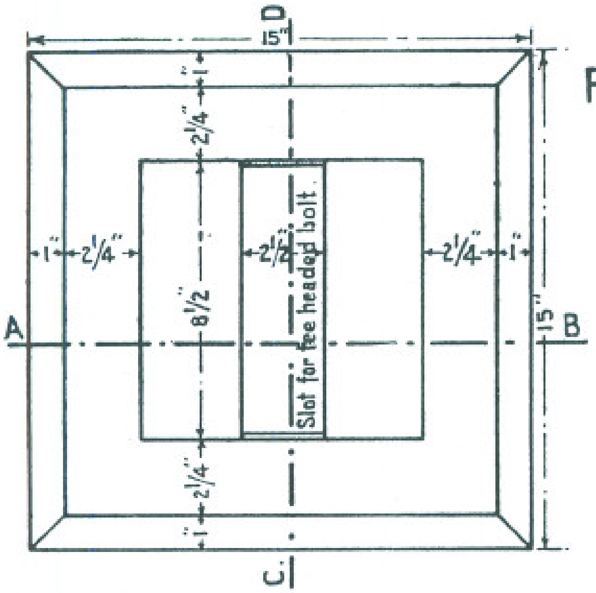
Sd. A. A. Musto

SUPERINTENDING ENGINEER

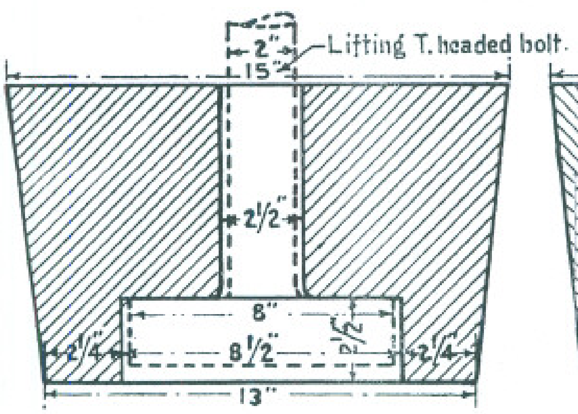
LLOYD BARRAGE CIRCLE.

PLAN

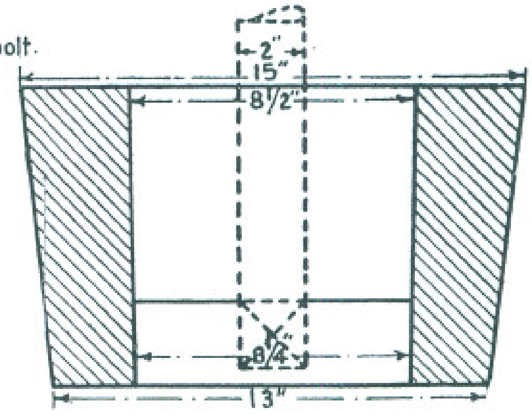
BOTTOM UPWARDS



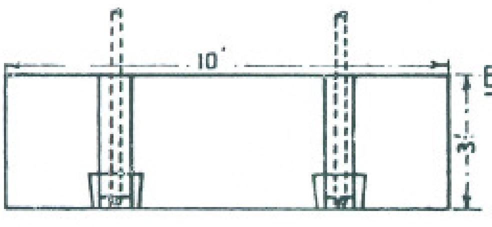
SECTION ON A.B.



SECTION ON C.D

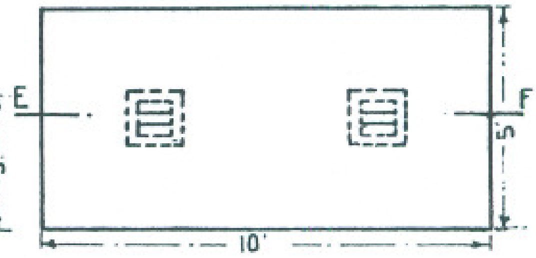


SECTION ON E F.



PLAN OF BLOCK.

SCALE – 3' = 1".



through the main block. The concrete form, or box then became, and remained as, a permanent integral portion of the main block. The cost of this concrete form was less than that of a wooden form, so that the whole cost of the forms was saved and the resulting recess and bearing for the T headed bolts was most satisfactory. Attached sketches illustrate the arrangement.

On pages 79 and 85, the Author had described the method of launching the caissons, but the weight of the caissons was not stated. He would be glad to know this figure. On page 85, the Author had referred to the unsuccessful use of water jetting and on page 79 he stated that a Worthington 4″ suction pump was used for the purpose. It was not stated what pressure was available with this pump. For successful jetting a multistage turbine pump giving a pressure of 600 to 1,000 lbs. per sq. inch was necessary.

On page 88, the Author had remarked that before the bund was breached, the stone pitching on the nose had "*begun to go*" The last words were somewhat confusing. Was not the pitching, laid round the nose, intended to fall as scour occurred, and thus prevent the undermining of the nose?

He would like to know what medical arrangements were made for the inspection and treatment of the men working in compressed air. It was usual to provide a medical lock for the treatment of "bends" and it was very advisable in the interest of the men that they should be medically inspected before every shift, as it was extremely dangerous for men to go into compressed air if they were unwell, and especially if suffering at all from cold in the head or catarrh.

Mr. M. D. Mithal said that the Author had mentioned about the allowance for afflux in the calculations of discharges, being 1·5 feet. On the speaker's experience at Marala, in charge during the record flood of 1929, it was found by actual observations that the afflux against each pier was between 2·5 feet and 3·5 feet. The velocities of the flood were between 20 and 30 feet per second and the total discharge of the flood at peak was 6,60,000 cusecs. The flood at Kalabagh had a discharge considerably over 8 lakhs and he imagined that the allowance of 1·5 for afflux was too meagre, for such high velocities of discharge.

Mr. R. R. Handa, referring to the arguments of Mr. Iqbal Hussain on the authority of various gauges reported from time to time, from various places, as regards the maximum discharge at Kalabagh, said that these gauges reported by the gauge readers should be accepted with discretion. He quoted his personal experience, when during the summer of 1930, he was getting practically constant gauges of the river Indus at Bilot, while the Paharpur canal dropped from 4·5 feet at its head to nil within four or five days. On his instantly going to Umarkhel, 17 miles from Bilot and 57 miles from Dera Ismail Khan to check the gauge, he found that the gauge reader, who was supposed to live at Umarkhel, three miles from the gauge, had gone on French leave to his native place, 23 miles from there and had arranged with someone to go on posting gauge cards regularly in his absence.

Readings at Khairabad, Attock and Kalabagh were probably reliable, but he mentioned an incident, during the high flood of 28th August 1929, when the peak probably took place at about 2-0 a.m., yet the subordinate in-charge, actually submitted the detailed calculations of observed discharge, with such niceties as observed surface velocities of the floods !

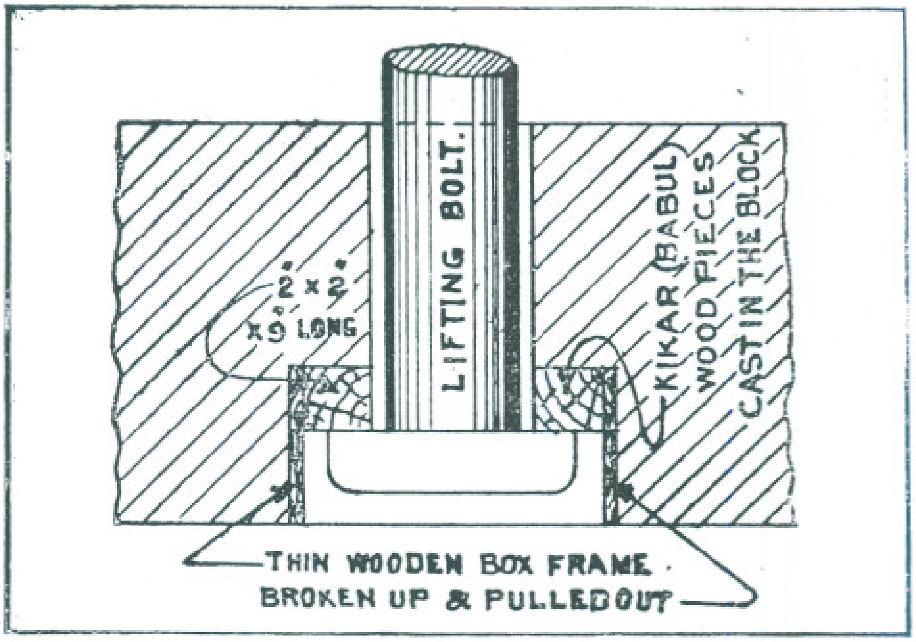
MR. H. W. NICHOLSON remarked that he was one of the members of the Committee which was appointed to examine the various discharges of river Indus. During the investigation, he scrutinized thousands of gauges and found that no reliance could be placed on the readings, many of which were fabulous. In this he confirmed the remarks made by Mr. Handa.

MR. F. C. JUDGES in reply to the discussion stated that the remarks in the paper about the absence of a stratum of conglomerate boulders was correct. It was true, as Mr. Vardon had said, that in some cases conglomerate boulders cemented together were undoubtedly found, but the actual stratum could not be described as such.

As regards the matter of pumps, he agreed that those used were far too small, but as the work was being done by contractors under a lump sum contract, there was no opportunity for experimenting, which would undoubtedly have been done on the lines of Mr. Vardon's suggestion had the work been carried out by the Railway in the ordinary manner.

Before touching on the question of the discharge, he said, he would first deal with practical points raised by Mr. Musto. He agreed with Mr. Musto that the cutting edge should be as sharp as possible. Also that the outer plate should be the lowest. But the fact was that owing to the difficulty of obtaining suitable material in India, a 12″ plate instead of a 14″ plate had to be used and the cutting edge had to take the form shown. In later designs the cutting edge was arranged with the outer plate the lowest. So far as skin friction was concerned, it was proposed to deal with this in a later paper, but at present he could say that skin friction worked out roughly to 5 cwt. or say 600 lbs. per square foot. The skin friction was affected considerably by the design of the caissons. The caissons used originally were twin octagonal in shape, and the triangular wedges at the centre of the sides undoubtedly increased friction. It had been found in the caissons for the extension wells, where straight sided caissons were used, that skin friction diminished considerably and wells went down much more rapidly.

As far as the handling of the blocks was concerned, this was done as shown in the following sketch :—

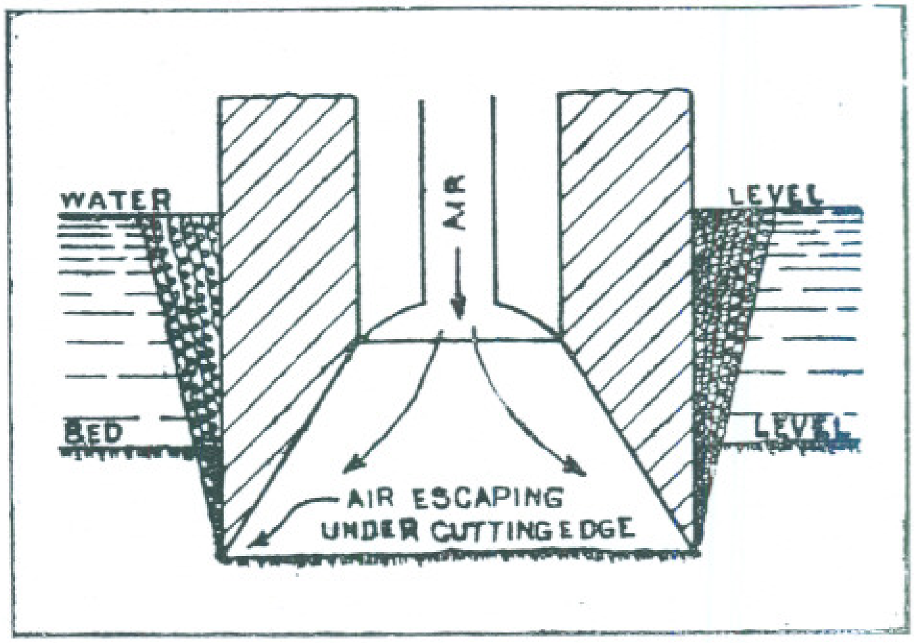


Mr. Musto had asked about the weight of the caisson. This was $47\frac{1}{2}$ tons.

As regards the use of water jets, the contractors did not choose to use them to any great extent, but it is probable that had suitable apparatus been provided, the method might have proved useful in helping the wells down.

Referring to Mr. Musto's query regarding the stone pitching at the nose of the bund, the point it was intended to bring out was that the action was not the usual one of the apron being underscoured and stone from the slope slipping down to take its place, but that the velocity past the nose was sufficient to remove stone bodily from the slope itself. After the flood the apron was found to be almost intact with no underscoring but the nose above it seriously damaged. It was therefore considered that a nose of pitching was not a safe form of construction in such a high velocity stream.

As far as the ventilation of the working chamber was concerned, no special ventilation was necessary as the air passed under the cutting edge of the caisson. There was thus a continuous flow of air and a special means of ventilation was not required. (See sketch below).



Regarding medical arrangements, they were fortunate to have a very good doctor in charge, and everyone before being allowd to work under pressure was sent to the doctor to get a certificate of fitness. No separate medical lock was provided, but in case of emergency one of the locks could always be used as such. A reference to figure 12 in the Paper would show that the First Aid room was fitted on the 150 ton barge, to be available in case of necessity.

References had been made by Messrs. Iqbal Hussain, Nicholson, and Lacey regarding the discharge. The criticisms made would be replied to by correspondence, as they could not be dealt with adequately in the short time available.

Mr. Isher Dass' remarks regarding the co-efficient for estimating the mean velocity were very interesting, and it was valuable to obtain these remarks from one who had first hand experience. He was inclined to think that a slightly higher co-efficient than that used might be more correct.

CORRESPONDENCE.

THE AUTHOR, in correspondence, expressed his thanks to Mr. Judges for introducing the Paper and for replying so capably to the discussion.

He wished to mention that, since the presentation of the Paper, Well "F" was completely righted and sunk to its full depth R. L. 614·10 by the 14th March 1931. Well "G" was commenced and sunk to its full depth R. L. 616·20 by the 24th March 1931. Of the work in the extension, the abutment, with open founds, had been completed and the three intermediate wells had been completed and sunk to R. Ls. 638·32, 638·11 and 637·76 respectively. All substructure work had thus been completed and girder erection had made such rapid progress that it is expected to open the bridge for traffic in August 1931 instead of March 1932. This had been made possible owing to the speed of girder erection, thereby eliminating the loss of time that would have been incurred otherwise during the flood season.

The Author thought that there was some misapprehension in Mr. Vardon's mind regarding the use of the term "Conglomerate boulders." This term was applied at the time the original borings were taken to a "stratum" and not to a particular boulder. Amongst the boulders met with, there was a proportion which were actually conglomerate but the Author maintained that it was incorrect to apply this term to any of the strata penetrated.

Referring to Mr. Vardon's second point, the object of de-watering was not merely to expose the bottom of the well and so enable workmen to pick out and displace the boulders. In the Author's opinion this could only be done satisfactorily for comparatively shallow depths, as for great depths, where the rate of infiltration was high, the cost of pumping would become prohibitive as would be seen from the figures of cost given by Mr. Vardon. This would have been all the more pronounced at Kalabagh, where the subsoil was so porous and the rate of infiltration very high in consequence. The value of de-watering lay principally in the reduction of buoyancy and a corresponding addition to the weight of the well. In the Kalabagh wells, for instance, every foot of de-watering was equivalent to adding a load of 18 tons to the well, thus increasing the sinking effort. Mr. Vardon's suggestion to use pumping as an alternative method of sinking would, the Author considered, be satisfactory for moderate depths only, and experiments at greater depths, whether successful or not, would prove costly. Without relying on the pumps as a sole method of sinking, there was no doubt that where open dredging was carried out, pumps of the type suggested by Mr. Vardon would have been of use in lowering the water in the wells quickly and allowing the rapid infiltration to loosen the shingle and boulders at the bottom. As a matter of fact, pumps of this pattern had been earmarked before it was decided to execute the work by lump sum Contract. The contractors hadnot, so far, attempted this method on the Sagaing Bridge in Burma. The Author was firmly convinced that where a substratum similar to that at Kalabagh was encountered the only satisfactory method was to adopt the pneumatic process as soon as open dredging gave unsatisfactory progress.

The Author observed that he was acquainted with Mr. Lacey's interesting and valuable Paper "Stable Channels in Alluvium" and was gratified that Mr. Lacey had taken part in the discussion. The points raised by Mr. Lacey concerned the discharge, width of waterway provided and scour.

As regards the discharge, the Author thought that Mr. Lacey's formula, while of great value in dealing with sandy bedded rivers in the plains, could scarcely be expected to apply to conditions such as obtained at Kalabagh, where the substratum consisted largely of boulders. In the alluvial plains river a "stable" bed rarely existed and Mr. Lacey's comparisons in his Paper of lineal waterways provided in certain railway bridges with those arrived at by his formula were made after the rivers had been rendered stable by restriction and training works. The case of Kalabagh was however, different. At the bridge site the bed could be considered fairly stable though it was not without the wide trough referred to by Mr. Lacey in which the main river flowed. The unrestricted river had a surface width at R. L. 704·1 (the level taken in the original design) of 3,507 feet and a wetted perimeter of 3,530 feet. If the formula was applied it would be found that the discharge based on the surface width worked out to 17,27,000 cusecs, and if based on the wetted perimeter to 17,50,000 cusecs, both obviously too high. The effective waterway of the extended bridge was 2,514 feet, after deducting twice the width of piers and allowing for the distance between the water-edge and abutments, at H. F. L. 705·20 (the level reached in 1929). This, according to the formula, would give a discharge of 8,90,000 cusecs.

With respect to depths of scour the Author was glad to take the opportunity of making a few remarks as he had designed the waterway for the Ravi Bridge at Dera Baba Nanak. He was much struck, at the time of reading Mr. Lacey's Paper, with the close agreement between the results obtained by Mr. Lacey and those calculated by him, and he agreed that the use of Mr. Lacey's formula was a very useful adjunct to the methods usually employed and formed a reliable cross-check. But as regards the conditions at Kalabagh, he did not think the formula would hold. Depths of scour were taken as from H. F. L. At Kalabagh, assuming a discharge of 12,00,000 cusecs, and a silt factor of 10, the minimum figure for boulders and shingle given in Appendix "G" of Mr. Lacey's Paper, V_o was 17·8 f. p. s. Classifying the River Section as Type B (Mr. Lacey's Paper, p. 279) the scour would be 34 feet below H. F. L., which was less than the depth of water in the main channel at high flood level. The conclusion seemed to be that it was expecting too much that a formula adapted to an alluvial bed would apply to a boulder bed. In Mr. Lacey's Paper on pp. 276 and 277, the utility of his formula for determining the stable waterway in "sandy beds" was emphasized. The Author was unable to believe that the formula was capable of such general application as to be suitable for a river with a sand and boulder bed.

The Author has seen nothing to change his opinion that the discharge in the 1929 flood was in the neighbourhood of 12 lakhs cusecs. Had the maximum discharge not exceeded 8,00,000 cusecs he was satisfied that the waterway provided originally was ample. It was perhaps providential that the 12,00,000 cusecs discharge occurred during the construction, and so enabled the required extension to be built simultaneously with the rest of the work. The figures indicated, especially the calculated discharge through the unrestricted waterway by Mr. Lacey's formula, that the formula was not applicable to a river with a boulder bed. Its suitability to the alluvial plain river, as evidenced by examples in Mr. Lacey's Paper, was further reinforced by comparing the waterway provided in the new railway bridge over the River Jhelum near Khushab and Mr. Lacey would be interested in the figures. A discharge of 4,46,000 had been estimated by the Irrigation Department as the maximum discharge at the bridge site. The bridge consists of 15 spans, 159 feet between centres of piers. Wells were 21′-6″ wide. Deducting twice the width of the wells and the distance between water edge at H. F, L. and abutments, the lineal waterway was 1,714 feet. The wetted perimeter, making similar deductions was 1,748 feet. Mr. Lacey's formula gave a width of 1,782 feet.

As regards the detailed hydraulic data referred to by Mr. Lacey, these were omitted as the Paper had to be condensed as much as possible. They were now given. The results were different from those in the Paper as a re-examination had shown that the cross sectional area was originally calculated hurriedly immediately after the floods from a drawing where the vertical scale was ten times the horizontal. This was brought to the Author's notice since the presentation of the Paper. The re-checked and corrected figures were :—

Fall per mile along Mari Bank .. 4·36 feet.
" " " Kalabagh Bank .. 5·25 "
Mean fall per mile = 4·8 feet = 1 in 1,100 = S
Area of Cross Section (From Plate XV) = 91,318 s. ft.
Wetted perimeter = 3,170 l.ft.

$$R = \frac{91,318}{3,170} = 28{\cdot}8 \text{ feet}, \quad \sqrt{R} = 5{\cdot}37$$

Discharge by Kutter's Formula.

N = Co-efficient of roughness taken as 0·30
C works out to 84·05 and V to 13·45 f. p. s.
Q = 13·45 × 91,318 = 12,28,000 cusecs.

Discharge by Bazin's Formula.

$$V = \frac{157{\cdot}6\sqrt{R.S.}}{1 + \frac{c}{\sqrt{R}}} = 15{\cdot}9 \text{ f. p. s.}$$

c being taken as 3·17,
Q = 15·9 × 91,318 = 14,29,500 cusecs.

It was five days after the flood before the river was quiet enough to take soundings, which occupied a week. It was likely that there was deposition of silt and that at the height of the flood the depth and therefore the velocity would have been greater. This would bring the velocity found from the curve (13·1 f. p. s.) in closer agreement with that from Kutter's formula (13·45 f. p. s).

The various figures of discharge for the 1929 flood, were as follows :—

		Cusecs.
1.	By Velocity Curve and Cross section ..	11,99,000
2.	By Kutter's Formula	12,28,000
3.	By Bazin's Formula	14,29,500
4.	By Lacey's Formula	8,90,000
5.	By Irrigation Branch	8,17,000

The above figures showed the difficulty of estimating the discharge with any great accuracy.

The details of the Haro and Sohan discharges were not available but they had been worked out by Kutter's formula. The Haro discharge was found to be 1·69 lakhs cusecs and the Sohan 1·39 lakh cusecs.

It would have been clearer, as Mr. Lacey suggested had some scale been given to Photo No. 3. The largest boulder was $2\frac{1}{2}'$ to $3'$ in dia.

Regarding Mian Iqbal Hussain's remarks, the Author observed that the subject of the maximum discharge of the Indus at Kalabagh had a whole Appendix to itself (App. M. 1) in the Thal Canal Project, in which the maximum flood discharge was calculated in two ways with results of 757,500 cusecs and 770,000 cusecs, respectively, followed by the definite statement that "for the purposes of design, etc., the maximum flood is being taken as 800,000 cusecs." The portion of para. 101 referred to by Mian Iqbal Hussain ran as follows:—" It is worthwhile to note that even if the maximum flood passing the weir should happen to be as much as one million cusecs it could be passed over the works." As the Railway's independent investigations agreed with those of the Irrigation Department in calculating the maximum discharge at 8 lakhs cusecs, there was no point in allowing for an extra 2 lakhs on the ground of a casual remark in para. 101.

Mian Iqbal Hussain had stated that more than one-third of the section was blocked by the embankment and the piers and caissons. Taking the cross section of the bed as it had been for many years before it was scoured by the great flood of 1929, the cross sectional area at water level R. L. 704 was 69,914 s.ft. The area blocked by the embankment and wells amounted to 13,300 s.ft. As the mean velocity in the portion blocked by the approach bank (6,715 s.ft.) was only $6\frac{1}{2}$ f. p. s. against 10 f. p. s. for the whole area, its effect was only equivalent to ·65 if 6,715 ft.=4365 s.ft. *i.e.* 2,350 s.ft. less. As the total of 13,300 must be reduced correspondingly to 10950, it would be seen that the restriction was only some 16 per cent. and not 33 per cent. as stated. Perhaps the most surprising statement made was that ıe officers of the Discharge Division were present at Kalabagh when the ıaximum flood passed and that actual observations of surface velocities ʳere made by fixing the position of surface floats (sleepers coming down ıe river) by theodolite and plane table. The Author could not refrain ·om pointing out that the peak of the flood occurred between 2 a.m. nd 4 a.m. on a dark night, and would be pardoned if he assumed that the peaker must have been misinformed. To any one acquainted with the .ischarge site, where the river passed through a narrow gorge, the diffi-ulties of gauging the discharge of a mighty river in full spate even in ıroad daylight were apparent. The value—or rather lack of value—of ·auge readings and discharge figures based on them and the severe emarks on their reliability by Mr. Handa and Mr. Nicholson lent dditional weight to the doubt that must have arisen as to their accuracy n this instance.

Mian Iqbal Hussain still thought that the maximum discharge did .ot exceed 8 lakhs cusecs. The Author had seen a hydrograph of the ndus floods of 1929, which showed the maximum discharge of the Indus ıoth at Attock and at Kalabagh as 8·18 lakhs. As there could only have ·een very little difference in time between the peak floods at the two laces, there was ***a priori*** something wrong. The catchment area drain-ıg into the Indus between these two points was 9,000 sq. miles, including wo large tributaries, the Haro and the Sohan rivers. It was known hat heavy rainfall occurred over the area during the high flood period. f a run-off of only 40 cusecs. a sq. mile was assumed, a low figure for an rea of this nature, the inflow between Attock and Kalabagh would be ,60,000 cusecs. The Author was unable to accept the figure of 8 lakhs usecs at Kalabagh and was sure that it must have been in the neighbour-ood 12 lakhs cusecs.

As regards the co-efficient of ·89 connecting mean with surface velo-ities commented on by Mr. Ishar Dass, there was room for variety of pinion as to the correct figure to be taken. Mr. Ishar Das's contribution › the discussion was very interesting ; actually the difference in the stimated discharge would have been between 1 and 2 per cent. had his gures been adopted, a comparatively small difference, considering the ifficulties involved in estimating the discharge of a large river with a reat degree of accuracy.

Mr. Judges had already replied very fully to the interesting contri-ution to the discussion made by Mr. Musto, and the Author found no ecessity for further comments.

The afflux referred to by Mr. Mithal in the Paper was not the afflux t a well. Most of the well-tops were under water at the time of the great lood, but affluxes up to 4 feet at a well had been observed in minor floods. These affluxes were purely local and were not to be compared with any ·eneral afflux in the main body of the water.

In conclusion, the Author desired to thank all those who had taken ıart in the discussion ; which had brought out many points of interest.