PAPER No. 158.

PRESSURE OBSERVATIONS AT JAURIAN AND DUGRI SIPHONS

By P. A. Turner, Assistant Engineer.

The Upper Chenab canal from its offtake at Marala traverses low: lying country which slopes from left to right for the first 15 miles or so of its length (see plate I). The average declivity of the river being about 1 in 3000, the canal which is graded at 1 in 6666 gradually gains in elevation with respect to the river. From 0 to R. D. 17000 it is in close proximity to the river on the right but gradually slants away below this.

The subsoil water table before the advent of the canal was higher than the designed bed of the canal in the reach 0 to R. D. 35000 as will be seen from the following levels :—

	Spring level.	Designed canal bed level.
R. D. 5000	802·0	789·41
R. D. 17000 (Tan Nalwah Siphon) ..	793·17	787·61
R. D. 35000 (Dugri Siphon)	785·66	784·91
R. D. 50000 (Palkhu Siphon)	779·15	782·66

With the opening of the canal the subterranean flow to the river from left to right was intercepted resulting in a general rise in spring level all round.

To make matters worse both the Tan Nalwah (R. D. 17050) and the Dugri (R. D. 35000) siphons were constructed with their barrel lips 4·0 feet, and 3·7 feet, respectively above canal bed. This effectively cut off all possibility of drainage from the left at a low level. In addition to this, no particular attention was paid to keeping the outfall channels of these siphons clear, which materially assisted in causing a rapid rise in the subsoil water table.

The reaches along which the spring level was lower than the bed of the canal, *i. e.*, beyond R. D. 45000, where the relative difference between the canal and river afforded a better outfall for seepage, there is still adequate slope in the subsoil water table which keeps the seepage level down.

Below the Jaurian Siphon (R. D. 63000) there are six other siphons four of which have had their up and downstream floors extended. All have shallow curtain walls, yet not one of them is giving the slighest trouble. This is explained by the better outfall afforded for the subsoil seepage flow which keeps the seepage level down adjacent to the canal and affords a steeper gradient through the banks.

Normal gradients.

The normal gradients of the water level through the bank observed at most of the siphons and shown plotted on plate II bear out the above. These gradients have been obtained by driving in pipes with filter points 100 to 200 feet upstream of each siphon. The difference between the canal water level and readings of pipe No. 1 may be called the loss of head at entry.

The pressure may be taken as the height above canal bed of the level in pipe No. 1.

The statement below gives these values tabulated.

Name and R. D. of siphon.	Loss of head at entry.	Spring level above canal bed.
Tan Nalwah R. D. 17050	1·06	13·25
Dugri No. 1 R. D. 35800	1·35	10·86
Palkhu R. D. 52200..	3·51	9·31
Jaurian R. D. 53450 (Upstream) ..	2·48	9·95
(Downstream). ..	5·14	6·32
Sambrial R. D. 90273	7·13	4·91
Kot Daran R. D. 100650	7·62	4·29
Passia R. D. 115900	3·40	8·14

The difference between the canal level and the level in pipe No. 1 given an indication of the state of waterlogging along the canal. Where waterlogging conditions are worst, as along the head reaches, the loss of head at entry is least due to all outflow having been stopped, and pressure is greatest. As the subsoil outflow increases along the lower reaches of the canal and waterlogging conditions improve the loss of head at entry increases and the pressure decreases. This accounts for siphons below Jaurian not giving any trouble, though all of them have shallow curtain walls.

It will be noticed from the statement that the loss of head at entry at the Passia siphon has again reduced, indicating an increase in water-logging. This agrees with conditions at site. Waterlogging in the vicinity of this siphon was at one time very bad due to flooding of the countryside by the Aik. New drainages have now been opened up and conditions are improving in this area, but the full effect has not yet been felt near the canal. It may be asked why this siphon with a pressure head of 4·26 acting on the upstream floor is not causing trouble. The reason appears to be in the fact that this siphon is founded on a 25 feet deep layer of clay. There are springs appearing in the flooring but these are clear and they cannot wash out the clay.

As regards the Tan Nalwah siphon where the loss of head is only 1 foot, serious trouble appears inevitable as soon as the outfall channel is cleared. The present state of the outfall channel is causing heading up at the siphon which minimises the formation of springs and the blowing of sand. This siphon will need very close attention as soon as any attempt is made to lower the outfall.

Adverting to the pressure observations at the various siphons referred to above, one very interesting point which was noticed while the pressure gradients were being observed was that at the Jaurian siphon the pipe observations on the upstream of the siphon gave very much higher readings than those on the downstream side and at the siphon itself. The reason for the higher gradient along the upstream pipes is that the original seepage drain on the upstream side leading to the siphon and close to the canal was filled in, and a new diversion drain was excavated 1000 feet away from the canal joining the siphon inlet nala.

The point where the water surface through the banks meets the general subsoil level having been moved away, the pressures on the upstream side of the siphon rose. This rise is still causing blowing of sand to take place in the left half inverted filter and from behind the sheet piles, causing this portion of the flooring to settle and new cracks to develop.

Most of the damage in siphons has been caused by percolation from the canal taking place under and around the sides of the structures. This filtration past the sides and bottom in gradually increasing quantities, causing displacement of sand particles, eventually renders an otherwise sound structure unsafe.

Dugri Siphon.

The history of the trouble experienced at both the Dugri and Jaurian siphons has been described by Mr. Khosla in his interesting paper "Hydraulic Gradients in subsoil water flow, etc." Punjab Engineering

Congress 1930. The measures adopted from time to time to protect the siphons from failure, up to the remodelling of the up and downstream floors of the Dugri siphon during the canal closure of January 1929, have also been described in the same paper. These last repairs described in Mr. Khosla's paper gave the impression that a solution of the difficulties experienced at this and the Jaurian siphons had at last been arrived at.

In this paper it is not intended to refute any of the arguments already advanced or conclusions arrived at by Mr. Khosla but to bring before the Congress the results of further observations carried out, the process of detecting the presence of cavities under the floor, and the effect of cement grouting of these cavities on the pressures as indicated by the pipe observations.

The author has been in touch with these works since 1927 and in immediate charge since November 1919, and puts forward the results of observations since those reported by Mr. Khosla.

The minute hair cracks which had appeared across the upstream floor during the summer of 1929 were not at first regarded as serious nor were they considered to be indications of any serious trouble. The cracks were found to coincide with cracks which existed in the old floor which had been boxed over when the new extensions were carried out and by November 1930 they had developed considerably. A spring in the inverted filter had also become active and was blowing large quantities of sand. It was realized that something had to be done and the sooner the better. As a temporary measure the exit of sand was checked by making a ring bund around the spring.

An examination of the readings in the pressure pipes, see table below, shows that for similar canal levels the water level in the pipes had dropped considerably from 22nd February 1930 to 26th November 1930, the average drop being about ·4′ in each pipe with cunette level ·09′ higher than on the first date. Under above conditions of canal and cunette level, the subsoil water level may be safely assumed to be, if anything, a bit higher at the time of the November observations, considering the period of high supply in the canal and the rise in subsoil water table due to the monsoon.

Date.	Upstream Floor.					Up-stream cunette.	Canal. level.
	Pipe No. 1.	Pipe No. 2.	Pipe No. 3.	Pipe No. 3.	Pipe No. 5.		
22-2-30 ..	93·49	93·45	93·34	93·29	92·30	89·10	794·62
26-11-30 ..	93·16	93·00	92·92	92·97	91·95	89·19	794·62
Fall ..	·33	·45	·42	·50	·35	·09	..

Another pecularity in the pressure readings was also noticed. The gradient had steepened considerably but while the slope was regular after the canal had been running some time with a steady gauge, on a rising canal the pressure in the pipes showed marked inequalities of rise.

The deduction from the regular drop in all pipes from February 1930, to November 1930, combined with the irregular rise was undoubtedly that cavities existed beneath the floor.

A change in the rotational programme of distribution of supplies afforded a 12 days' closure early in December and gave an opportunity for carrying out some observations. Repairs could only be carried out during a long closure but it was desirable before attempting any repairs to ascertain the cause of the trouble.

A series of observations were made on 14th December 1930, on reopening the canal, to see the effect of a gradual rise of the water level in the canal on the pressure under the floor as indicated by the pressure pipes along the central wall (see plate III for their positions). The results of these observations are shown plotted in figure 1, plate IV. It will be seen that the pressures in the various pipes for the same canal gauge do not follow any regular gradient and produce a zig-zag line, while from pipe No. 4 to the central strainer, and on to pipe No. 5 they slope down rapidly.

Similar observations on the rise of pressure in the pipes were taken on 19-4-31 after the grouting of the cavities and are shown plotted in figure 2, plate IV, spring level being again down to 787·0. These two diagrams indicate the extent to which the cavities have been filled and flow past the sheet piles reduced.

Grouting operations.

The presence of cavities having thus been established, it was decided to pump in neat cement grout under the floor. Plate III shows the various pipes lettered A, B, C, etc., through which grouting was done and the number of cement bags consumed in each grout hole. The total number of bags consumed was 476. The grouting was carried out in two instalments, 276 bags being pumped in during the January closure and the balance 180 bags during a 12 days closure in April.

Further grouting during January was discontinued when it was noticed that on reaching 219 bags in pipe E the grout was getting past the line of sheet piles and was appearing in the inverted filter. The area in which this took place is shown in plate III. The fact of the cement getting past the sheet piles indicated the presence of cavities adjacent to the line of piles and the fall in the pressure of pipe No. 5 also indicated this. That the grout passed and spread almost under the entire floor was indicated by the pressures which were observed while the grouting was in progress. These rose in all the pipes as the grouting progressed, in some more than in others, according to the extent of the cavities adjacent to them. All existing cracks both along the high floor and at the junction of the siphon barrels with the new work showed very clear signs of moisture oozing out indicating that water was being displaced and cement was finding its way into the cavities.

Mr. J. B. G. Smith, Chief Engineer, inspected the Dugri siphon on the 5th April 1931, and approved of a proposal to replace the inverted filter by a 2·0 feet layer of puddle and ordered that a 10" Tej strainer be installed at the site of the spring. He also approved of further grouting being done during the canal closure from 7th to 19th April 1931. This work was accordingly carried out and the following particulars may be of interest.

While grout was being forced into pipe F, which took in all 155 bags, cement discolouration appeared in the spring indicated by the position of the strainer. (See plate III). This showed that creep under the floor was directed to this central spring.

The chief difficulty which confronted one during the process of grouting was expelling the water from the cavities under the floor. The closure being a short one the subsoil water level had not dropped sufficiently to dry out these cavities, I believe that if the subsoil water level could have been lowered, a far greater quantity of cement could have been pumped into the cavities. The total number of bags consumed in this second attempt was 180.

On conclusion of this work it was decided to drill trial holes through the flooring in order to ascertain whether any further cavities existed and also to see the extent and thickness of the grout seams. For this purpose two holes were drilled in positions X and Y indicated on the plan (plate III). These were set back 3 feet from the line of sheet piles. The designed thickness of flooring here is 2·5 feet but at both the sites the borings revealed a thickness of 3 feet probably due to 6" extra thickness having been rammed into the puddle during construction of the floor.

Under the right half high floor, position X, there was in addition to the 3 feet thickness a seam of 1'-9" of neat cement below the concrete and below this the puddle was tightly packed against the bottom. The 1'-9" seam of neat cement was the result of the January grouting.

Under the left half at position Y, below the 3 feet of concrete, there was a seam 10" thick of January grout and below this again a seam of 11" of new grout, the result of the 155 bags cement consumed. Below this again the puddle was tightly packed. The seam of new cement under the left half high floor represented the extent of the cavity developed or left unfilled since the January grouting was carried out.

It has already been mentioned that pipe E took 219 bags after which it was noticed that grout was escaping past the line of sheet piles into the inverted filter. Before laying the puddle which was to replace the inverted filter, a point was made of investigating the creep line taken by the cement slurry as some doubt existed about this and it was required to see whether this had been forced through a faulty joint between the concrete and the head of the piles or had crept up the sides. By excavating to depth of 6 feet below the cunette floor it was seen that the cement had crept down and risen up the outer face of the sheet piles in a seam about ½ inch thick and coming to the surface has spread along a considerable area of the inverted filter.

The extent of cavities which existed prior to grouting can be visualized from the fact that in all 476 bags of cement grout was absorbed in them. When the new floor was constructed during the January closure of 1929 there were numerous cracks in the old cunette as well as in the high floor and vigorous springs had been blowing tremendous quantities of sand. Grouting had been carried out but 30 bags cement was the maximum consumed in any one cavity. It was obvious therefore that most of the cavities had been left unfilled when the old flooring was boxed in by the new. So long as the boxing was complete no serious harm resulted, but no sooner had the spring made its appearance and commenced blowing sand than the cavities already existing under the floor afforded an easy passage for flow to take place and to dislocate further particles of sand.

It has been observed that on opening the canal the spring in the inverted filter begins to work within 15 minutes of the water reaching the siphon and when level in canal has risen only to 789·0.

In order to see the effect of the final grouting of the cavities in restoring the pressure gradient under the floor and to compare these with the normal gradient prevailing at the site of the siphon, a second line of pipes with strainers was fixed 100 feet upstream of the siphon. The pipes in this line correspond to those in the central wall both as regards their distance from the water edge and depth of their filter points. Reference is invited to plate V. The top firm line shows the normal gradient as obtained from the new line of pipes for a canal gauge of 797·0. The middle line shows the gradient as obtaining at the siphon. All strainers are working and the fall below the upper or normal gradient represents the extent of relief afforded by the strainers. All creep has been eliminated by the grouting and the loss of head between pipe No. 1 and pipe No. 5 is brought within reasonable limits. The dotted line indicates the pressure gradient for the same canal gauge prior to grouting. The statement below shows the gain at each pipe :—

Date.	Upstream floor.					Up-stream cunette	Canal level.
	Pipe No. 1.	Pipe No. 2.	Pipe No. 3.	Pipe No. 4.	Pipe No. 5.		
27-6-29 ..	94·44	94·30	94·07	93·74	92·80	89·46	796·95
30-5-31 ..	95·25	95·10	94·93	94·73	94·55	89·30	797·00
Rise due to groutings.	·81	·80	·86	·99	1·75	Conditions practically simliar.	

The effectiveness of the grouting in restoring the pressures is further illustrated on plate VI. With the cunette free water level ·57′ higher on 6th July, 1929 than on 12th May, 1931, the rise in the pressure gradient due to the filling up of the cavities is very marked. It has further been observed that in the absence of cavities, a rise in the free water level over the cunette, produces relatively a small rise in the pressure gradient. This is shown on plate VI. The canal gauge is identical on both dates but cunette free water level 1·28 feet higher on 22nd April, 1931 than on 16th May, 1931. The maximum rise is in pipes 4 and 5. A contributary cause of this is possibly the increased head on the central strainer which discharges into the cunette at R. L. 789·0.

Jaurian Siphon.

The foregoing briefly describes the grouting of cavities under the Dugri upstream floor and the influence of this grouting on the pressure gradient. Similar grouting was also carried out under both the up and downstream floors of Jaurian siphon and the following is a brief description.

The positions of the grouting pipes have been given in plates VIII and IX. The downstream floor was treated first with very satisfactory results. Grouting was commenced with pipe A in the right half high floor (see plate VIII). This pipe consumed 43 bags but grouting was stopped at this stage when a quantity of grout suddenly burst through the inverted filter on the left side, immediately above the railway bridge.

The grout, in this case also, went past the sheet piles and, it is presumed, under them as in the case of Dugri siphons. Before this stage was reached, however, it was noticed that grout had found its way along the cunette and in addition to coming out on both sides of the central railway pier at its junction with the cunette floor, it had also risen to a height of 5 feet above the cunette floor through the masonry of the central pier till finally all cavities had been tamped. Pipe B was next treated but the results here were not satisfactory as the grout outflanked the line of sheet piles from the extreme left after only 12 bags had been pumped in and burst out downstream of the left wing wall as shown on the plan.

Further grouting of the downstream floor was discontinued and the plant was moved upstream. On this side only one pipe, in position marked A on the plan (plate IX), was fixed but the results of grouting through this pipe were most satisfactory, 39 bags of cement were consumed. The grout spread over the entire floor and rose above the high floor level on both sides through all cracks. These have been indicated on the plan. As at Dugri the pressures in all the pipes rose during the process of grouting, where cavities existed. No grout, however, appeared to have got past the line of piles as the strainers on the outer side of the piles were unaffected.

With regard to conditions prevailing at this siphon the floors were remodelled and extended during May 1927 and as originally constructed had shallow curtain walls. The canal bed and side slopes were puddled to a distance of 125 feet up and downstream of the centre line of the siphon. The outfall channel for this siphon was opened up and lowered during 1928 and 1929. The shallow curtain walls both up and downstream were replaced during January and April 1930 closures by 11 feet sheet deep piles.

Observations of the pressure pipes in the upstream floor of the Jaurian siphon are of interest in this connection, and are shown in the table opposite. Their position is shown on plate IX.

The observations of 25th August 1927 were taken soon after the floors of the siphon were remodelled. By the 17th August 1929 the Jaurian outfall channel was opened up and lowered. The bed level adjacent to the siphon was lowered to R. L. 776·0, *i. e.*, 3·2′ below downstream cunette floor. The effect of this lowering is seen by the drop in the pressures of nearly all the pipes.

Comparing the observations of 16-8-1929 with those of 25-8-1930 it will be seen that there has been a further drop in pressure since the sheet piling was carried out.

Considering the pipes in the central section, *viz.*, Nos. 8, 9, 10, and 11, it will be seen that there has been a steepening of the pressure gradient between pipe 8 and 10 from August 1927 to August 1929 due to the lowering of the outfall. This steepening from ·46′ to 1·11′ appears out of all proportion to the difference in levels between canal supply and the pressure in pipe No. 11 on these dates, *viz.*, 7·18′ and 7·84. Between pipe No. 10 and pipe No. 11 there has been slackening . This indicates movement under the floor.

By August 1930 when sheet piles had been put in, the gradient between pipes 8 and 10 has slackened, as was to be expected, while it has steepened between Nos. 10 and 11. After grouting of the flooring the observations of 4-5-1931 show a further slackening up to the line of piles and the main difference in pressure is concentrated between pipes 10 and 11 across the piles, indicating that the grouting with the piling has rendered the structure reasonably safe by reducing the possibility of movement taking place.

Conversely any steepening of the gradient under the work in future will indicate that movement has taken place.

In this paper I have indicated how structures originally safe as designed have become unsafe owing to changes in the subsoil water conditions and have shown how they have been restored to stability.

I would like to bring prominently to notice the danger of altering the subsoil water conditions without considering the effect on such structures, and in conclusion to lay stress on the fact that any steepening of the water pressure gradients under structures unaccompanied by a corresponding change of the subsoil water level outside indicates that movement has taken place and that immediate action is called for.

Pressure observations Jaurian siphon upstream.

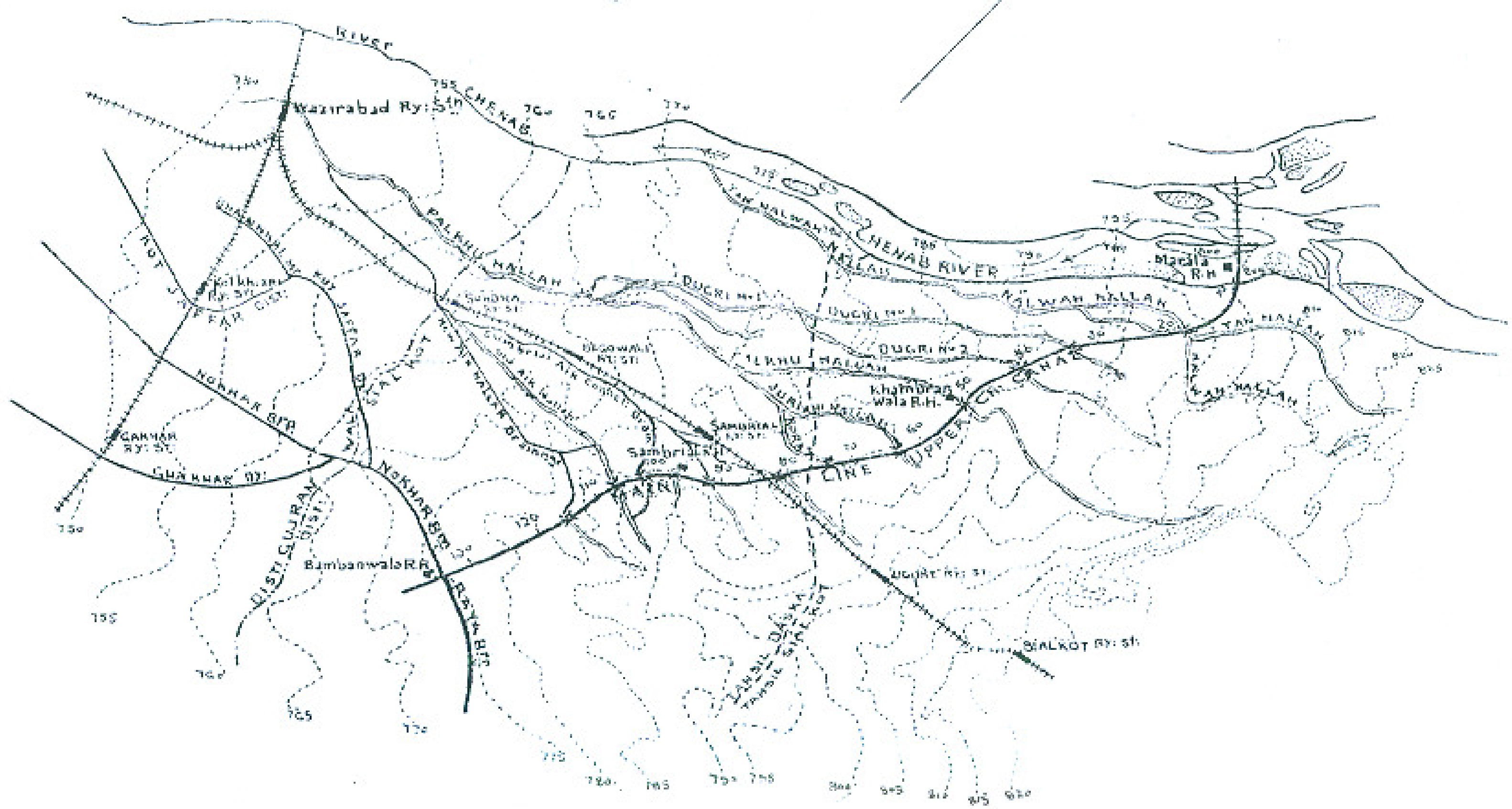
Date.	Canal gauge.	Cun-ette.	Pipe No. 1.	Pipe No. 2.	Pipe No. 3.	Pipe No. 4.	Pipe No. 5.	Pipe No. 6.	Pipe No. 7.	Pipe No. 8.	Pipe No. 9.	Pipe No. 10	Pipe No. 11	Pipe No. 13	Pipe No. 14	Pipe No. 17	Pipe No. 18
25-8-27 ..	791 ·9	..	88·07	87 ·79	87 ·79	87 ·40	87 ·42	87 ·60	88 ·12	87 ·85	87 ·71	87 ·38	84 ·72	87 ·10	87 ·58	87 ·95	85 ·80
17-8-29 ..	791 ·9	81 ·60	87 ·14	87 ·19	87 ·11	85 ·86	85 ·95	86 ·71	87 ·23	86 ·77	86 ·19	85 ·66	84 ·06	86 ·79	86 ·96	97 ·03	86 ·62
		Fall	·93	·60	·68	1 ·54	1 ·47	·89	·89	1 ·08	1 ·52	1 ·72	·66	·31	·62	·92	+ ·82
16-8-29 ..	791 ·72	81 ·60	87 ·04	87 ·09	87 ·06	86 ·66	85 ·86	86 ·64	87 ·10	86 ·74	86 ·06	85 ·15	84 ·01	86 ·62	86 ·89	86 ·90	86 ·54
25-8-30 ..	791 ·73	81 ·40	86 ·64	86 ·40	86 ·16	86 ·21	86 ·48	85 ·56	86 ·70	5 ·94	85 ·84	86 ·54	83 ·31	85 ·52	86 ·48	86 ·57	86 ·07
		Fall	·40	·67	·90	·45	+ ·62	·78	·40	·80	·22	+1 ·39	+ ·70	1 ·10	·41	·33	·47
Total Retro-gression since 25-8-27.	..	..	1 ·33	1 ·27	1 ·58	1 ·99	·85	1 ·67	1 ·29	1 ·88	1 ·74	+ ·33	1 ·36	1 ·41	1 ·03	1 ·25	..
4-5-31 ..	791 ·6	81 ·25	86 ·64	86 ·64	86 ·58	86 ·31	..	86 ·26	86 ·50	86 ·26	85 ·86	86 ·04	82 ·65	86 ·02	86 ·20	86 ·33	85 ·99

PLATE I.

UPPER CHENAB CANAL

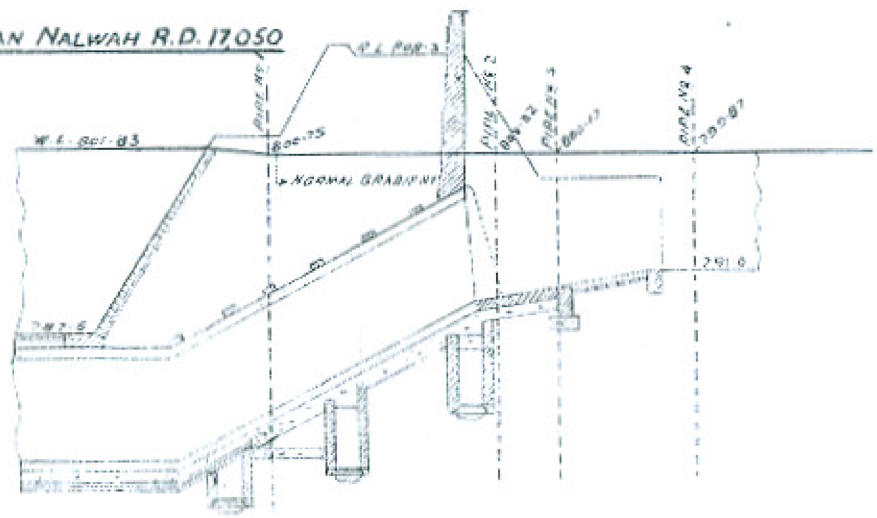
INDEX PLAN SHOWING DRAINAGES & SIPHONS

SCALE 1" = 4 MILES

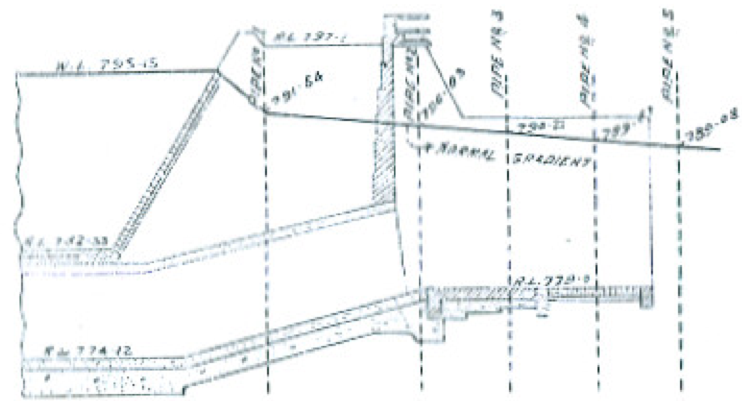


PRESSURE GRADIENTS THROUGH BANKS AT SIPHONS

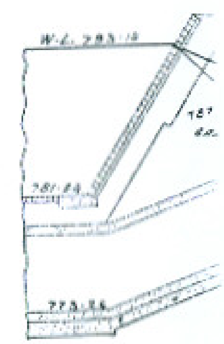
TAN NALWAH R.D. 17,050



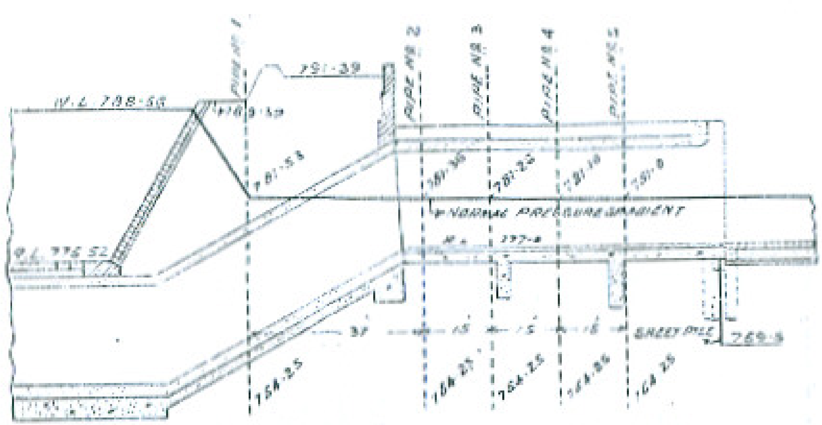
PALKHU R.D. 52,200



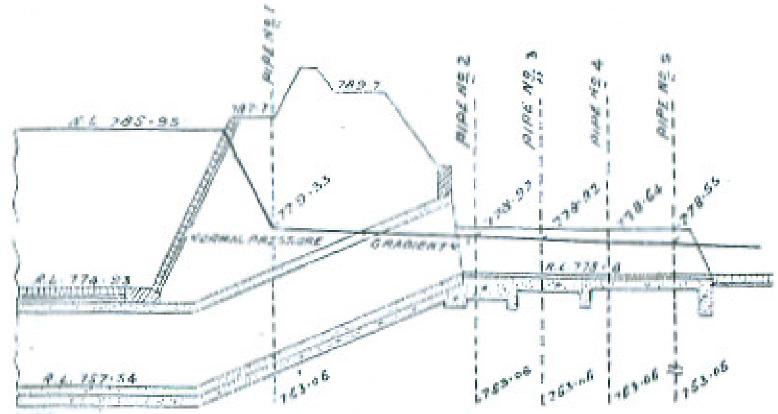
JAURIAN R.D



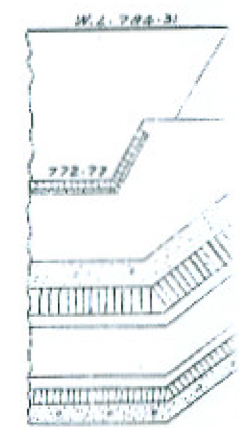
SAMBRIAL R.D. 90,275



KOT DARAN R.D. 1,00,650

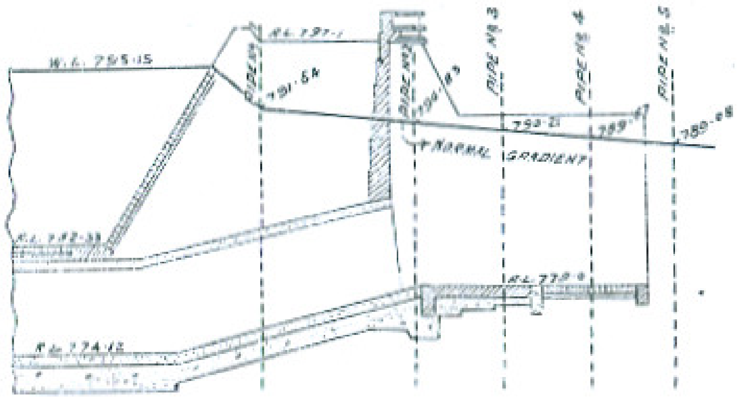


PASSIA R.D. 1,15,90

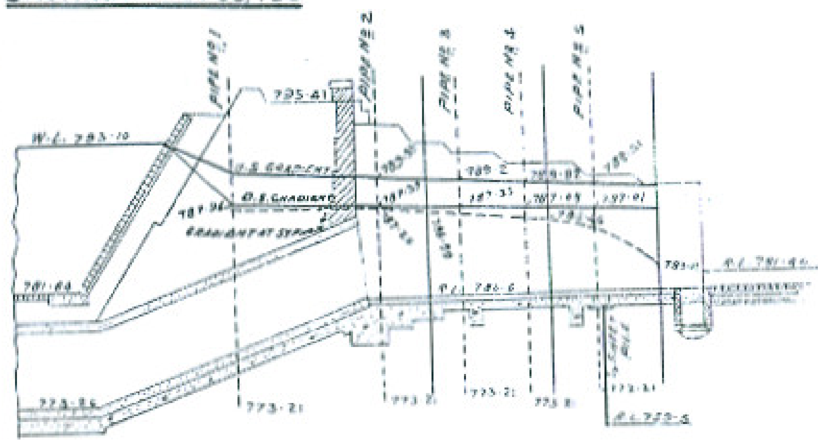


PRESSURE GRADIENTS THROUGH BANKS AT SIPHONS

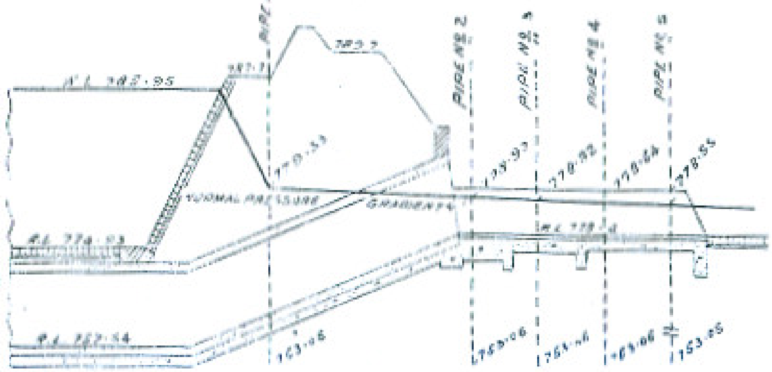
PALKHU R.D. 52,200



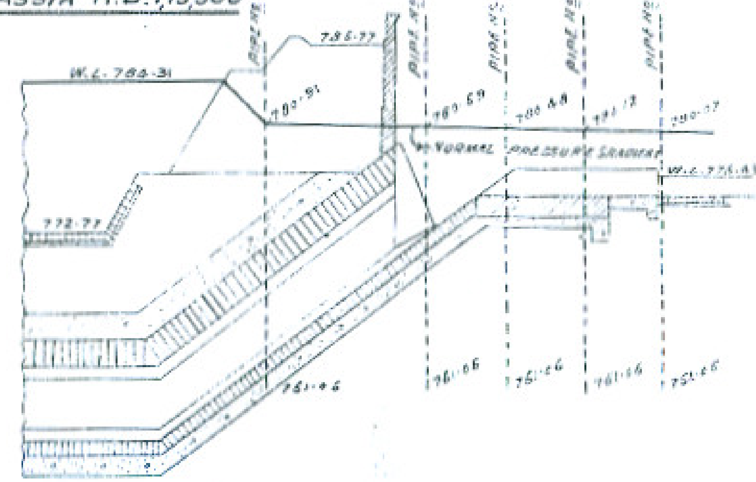
JAURIAN R.D. 63,450



KOT DARAN R.D. 1,00,650



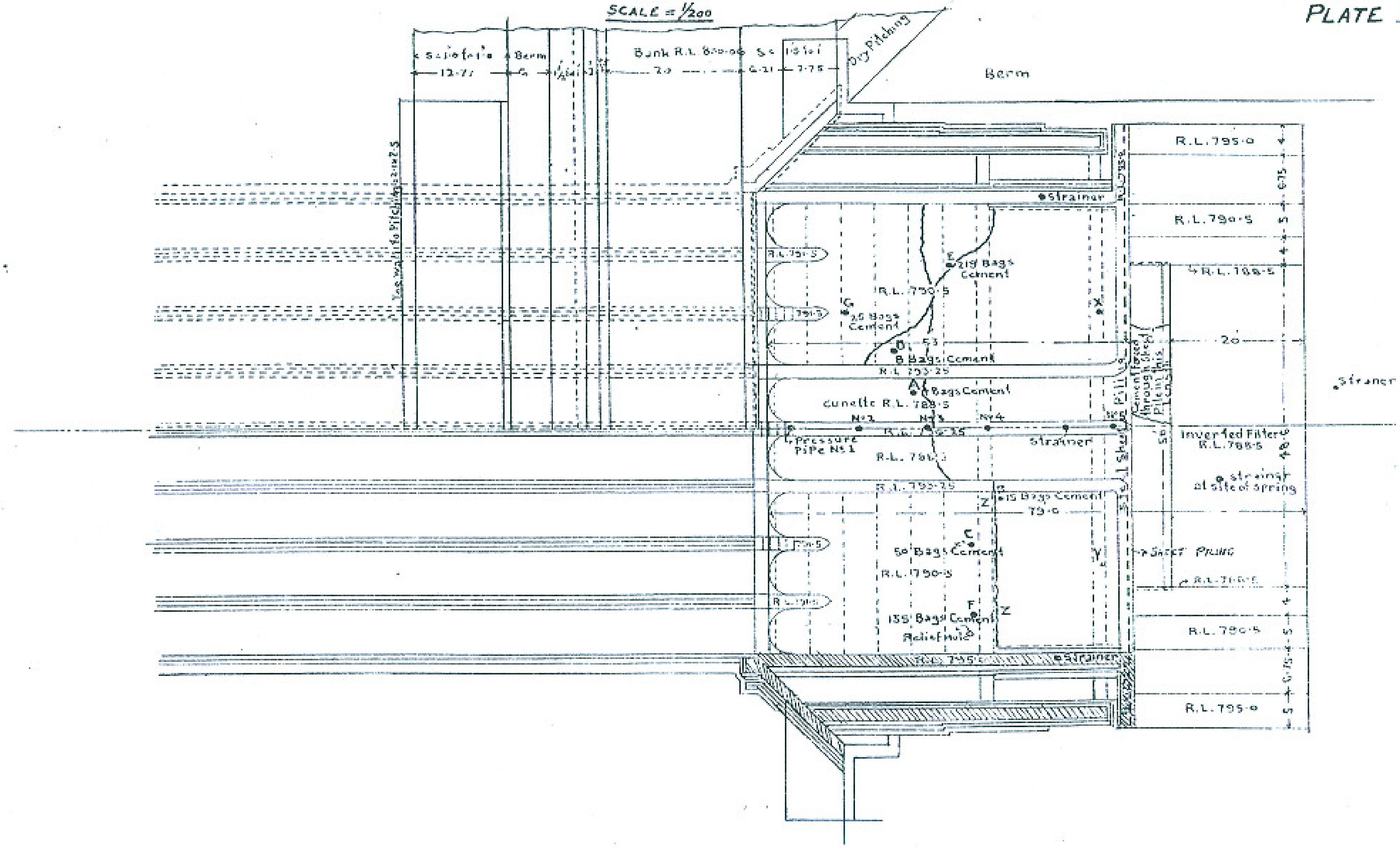
PASSIA R.D. 1,15,900



UPSTREAM FLOOR DUGRI No. I SIPHON

SCALE = 1/200

PLATE III



Pressure observations Du

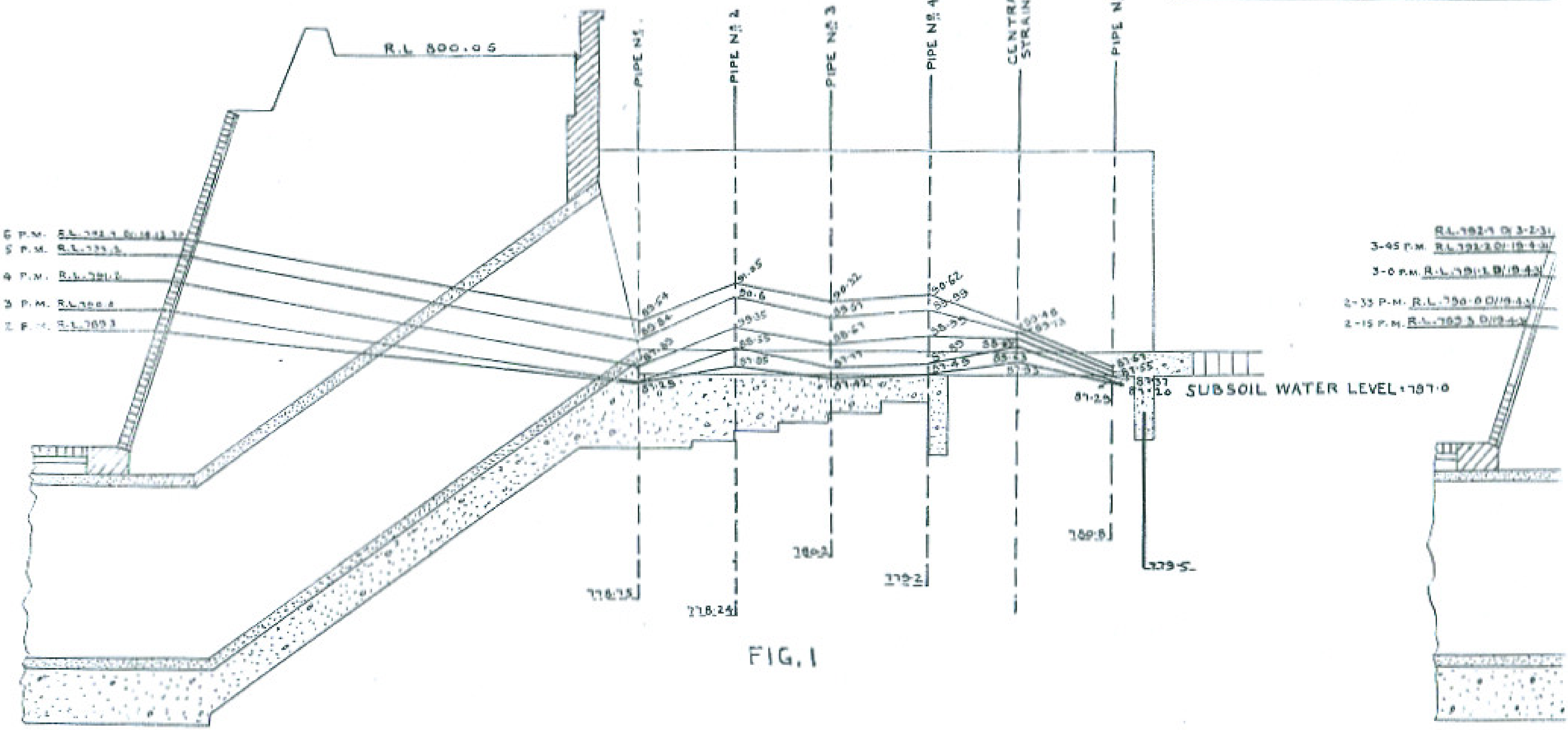


FIG. 1

PLATE IV.

PRESSURE OBSERVATIONS DUGRI NO. I SIPHON IN RISING GAUGE

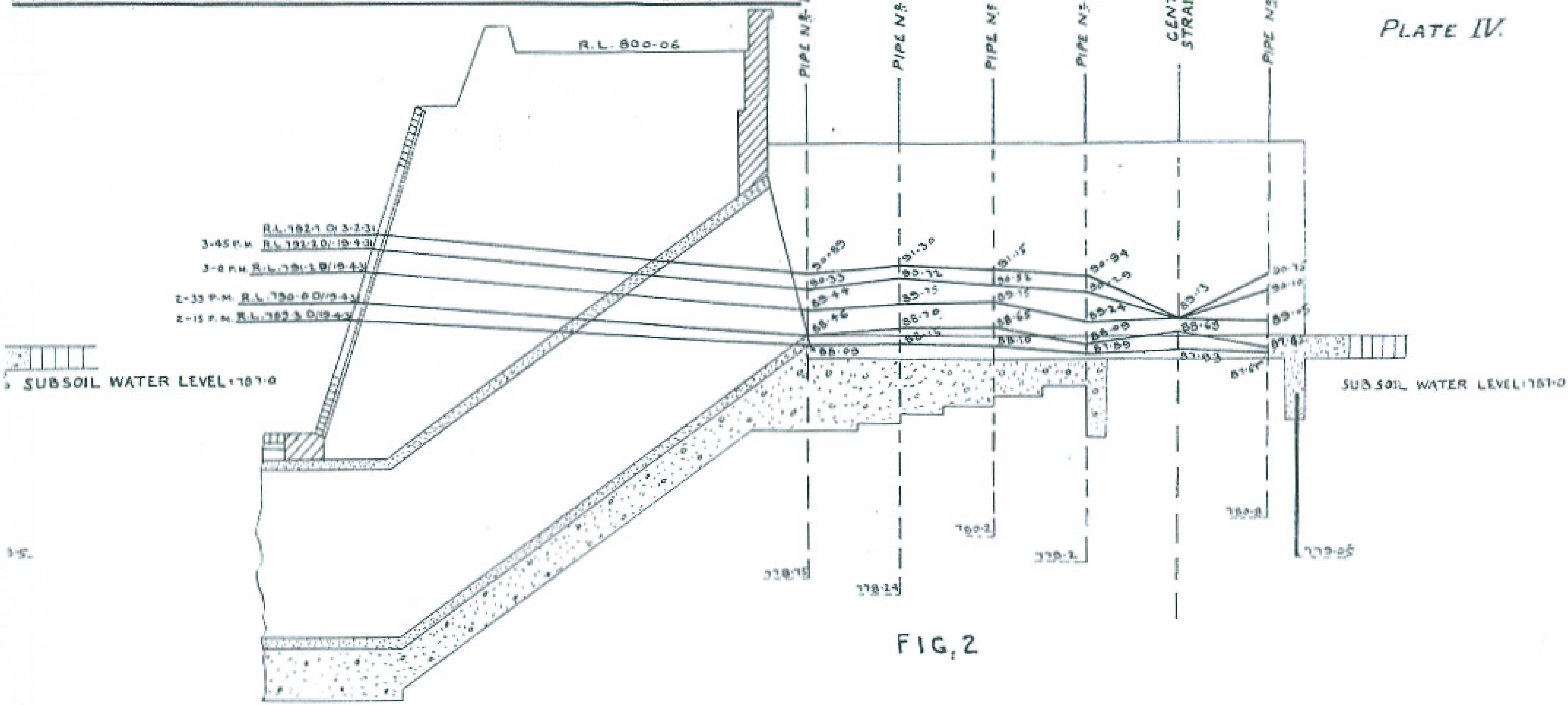


FIG. 2

PLATE V.

PRESSURE OBSERVATIONS DUGRI No. 1 SIPHON

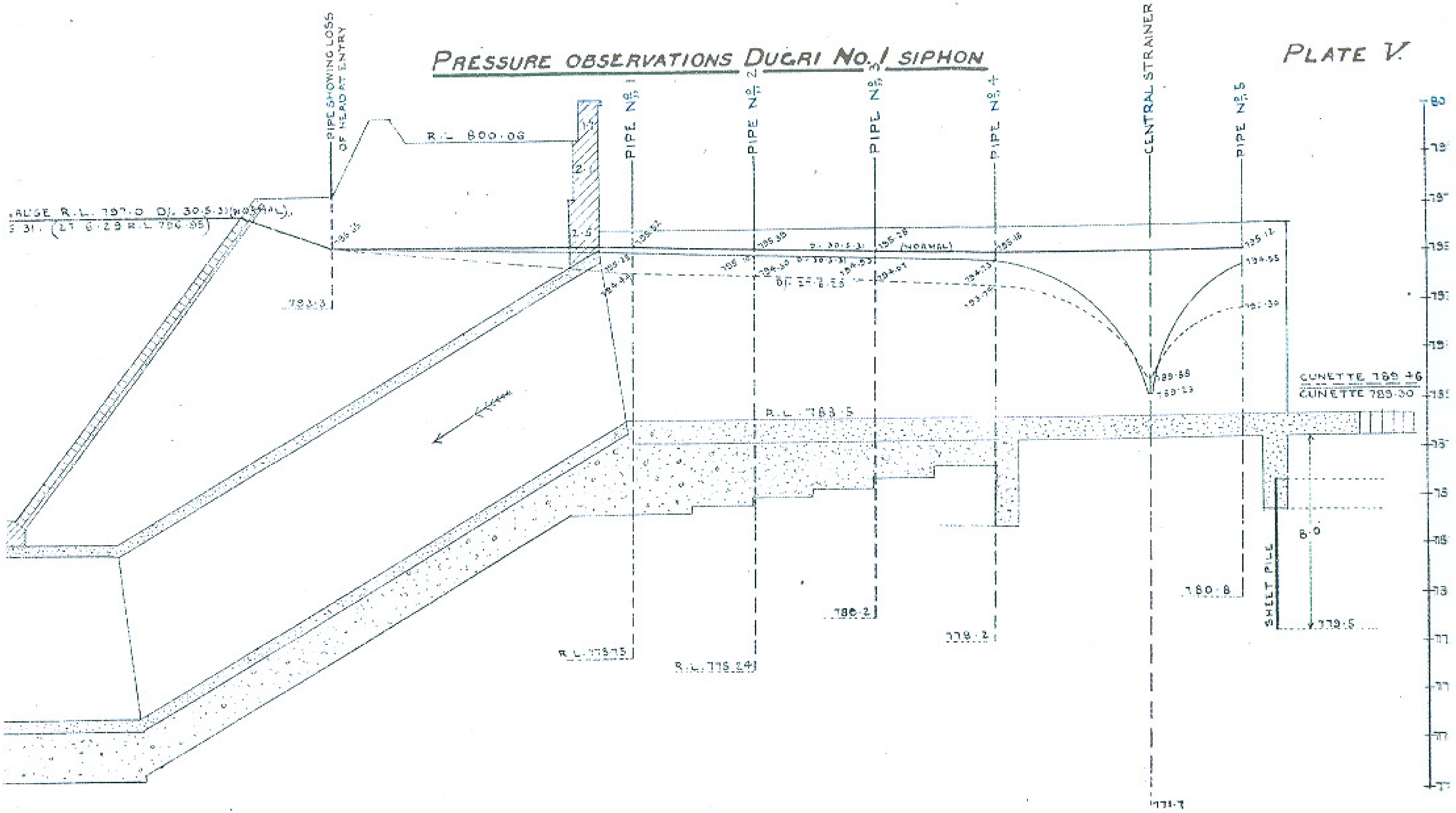
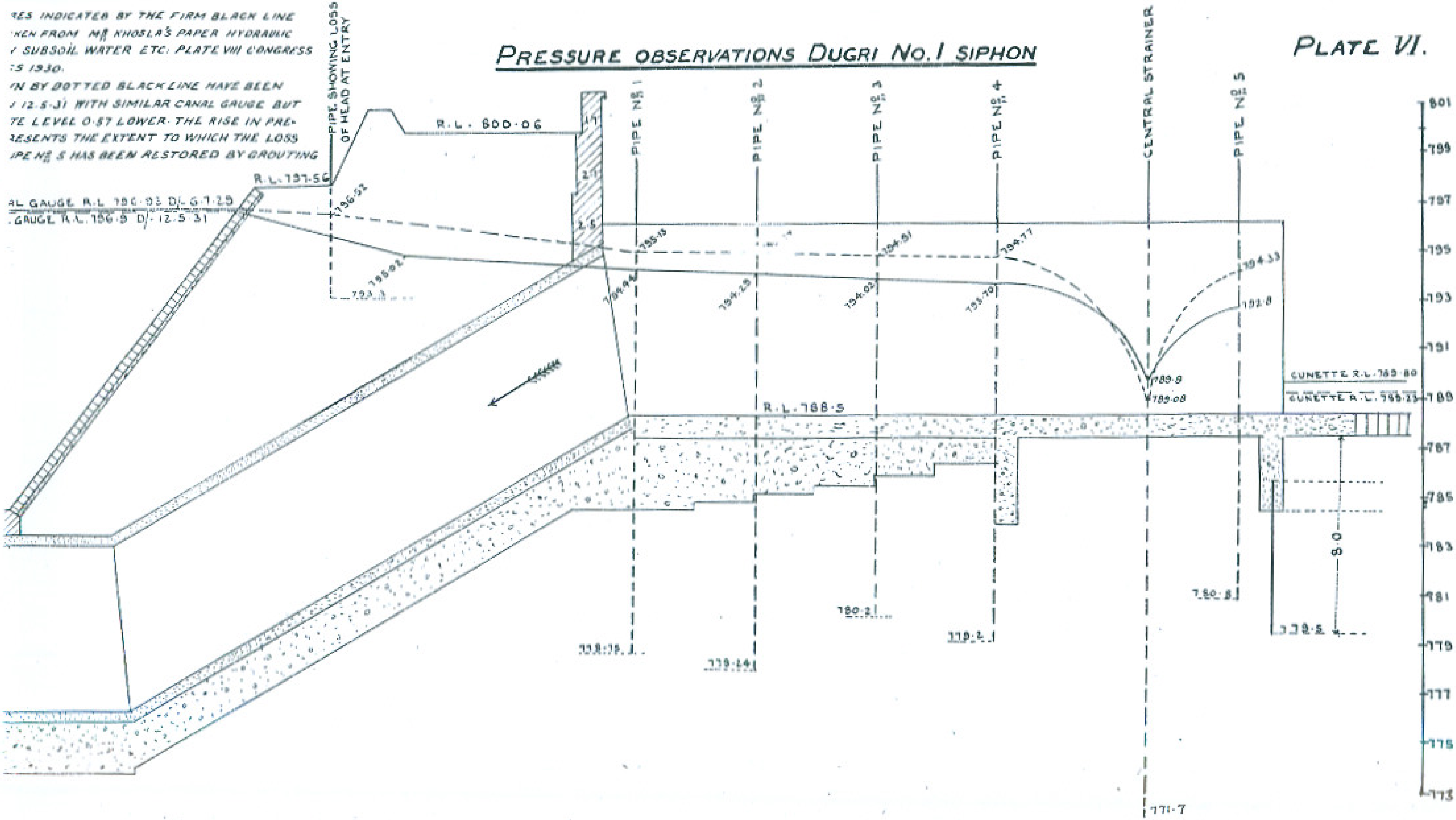


PLATE VI.

PRESSURE OBSERVATIONS DUGRI No. I SIPHON



PRESSURE OBSERVATIONS DUGRI NO. 1 SIPHON

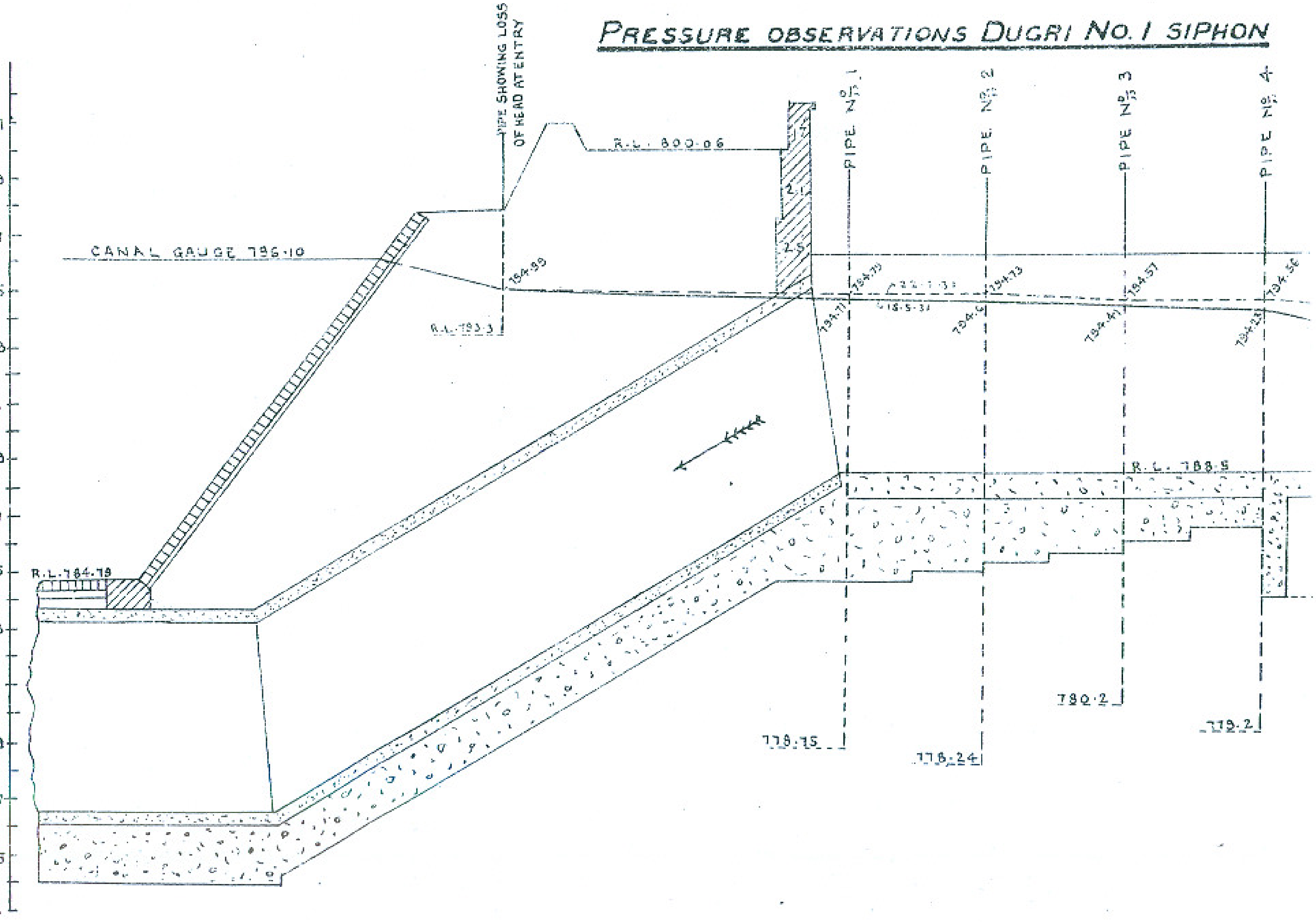
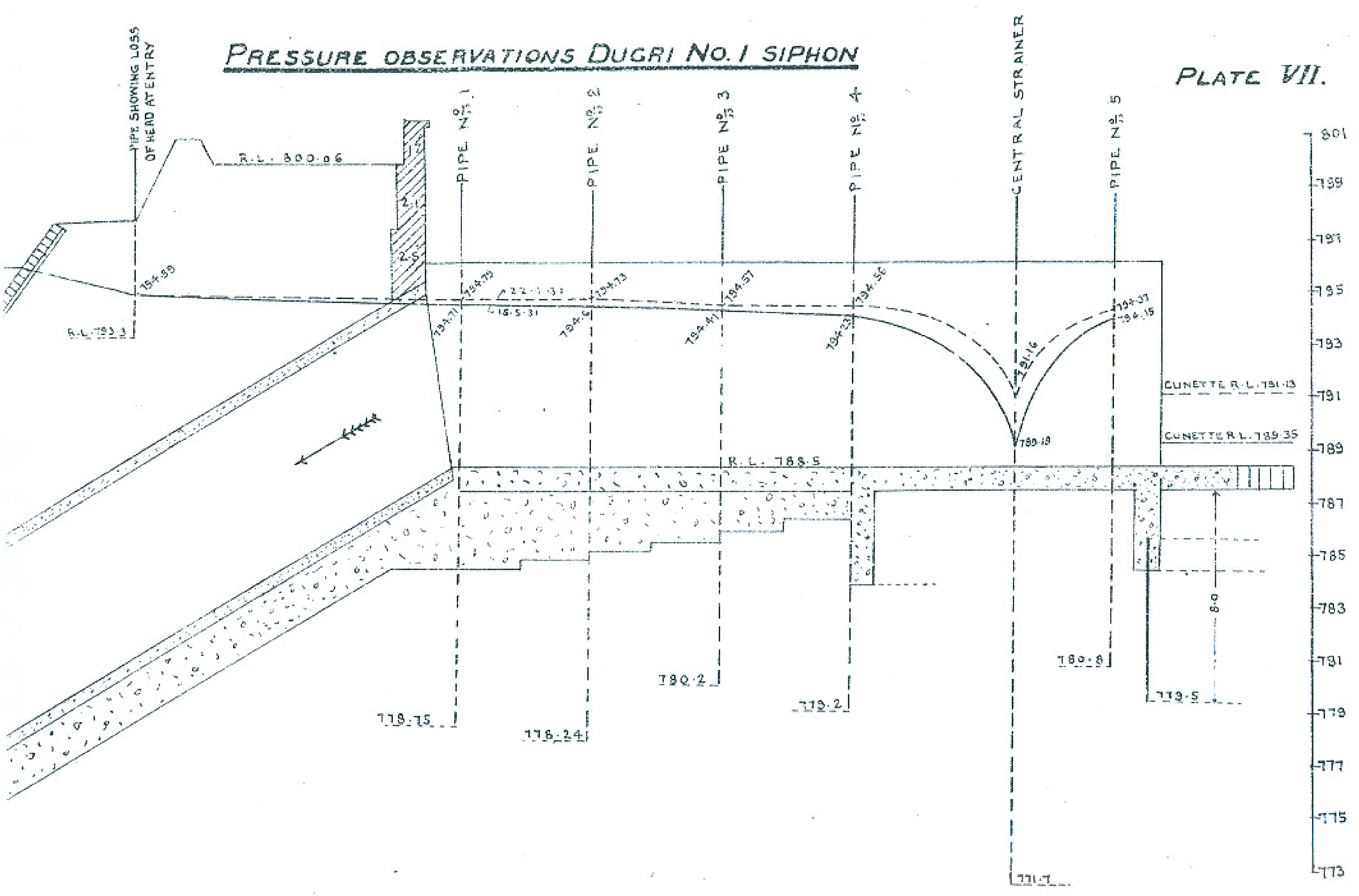


PLATE VII.

PRESSURE OBSERVATIONS DUGRI NO. I SIPHON



DOWNSTREAM FLOOR OF JAURIAN SIPHON

SCALE 1/200

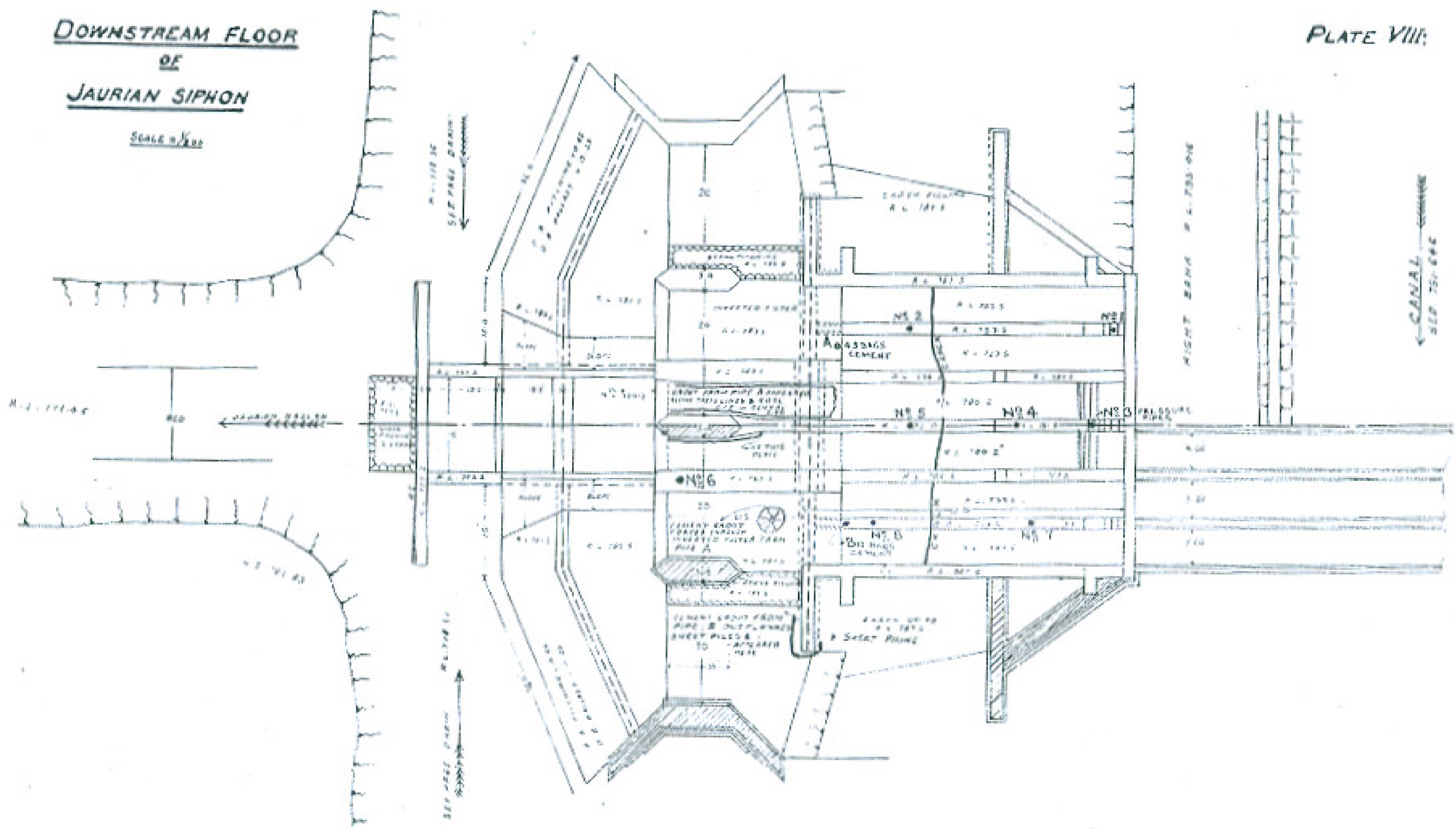
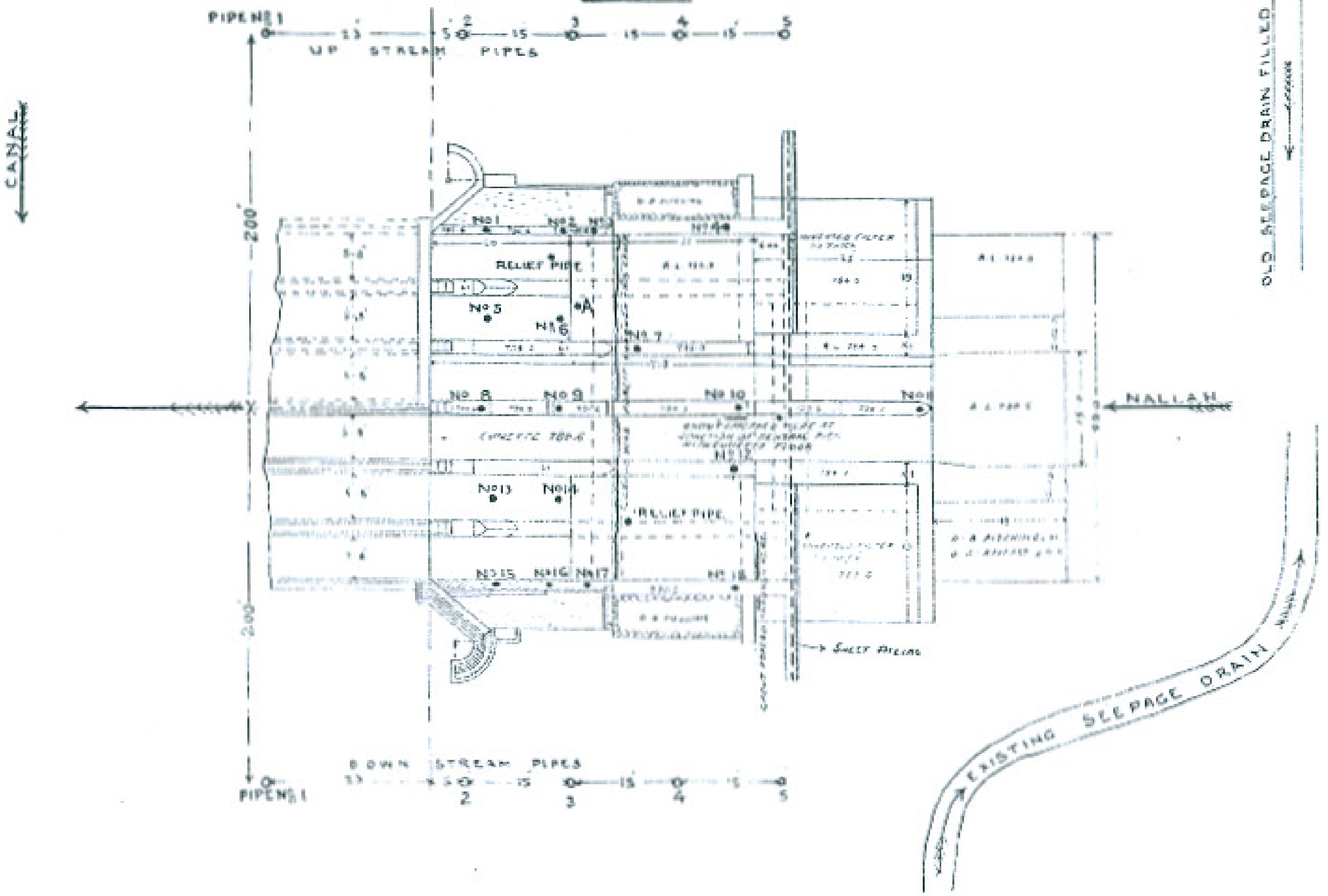


PLATE IX

UPSTREAM FLOOR OF JAURIAN SIPHON

SCALE = 1/200



R. B. BAWA NATHA SINGH, in introducing the paper on behalf of Mr. Turner remarked that the author of this excellent paper on 'Pressure observations at Jaurian and Dugri Syphons' was unfortunately not present owing to his shortly proceeding on leave, and he had asked the speaker to sponsor the paper for him and reply, if possible, to the questions raised in the discussion.

R. B. BAWA NATHA SINGH remarked that out of the two syphons dealt with in the paper Dugri No. 1 was more important having given more trouble. He believed everyone in the Hall was acquainted with the previous history of the trouble on the syphon in question, which was described in detail by Mr. Khosla in his paper which he presented to this Congress in 1930. A brief account of the upstream side with which this paper dealt, would not be out of place for a better understanding of the subject.

The syphon was constructed about the year 1912 and by 1923 the barrels, face walls, wing walls and floor on the upstream side had all cracked. In the two succeeding years, the brick floor was replaced by a cement concrete floor and the side walls entirely rebuilt. The springs however continued to blow sand at the end of the floor, and settlement cracks started appearing in the new floor.

The situation in 1928 was considered to be very dangerous. In January 1929 a line of sheet piles 8 feet deep was added at the end of the floor. Three relief strainers were also put in above the line of piles at the same time.

Up to the end of 1929, there was no trouble, but soon after one spring burst out through the inverted filter upstream of the sheet piles and started blowing sand vigorously. The history of the subsequent trouble and measures adopted to deal with it were described in Mr. Turner's paper.

The trouble, however, did not finally cease in May 1931 up to which date the repairs are described in the paper. Soon after the grouting in April, two springs burst out in the area of the inverted filter which had since been replaced by puddle. Position of these springs was at the site of the two strainers shown in Plate III. These were prevented from sand blowing by constructing brick enclosures about 2'-0" high round them. With the rise in canal supply at the end of May the depth of water in the enclosures was not found enough and the spring near the sheet pile line started blowing sand suddenly. It would be interesting to mention here that the bursting of this spring was accompanied by a sudden fall in pressure of Pipe No. 5, *i.e.*, the last one in the central pier, by 2 inches, and in other pipes proportionately. As nothing could be done until the closure of the canal, and this would not take place before December, it was decided to head up water above the floor to provide the necessary pressure for suppressing the spring. One and a half feet depth of water over the high floor was found sufficient for this purpose.

Various measures were then considered to provide an effective remedy for stopping the blowing of springs because so long as these springs were not stopped, the formation of cavities under the floor could not be prevented. The speaker briefly mentioned the following measures without attempting to describe their merits and demerits in detail:—

(1) Lining the canal bed and side slopes with cement concrete for a distance of 250 feet up and 250 feet downstream of the syphon.

(2) Replacing the existing puddle round the upper half of the syphon barrels by cement concrete.

(3) Sheet piling 20 feet deep across the bed on the upstream of the pucca floor, as the existing 8 feet piles were obviously not sufficiently deep to kill all the head.

Out of these alternatives, sheet piling was the one most favoured but was ultimately rejected as not likely to be certain in results owing to the high spring level on both sides. It was finally decided to raise the low area in front of the pucca floor to the ground level for a distance of 100 feet and do away with the cunette. In ordinary circumstances this would result in stopping seepage water from flowing into the syphon and causing waterlogging in the area upstream. In this case, however, it was possible to divert the seepage discharge into the next downstream syphon, Dugri No. II, which was situated at a distance of 1½ miles.

This work was completed last month. Up to this time the puddle was absolutely dry on the surface, and there were no signs of springs and the pressures were maintained though the canal had been flowing. An attempt was made to grout with more cement if any cavities could be found. For this purpose 16 holes were bored through the high floors but none of them revealed the slightest cavity. At the time of suppressing the springs, the floor may be said to be in a perfect condition.

Effectiveness of the measure adopted can only be tested in the next hot weather when high supplies would run in the canal.

Dr. N. K. Bose, remarked the author of this paper shows on page 1 the following levels:—

	Spring level higher than the bed level.
R. D. 5,000	12·6
R. D. 17,000	5·5
R. D. 35,000	0·75

Up to 17,000 it appears that the canal works more as a surface drain ; hence instead of adding water to the subsoil in this vicinity it will drain it off. From 17000 downwards there will be more seepage from the canal, and from what the author says the slope in the subsoil water-table should have been sufficient to drain this seepage water into the river.

From theoretical considerations, I have proved elsewhere that if q be the seepage from unit length of the canal, b the distance of the subsoil water table from the water surface in the canal and u the velocity with which water will percolate through the bed of the canal then the slope that will be necessary to drain off the seepage is given by $\sin \frac{q}{bu}$ so that if we increase q, the total seepage discharge from the canal, then a greater slope will be required to make all the seepage water flow down, if the slope is insufficient there will be a piling up of water on the upstream side.

If we diminish b, i.e., if the subsoil watertable be brought nearer to the canal, then a greater slope will be required and the same consequences will follow.

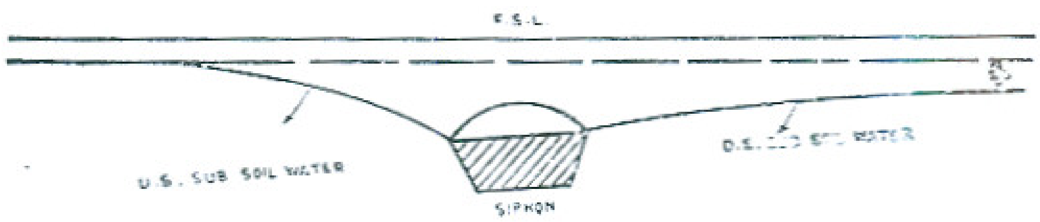
If we diminish u, i.e., if the velocity of water in the soil be decreased the same result will follow with the existing slope.

From the above considerations, it will be apparent that the next deduction that the author makes that "with the opening of the canal the subterranean flow to the river from left to right was intercepted resulting in a general rise in the spring level. This assertion does not hold good. Instead of the canal intercepting the subterranean flow the canal works as a drain part of its way and helps the drainage of the sub-soil watertable. What is responsible for hastening waterlogging in this area is I think the fact that the alignment of the canal runs across the surface drainage of this area and intercepts the surface flow. This is apparent from the contour map supplied. Though it might be said that syphons were put in to deal with this flow; but I am afraid this was not sufficient.

The next point is about the pressure observation. The author writes on page 2. "These gradients have been obtained by driving in pipes with filter points 100 to 200ft. upstream of each syphon." The author does not say how deep these pipes were driven and with what length of strainer. If the length of strainer be 2 ft. as in other pipes put in by Mr. Khosla at the same spot, the depth of these strainer points below the subsoil watertable is of great importance. Because we know if we take pressure at a depth of say 7 to 8 ft. below the subsoil watertable and there is a steep curvature in the streamlines, the pressure recorded is much higher than the head of water above the point, and moreover as these strainer points do no tlie on the same streamlines their pressure levels cannot be connected together with 'Pressure gradients' as the author has done in Plate II. Of course where the water table is very high, the error might be negligible as in cases at R. D. 17,050 and R. D. 63,450.

In other cases if the idea is to obtain the subsoil water level the strainer points should be in the water surface itself.

The next point is about the author, is observations on the drop in the water level between the upstream and downstream points of the Jaurian Syphon. If I draw a section through the subsoil watertable parallel to the canal at this syphon it will be something like this.



The drop in the upstream and downstream waterlevel is 2.6 ft. and the increase in what the author calls the loss of head between the upstream and the downstream points is also 2. 6 ft. This shows that this drop is due to the draining action of the syphons and not as the author supposes on page 155 as follows :—

'The point where the water surface through the banks meets the general subsoil level having been moved away, the pressures on the upstream side of the syphon rose.'

This removal if it is going to have any effect will rather lower than raise the watertable.

Mr. M. D. Mithal, remarked that the author has brought again into prominence the theory enunciated by Mr. Khosla regarding hydraulic gradients in subsoil flow in relation to stability of structures resting in saturated soils and presented to this Congress in his two papers Nos. 138 and 142.

Referring to the first page, the speaker went on to say that there was a difference between surface drainage and subsoil drainage. The syphons on the Upper Chenab Canal as elsewhere were constructed for the passage of surface drainage and they served as such. They were, however, useful even now in draining off the seepage, when the subsoil level had risen above the natural surface level.

Referring to page 156, the minute hair cracks mentioned regarding Dugri No. 1 were also grouted in February, 1930, and abcut 54 bags of cement were used.

There could be no question of refutation of any of Mr. Khosla's arguments as the observations detailed in the paper had gone very far to support Mr. Khosla's conclusions regarding the utility of sheet piles at the ends of pacca floors. The author did not suggest any improvement in design nor did his paper advance any remedy. The speaker, however, remarked that he had been suggesting and again suggested a remedy which appeared to him useful. A reference to Plate III would show that the maximum amount of cement was taken by the side grout holes and very little, rather negligible, by the grout hole in the cunette. Two bags is a negligible amount when one takes into consideration the small voids that exist in sand. The problem about the ends can best be met by continuing the sheet piles along the wings and these can be stopped up to suit the pressure.

Mr. Inder Sen, remarked that they were grateful to Mr. Turner for his interesting paper.

The author in his paper had described how certain syphons on the Upper Chenab Canal particularly Dugri No. 1, and Jaurian had been giving trouble and how after the repairs done in 1927 to 1929 the pressure in the observation pipes had been gradually falling, blowing started, cavities formed, and cracks appeared and how again they had been restored to stability by cement grouting under pressure.

The speaker believed grouting under pressure was first started at Dugri No. 1 in December 1923.

The speaker wanted to mention the extreme care required in grouting structures under pressure, just like boilers there should be some pressure guage. To do that, pressure pipes should invariably be inserted in the floor and the pressure carefully recorded at the time of grouting. As the cavity was being filled, water would rise in the pipes. Utmost care was essential so that the pressure indicated did not exceed the safe limit otherwise you endanger your structure and may even burst it. Grouting should be stopped when the pressure indicated begins to exceed the safe limit.

Another remedy was to insert a few relief pressure pipes so that the pressure never exceeded the safe limits at the time of grouting. Of course care had to be taken that the relief pipes did not start blowing. To avoid excessive pressure and to ensure satisfactory grouting it was best to have the grouting pipes close together about 6 to 8 feet apart so that the cavity could be filled even under low pressure.

Another remedy will be that we get grouting machines fitted with pressure gauges, but so far the speaker had seen none.

If necessary care was not exercised the speaker was afraid the grouting which in Mr. Turner's opinion had restored syphons to stability might be a reverse action and endanger the stability of an otherwise safe structure. In this connection the speaker referred to page 160, paras 3, 4 and 5 where luckily the pressure found a way out before it could do any damage.

Cement grouting as a permanent remedy against blowing was very doubtful. It was only a temporary remedy and time would soon show how far the contention of the author is right. It may also be questioned as to why filling of cavities with expensive cement was necessary. A mixture of sand and cement or even pure sand could be satisfactorily used and serve the same purpose. Cavities had been filled successfully at Islam and Ferozepur Headworks with sand grouting. Of course for grouting of cracks use of cement was essential.

In replying to the discussion, R. B. BAWA NATHA SINGH said with reference to the remarks of Dr. Bose that the bed level of the canal was more than the spring level, because there was 12 ft. of water in the canal and that rise of spring level was due to the non-existence of proper drainage. He pointed out that we had got sufficient surface drainage all along the canal and that we had got channels and other outlets all along the canal.

In reply to the remarks of Mr. Mithal, R. B. Bawa Natha Singh pointed out that in case of grouting, the sheet piles should have been placed along the wings. This was a very good suggestion and they were adopting it in their future designs.

In regard to Mr. Inder Sen's remarks, that the cement grouting should be done under careful supervision.

The speaker assured Mr. Inder Sen that the grouting was done under the personal supervision of the S. D. O. in charge and of the X. E. N. It was merely a hand grouting machine and not a power driven machine. There were also a number of pressure pipes to the floor of the siphon.