NOTES ON SOME WORKS ON THE UPPER SWAT CANAL.

By A. J. WADLEY,

Superintending Engineer, Punjab Irrigation, Peshawar.

"The velocity which various classes of material will stand, is an important question in canal construction, and the following information on this point is contained in Colonel Clibbon's Treatise on Irrigation Works in India."

Large boulders	.. 20 to 25 f. s.
Small boulders	... 8 to 15 ,,
Shingle	... 5 to 7 ,, if without much sand.
Nodular kankar ...	... 5 to 10 f. s. according to compactness.
Compact clay	... 4 to 5 f. s.
Loam	... $2\frac{1}{2}$ to $3\frac{1}{2}$,,
Coarse sand	... $1\frac{1}{2}$ to 2 ,,
Fine sand	... 1 to $1\frac{1}{2}$,,
Very fine silt	... 1 to $\frac{1}{2}$,,

Jackson's Hydraulic Manual,* gives the following ;—

Very sandy soil	... $2\frac{1}{2}$ f. s.
Sandy soil	... $2\frac{3}{4}$,,
Loam	... 3 ,,
Gravel and very firm soil ...	... 4 ,,

Thus generally a velocity of eight feet a second is safe for beds composed of small boulders and shingle, and four feet a second for compact clay.

Several of the unlined distributaries on the Lower Swat Canal exhibit surprising bed slopes and velocities. Thus 150 cusecs are being safely discharged down a bed slope of 1—1220, 100 cusecs down a slope of 1—833, 50 cusecs down 1—333, 15 cusecs down 1—168, and 10 cusecs down 1—125. The explanation lies in the fact that the beds and sides are

* Page 296.

composed of very compact clay mixed with kankar. On the Upper Swat Canal, full use has been made of the principle that the velocity may always be quickened up to the extent which the material forming the channel will stand. For instance the velocity in rock cutting and tunnels varies from 9 to 15¼ f. s. according to the nature of the rock and the stratification.

Plate I illustrates the type design adopted for the pitched channels on the main line of the Upper Swat Canal, and in this case the velocity was taken at nine feet a second, the bed slope is 1—250, and the banks are 2½ feet above full supply level. The dry pitching on the bed and banks is twelve to eighteen inches thick according to the nature of the subsoil, and there are six inches of spawls under the pitching. Kutter's "N" was taken as ·025.

In order not to exceed a slope of 1—250, rapids of about one foot drop have been introduced as often as necessary, and there are 197 of these in a distance of 20,755 feet. They consist of masonry cross walls with a 1 in 10 glacis of grouted pitching between them. A total fall of about 280 feet is thus negociated in a distance of four miles. The bed width of the pitched channel is forty-seven feet, the full supply depth 4·33 feet and the side slopes 1½ to 1. The cost per linear foot of channel was Rs. 24.

Similar principles have been followed in the case of the Upper Swat Canal distributaries, many of which are far steeper than any yet constructed on the Punjab canals. Wherever concrete flumes have been found more economical than a series of falls in close proximity to each other, they have been given the preference, and in this connection a useful formula by Manning will be found in Buckley's Irrigation Pocket Book.*

In order to allow for future expansion of irrigation, the velocity taken in the concrete flumes on the distributaries has been limited to six feet per second, and Kutter's "N" for rough concrete lining has been taken as ·017, a value found to be good for rubble masonry. Water cushions six inches deep, each provided with a short cistern, have been introduced wherever necessary in order to check the acceleration and thus overcome the slope of the country.

The concrete in the flumes is four inches thick except at the cushions where it is nine to twelve inches thick, the matrix being composed of gravel and small shingle, obtained by screening

* Page 118.

the deposits in the adjacent *nullah* beds. The linings are laid in lengths of four to five feet with clay and bitumen joints to allow for temperature effects.

The main channels of the canal cross 167 drainages of all sizes, varying in discharge from a few hundred cusecs to 83,000 cusecs. The rainfall fluctuates between ten and thirty-five inches. The latter gives the maximum flood conditions, but of rare occurrence. The drainage works were however rightly designed for the worst conditions, and in order to economise in the sectional area of the culverts, the velocity in the barrels was taken at 15 to 20 feet a second.

Floods are of short duration but violent. The slope of the country is too steep to admit of much impounding, nevertheless the upstream bank of the canal is raised to impound as much flood water as can be contained without flooding the adjacent lands to an unwelcome extent, while the shortness and infrequency of maximum floods permits of the use of a high barrel velocity in negociating the worst conditions.

It is not always possible to secure flood discharges of *nalas* from actual discharge observations, but reliable results can be calculated from the marks left by floods. The surface slope is obtained from such marks, and by observing cross sections and applying a value of ·0275 for Kutter's "N," the maximum flood discharge can be calculated with reasonable accuracy. Self-registering gauges, consisting of wooden posts containing crevices filled with pellets of dry clay (on the downstream side), are also used to check the surface slope. A perforated sheet iron case, placed over the gauge, will keep the pellets dry which are situated above the flood line. The iron case needs one perforation to let in water and another to let out air.

Plate No. 2 shows a culvert in an embankment twenty-eight feet high on the Machai Branch of the Canal In order to withstand the earth pressure the abutments and wingwalls have been battered, and an invert has been introduced in the flooring.

The thickness of the abutment has been increased under the canal banks, and in order to check creep along the outside of the barrel, projections or collars have been given in the concrete forming the hood. As a further protection against water percolating under pressure from the canal above, the bed and sides of the canal are puddled, and it is usual to jacket the barrel with puddle above the natural surface, as shown by the dotted lines in the cross sections on A B and C B

One of the most useful text books for the design of such culverts is " Calculations in Hydraulic Engineering Part II " by T. Claxton Fiddler. Formula (21)* has been employed for calculating the total head necessary through the culvert in order to meet the requirements of (i) head to generate velocity (ii) loss of head at entrance to barrel (iii) loss by friction in the barrel. The table shown on page 74 gives useful values for culverts constructed of various materials, including steel.

Afflux level upstream is sometimes restricted, owing to diversion channels of adjacent torrents discharging into the one under design. The consideration of the surface curve and velocities prevailing downstream, and the design of outfall channels, have been made the subject of a special paper entitled " The design of outfall-channels for depressed works " by Mr. R. Egerton Purves, Chief Engineer, Irrigation Department, which is valuable for reference when designing an outfall. In the case of the culvert at R. D. 36,200 a good surface slope exists, and it is merely necessary to provide adequate protection to withstand the exit velocity. Usually a deep curtain wall is given, with a talus of concrete blocks beyond it. The length of this talus should be such that after settlement it will afford protection at a slope of 3 to 1 carried down to the calculated depth of scour, by a method based on an adaptation of Kennedy's silt formula.

The economical design of drainage works is a most influential item in keeping down the cost of a canal which skirts ranges of hills. It will occasionally happen that, owing to the expense of a heavy embankment, it is more economical to adopt an aqueduct than a culvert, and this would certainly be the case if the culvert also involved the excavation of a long and deep outfall channel.

In designing a canal through rough and broken country, it pays to have a good deal of head available for utilization in connection with the drainage works. It gives the designer a free hand, and enables him to quicken up velocities where possible.

Plate No. 3 shews the steel tube syphon-aqueduct at R. D. 78,000 on the Machai Branch of the Canal, where the ravine is 74¼ feet deep, and its sides are abrupt.

A culvert design, an aqueduct design of masonry, a ferro-concrete tube design, and a steel trough aqueduct design, were

* Page 161.

considered for an adjacent site, *i. e*, across a similar ravine about half a mile upstream, but eventually the enticing advantages of a steel tube design won the day. These advantages were :—

(*i*) Moderate prime cost.

(*ii*) Rapidity of construction.

(*iii*) Economy in earthwork.

(*iv*) The absence of risk and anxiety with regard to scouring action or to earthquakes.

The cost of the various designs compared as follows :—

Steel tube syphon ...	... 144 eventually	175
Ferro-concrete tubes ...	... 201	
Masonry aqueduct 40 feet spans	... 219	
Steel trough aqueduct	... 235	

A velocity of 10·9 f. s. was taken through the steel tubes. These were raised on a bridge to avoid having to lay them in the bed of the *nala*, which contained water, but this manœuvre is a complicated one, as it introduces the question of expansion joints.

The calculation for the spacing of the stiffeners in the short length of tubes resting on the bridge (which are not buried in concrete and earth) involved some mathematical calisthenics, and eventually a spacing of four feet was given. In America Z bars are used for this purpose, in order to get more metal in the most advantageous position.

A concertina expansion joint, with two inches play, was given in each exposed length of tube to allow for a range of temperature of 160°, while the saddles admit of the tubes sliding.

The steel plates were bent and drilled in India by Messrs. Richardson and Cruddas, Bombay, but as the prices of steel plates vary from month to month, a considerable margin of safety must be allowed in estimating such work, especially while there are labour troubles in England. The Project Estimate allowed Rs. 350 per ton for completed steel work (*i. e.*, Rs. 17-8 per cwt.) and it was not found possible to get the work done for less.

The thickness of steel plates allowed is $\frac{1}{2}$ inch. It was always known that this is considerable in excess of strength, if the bursting pressure alone be considered. A tempting suggestion was made to reduce the thickness of the plates to $\frac{5}{16}$ inch,

also another suggestion was to reduce the plates by $\frac{1}{16}$ inch for each twenty feet reduction in head, but having before them an alternative design for a masonry aqueduct, which promised long life (albeit with some risks perhaps) at not much greater cost, the powers that be wisely decided to retain the thick metal.

It is not reasonable to suppose that steel, which is under the action of water, will last for ever. Common knowledge contradicts such a supposition, but there appears to be strong evidence that steel which is under a fairly high velocity, and which is very seldom exposed to the air, is much longer-lived than is popularly supposed. Of course the nature of the sediment carried by the water, and the nature of the air with which the steel occasionally comes into contact, are influential factors in determining its life ; but if the sediment does not consist of heavy grit, and if the velocity through the tubes is not less than nine feet per second, and if the air is not charged with city or factory fumes, and if closures of the canal are so few and far between, that even the purer air of the country seldom gets a chance of attacking the tubes, there is strong evidence that the metal will last a very long time.

The advantage of a velocity of nine feet a second is that it keeps the tubes clean. No vegetable matter can lodge within, and give off injurious gases ; and rust does not appear to be able to get a start under such conditions.

There remains the danger of the pipes rusting from the exterior, and to prevent this a thin coating of cement-mortar, next to the metal, and a shell of fine water-tight concrete around the whole tube are imperative.

If the water carries large sand and grit, the filing action of this material is bound to shorten the life of the steel and most canal engineers are familiar with the effects of grit, gravel, and shingle on the submerged steel shutters of weirs, and on the gates of undersluices.

On the Upper Swat Canal we have tried both masonry aqueducts and steel tubes under very similar conditions, and the proof of the pudding must remain in the eating ; but the writer is inclined to believe that the masonry will outlast the tubes, unless earthquakes become more severe in the centuries of the future.

It has been found in practice that large steel tubes are slower in construction than masonry aqueducts, when the locality is out of the way for ironworks and when the materials for the aqueduct are on the spot.

On Plate No. 4 will be found details of a masonry aqueduct at R. D. 95,600 on the Machai Branch of the Canal. The *nala* flows in a deep ravine, carved out of firm soil consisting of alternate layers of compact clay and gravel with an occasional layer of conglomerate. The foundations of the aqueduct rest upon hard conglomerate.

It will be noticed that the total height of the aqueduct, from the foundations to the top of the flume walls, is 74·7 feet. There was therefore some doubt as to whether the structure was not too lofty for a region in which earthquakes occur, and a tube syphon design (two tubes of 9·1 feet diameter) was considered and brought into comparison with the aqueduct design. The latter design was able to hold its own in point of cost, while possessing considerable advantages in point of longevity. The life of steel tube syphons is a less certain factor than that of a masonry aqueduct ; but where the foundations are not good, or where there is insufficient headway available for an aqueduct, or where the height would be too great, an inverted syphon becomes necessary. Moreover an aqueduct consumes less head than an inverted syphon. In this instance the head required for a syphon would have been 3·7 feet, whereas the aqueduct does not need more than a fall of 1·24 feet to speed up the water in the flume to a velocity of 9·88 f. s. Kutter's "N" was taken at ·017 ; as in the case of rubble masonry ; a safe value, permitting of some future increase in the supply. Comparing cost, a steel trough aqueduct design, on steel trestles, was found to be the most costly ; the relative whole cost of each style of design for the site in question being as follows :—

Masonry aqueduct	...	Rs. 1,70,000
Steel tube syphon	...	,, 1,78,000
Steel trough aqueduct	...	,, 2,22,000

An aqueduct also affords support for a footway (to be added), while a tube syphon would lend no aid to the traffic across the *nala*.

It will be observed that of the six spans provided, practically only three are used as waterway ; the remaining three spans conveying the flume well into the banks of the ravine. On the right bank, where the work will be enveloped in made soil, the hydraulic gradient allowed is $2\frac{3}{4}$ to 1 up to the beginning of the wings, and 3 to 1 to the beginning of the pitching. On the left, where the aqueduct is buried in natural soil, the hydraulic gradient is 2·2 to 1 to the end of the wings, and 2·6 to 1 to the end of the pitching.

The foundations of both the abutments and the wings are placed below the flatter gradients to obviate danger from slips, this being a precaution rendered necessary when water is being carried overhead almost continuously. The mean intensity of pressure on the foundations of the central piers is 2½ tons per square foot.

The method of securing junctions with the banks of the *nala* by means of additional spans is more economical and graceful than heavy wings, while spans of forty feet with semi-circular arches proved more economical than spans of twenty-five, thirty or even thirty-five feet.

The *nala* is rapid and tortuous, so that a straight run above the aqueduct was not obtainable. Accordingly the left water-wing or guide wall, has been built higher than the right, as floods will pile up on that side. Provision has however been made for raising the right water-wing later, if found necessary, and it will be noticed that the concrete slab, in the foundations of that wall, is of the same width as that of the left water-wing. The right bank of the *nala* has practically no water action against it at present, but the design admits of the *nala* being straightened and the water action being directed more equably against the water-wings, if found desirable later. These water-wings have the same batter as the piers, and are built in continuation of them. The bed in both the approach and outfall is protected with heavy concrete blocks, while the waterway has a stone floor and curtains.

The centerings for the semicircular arches were not costly. Built wooden ribs, breaking joint, and having iron plates bolted over the joints, were used. The first thirty degrees at each haunch of a semicircular arch requires no support. Centres of earth and shingle were used in the side spans, where it was not necessary to keep open a waterway for floods. Perforated spandrels were not adopted, because the concrete was not sufficiently fine (watertight).

A special entrance to the flume was considered, but the working of other aqueducts on the adjacent Lower Swat Canal did not show that an entrance of any special shape was necessary.

A re-inforced concrete design for this aqueduct was not considered. The present price of cement, and the cost of constructing high centres appeared to preclude the possibility of successful competition with the masonry design, especially as the local stone is not costly.

Plate No. 5 gives particulars of the twin steel tube syphon at R. D. 142,500 on the Machai Branch of the canal. The steel tubes were estimated to cost Rs. 1,94,000, but eventually, owing to a rise in the price of steel plates and other causes, the estimated cost rose to Rs. 2,43,000. The total length of the tubes is 663 feet, and the head of water pressure under which they have been designed to work is eighty feet.

An aqueduct design was considered, but was not pressed owing to the height of about eighty-three feet at which the structure would stand. This question as to when an aqueduct design is to be preferred to a steel tube design is an interesting one. Re-inforced concrete aqueducts have been built to a height of a hundred feet, and steel tube syphons constructed to withstand a head of pressure of 850 feet. In point of size the latter have reached a diameter of eighteen feet. The conclusion the writer has arrived at, after studying the initial cost and the prospect of life of each method of construction is, that if there is headway available in the *nala*, and the subsoil offers a good foundation, and if the height of the structure will not be in excess of a hundred feet, an aqueduct design is greatly preferable to a tube syphon design. Future developments in re-inforced concrete might enable the height of the structure to exceed a hundred feet, and in that case a standardised design would still give the aqueduct the advantage over the steel tube syphon.

It is necessary to entirely cover with steel gratings the upstream ends of such tubes, to prevent men, boys or cattle from being swept into them and drowned.

If the velocity through the tubes is not considerably in excess of the normal velocity of the earthen channel, they are apt to partially silt up and give trouble in clearance.

The method of packing the concrete under the tubes in order to secure good contact, requires care, especially in the case of large tubes. One method is to build dwarf masonry walls, running parallel to the tubes, and to fill up between these with a rather wet concrete, pushed into position with tamping bars.

In addition to the efficient rivetting and caulking of the plates of the tubes, there is the question of testing them for leakage before placing the concrete shell. Rivetting and caulking can best be done by the use of pneumatic tools. In the case of the tubes under discussion, a portable engine, mounted with a compressor and two air receivers, was used. These were capable of working eight pneumatic tools. Ninety pounds of steam pressure gave a hundred pounds air pressure. The same portable engine

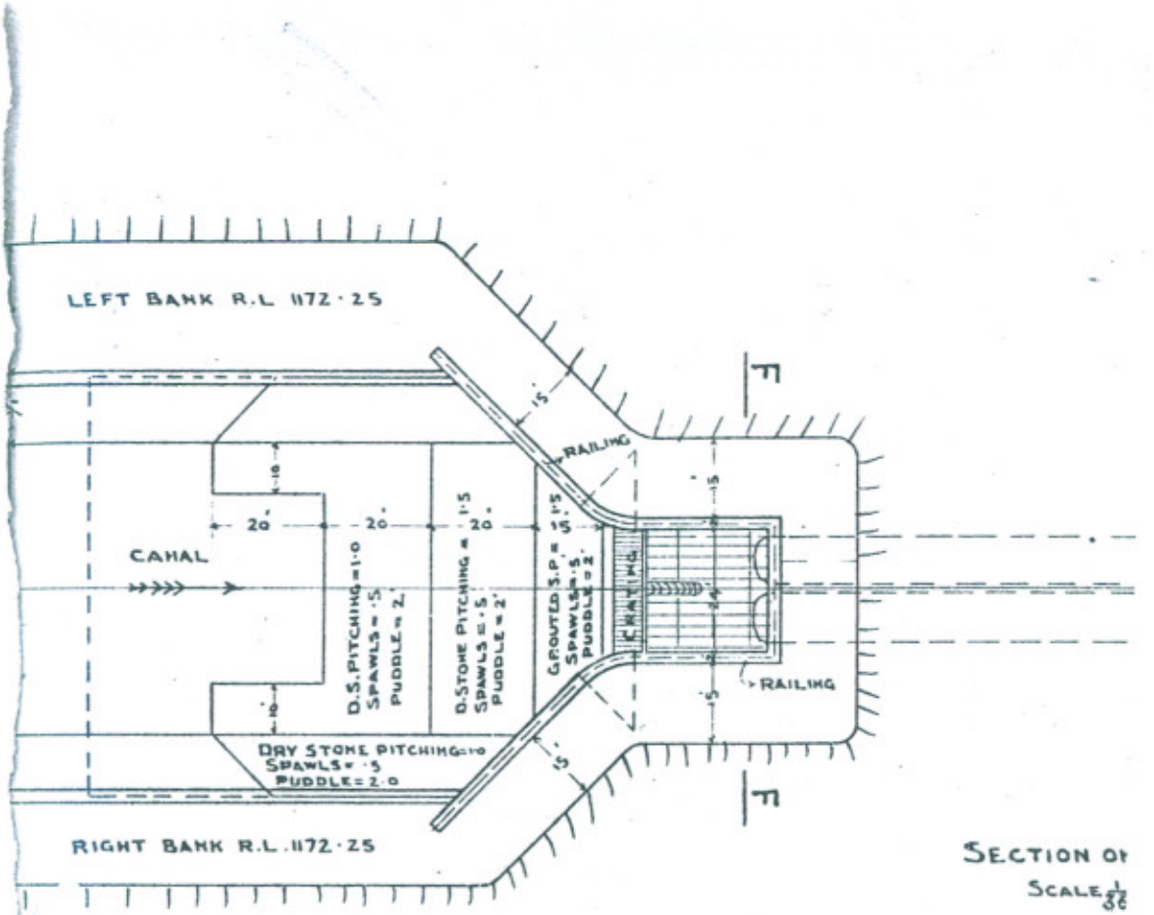
also supplied the water pressure for testing the joints. A suitable pump and nozzle gave a pressure of fifty pound per square inch at the nozzle, which was connected to flexible tubing. This pressure was applied to each caulked joint and line of rivets, and is nearly fifty per cent. in excess of that to which the tubes will be subjected while in use.

The section on D D shows the unwatering device, which however has not yet been erected. An air-chamber with a stop valve is necessary at the top of the unwatering pipe, as the effluent water carries with it a certain amount of air which would collect at the highest point (*i.e.*, in the air vessel) and stop the flow if not allowed to escape occasionally. Unless the *nala* has a steep bed, this syphonage cannot be effected without a long and costly escape pipe, and a corresponding reduction in the discharging efficieney of the pipe. The manholes also admit of the tubes being emptied by means of a pulsometer or a centrifugal pump.

On one occasion during construction, sixty feet of tubing in another syphon became displaced by a flood, which had breached into the foundations, and as these tubes are of considerable weight, the restoration of the tube to its correct position became a problem, which was solved by partially closing the two ends of the tube with bulkheads and floating it back, after pumping out the water.

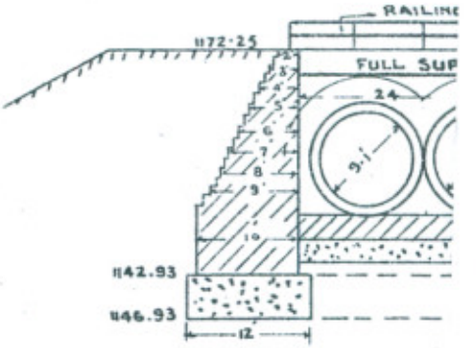
It may be observed that Messrs. Stewarts and Lloyds manufacture lock-bar steel pipes in lengths of about thirty feet up to a diameter of seventy-two inches. The interiors of these pipes would be smoother than those of rivetted steel pipes, and the number of joints and seams would be much reduced. It is believed however, that bends, on the lock-bar principle, are not yet obtainable

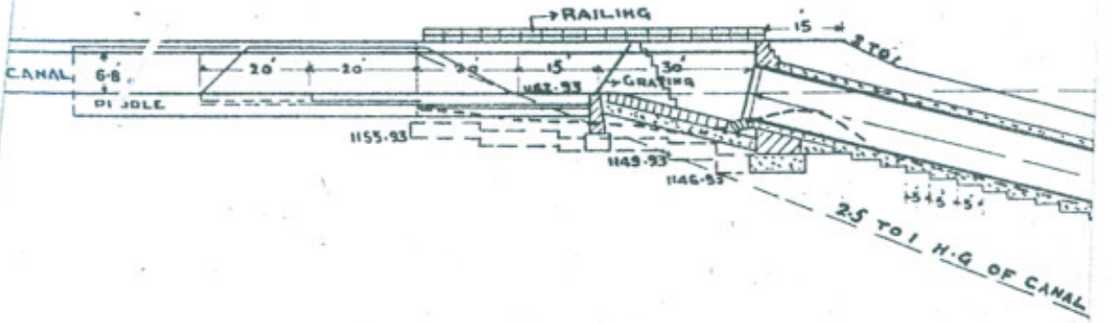
Although a design for a re-inforced concrete tube syphon has not been shown in this paper, several have been constructed on the Upper Swat River Canal, the largest being 6·55 feet diameter. Their life would certainly be greater than that of a rivetted steel tube, and owing to the smoothness and evenness of the interior their discharging efficiency is much superior. Unless however, the concrete is water-tight and the head of pressure is not more than a hundred feet, there is apt to be sweating, which might in course of time rust the steel and rob the concrete of its lime. A rich water-tight plaster is necessary within. Reinforced concrete tubes are specially



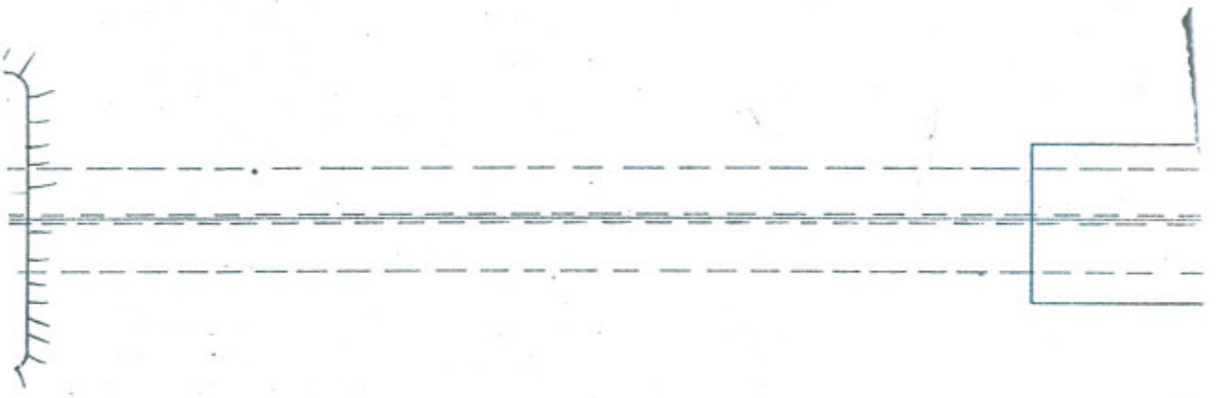
SECTION OF

SCALE 1/50



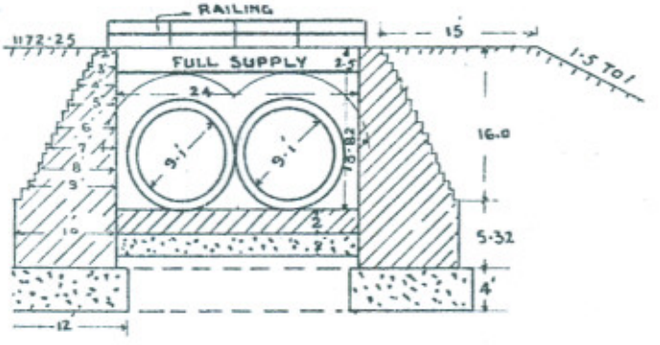


PLAN

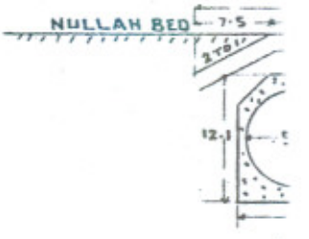


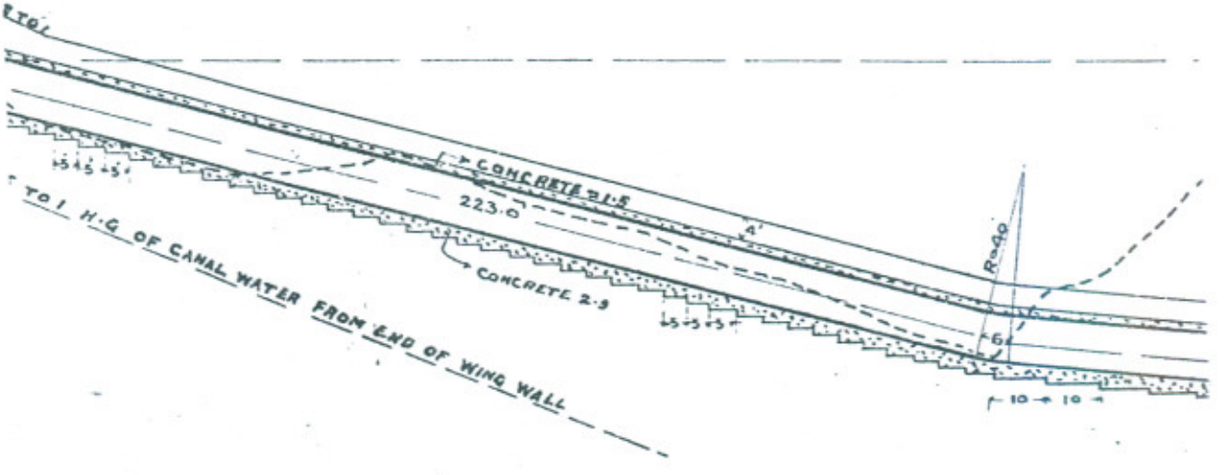
SECTION ON F.F

SCALE $\frac{1}{80}$



SE





useful when the subsoil is not very firm, as the base slab can also be reinforced.

When the price of cement becomes lower than it is at present, the reinforced concrete tube will beat the steel pipe, except under extreme heads.

The 9·0 feet steel tubes of the syphons on the Upper Swat Canal cost Rs. 227 per linear foot of double tube, the concrete and other works cost Rs. 139 per linear foot of double tube so that the total cost works out to Rs. 366 per linear foot.

Plate No. 6 is an aqueduct at R. D. 157,000 over the Mohkam *nala*, on the Machai Branch, of the Upper Swat Canal. A tube syphon design was also considered, but as the height is moderate, *viz.*, only fifty-nine feet from the bottom of the foundations to the top of the flume walls, preference was eventually given to an aqueduct.

The following table shows the comparative advantages of the forty feet spans adopted in the design :—

Sizes of spans.	Percentage of waterway taken up by piers.	Probable mean depth of scour over whole waterway.	Comparative cost of aqeduct with various spans.
40 feet spans ...	14 per cent. ..	0·9 feet ...	478
35 feet „ ...	18 „ ...	1·2 feet ...	518
30 feet „ ...	24 „ ...	1·6 feet ...	554
25 feet „ ...	31 „ ...	2·2 feet ...	582

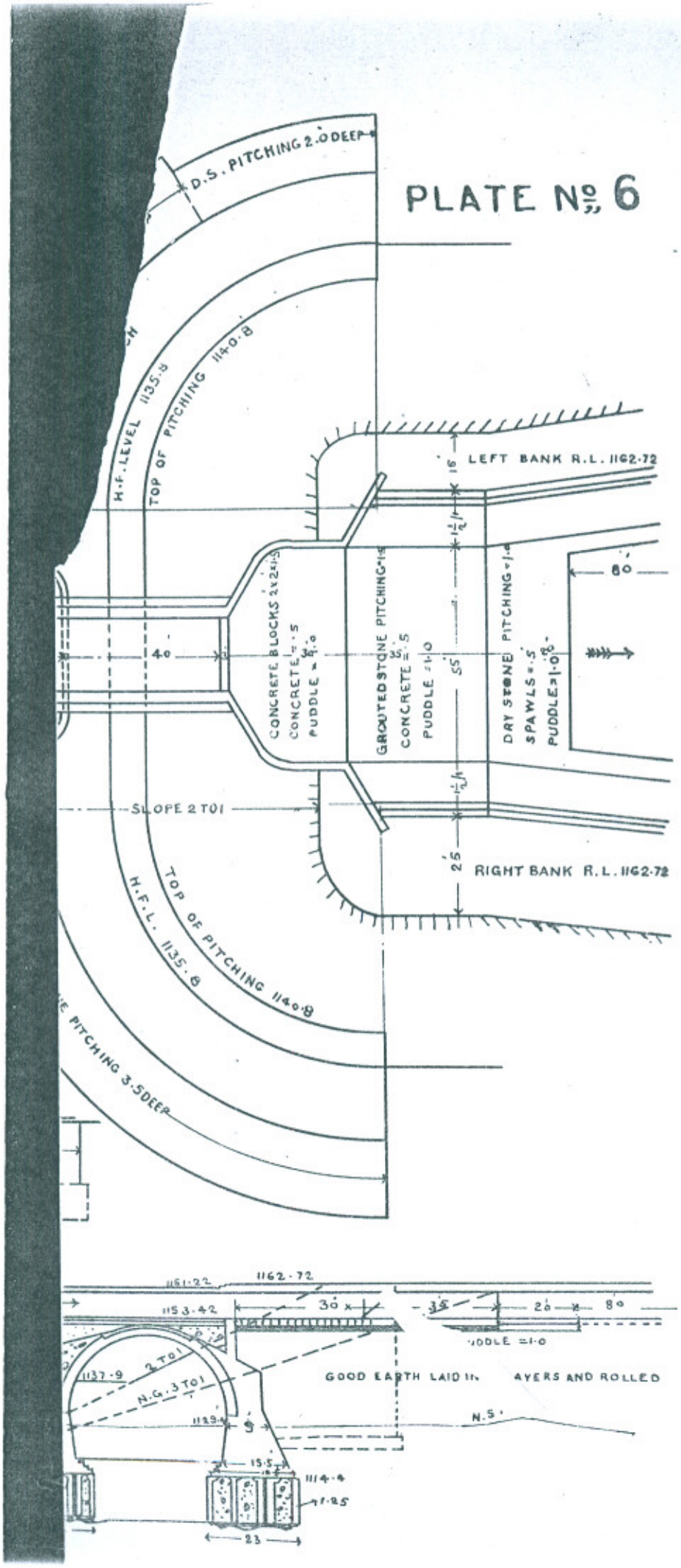
Well foundations were necessary, as the sub-soil contained water, and consisted of sand and shingle over a good deposit of stiff whitish clay, compacted by copious nodules of hard kunkar. To avoid increasing the number of piers and wells, and in order to use the standardised centerings, forty feet spans were adhered to. A wide pediment was given, under the footings of both piers and abutments in order to reduce the mean pressure on foundations to two tons per square foot.

The calculated velocity through the flume will be 10,004 f. s. with Kutters "N"=·017. These are safe figures, and allow for future expansions in irrigation.

The aqueduct is sit. ed on a bend of the *nala*, hence a strong masonry waterwing a.. floor have been provided on the right, while on the left, hich is not subject to severe action, there are guide bunds on Bell's principle. As there is a cliff of firm clay on the right bank, the hydraulic gradient allowed on that side is steeper than that on the left, where there will be made soil. A good junction with the embankment is effected by carrying the last span into it.

In this paper, long technical descriptions with detailed calculations, have been omitted to avoid making the paper too lengthy. The drawings are fully dimensioned however, and any points which cannot be followed will no doubt be brought out when the paper is discussed at the Congress.

PLATE No. 6

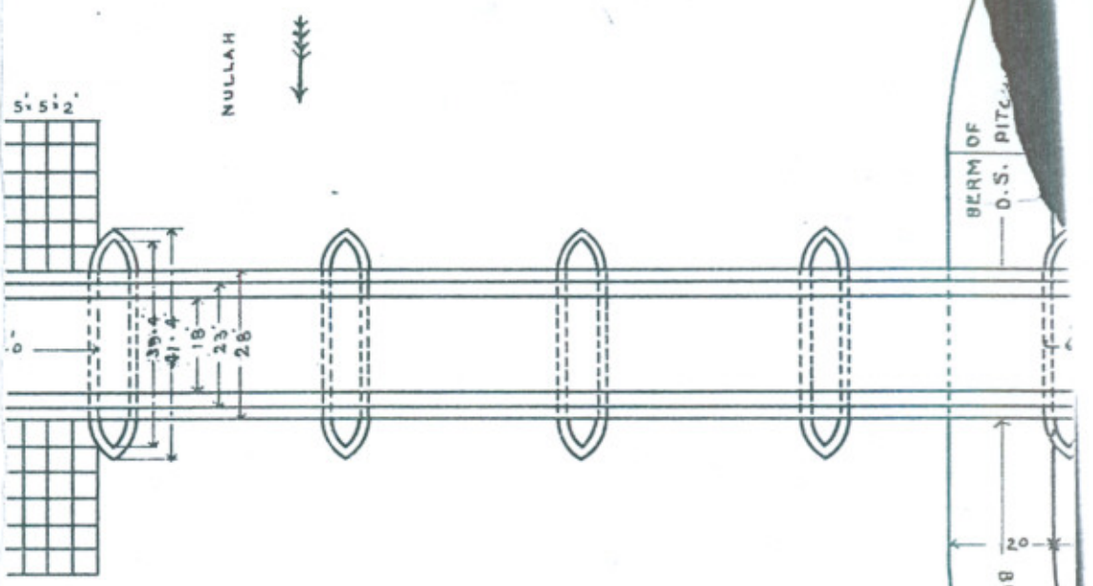

D.S. PITCHING 2.0 DEEP
H.F. LEVEL 1135.9
TOP OF PITCHING 1140.8
LEFT BANK R.L. 1162.72
18'
1½'
80'
40'
CONCRETE BLOCKS 2'x2'x1'
CONCRETE = 1.5
PUDDLE = 4.0
GROUTED STONE PITCHING = 1.5
CONCRETE = 1.5
PUDDLE = 1.0
55'
DRY STONE PITCHING = 1.0
SPAWLS = 1.5
PUDDLE = 1.0
SLOPE 2 TO 1
1½'
25'
RIGHT BANK R.L. 1162.72
H.F.L. 1135.8
TOP OF PITCHING 1140.8
PITCHING 3.5 DEEP
1161.22
1162.72
1153.42
30'
3.5
25'
80'
PUDDLE = 1.0
1137.9
2 TO 1
N.G. 3 TO 1
GOOD EARTH LAID IN LAYERS AND ROLLED
1129.4
N.S.
15.5
1114.4
1.25
23

ER SWAT RIVER CANAL

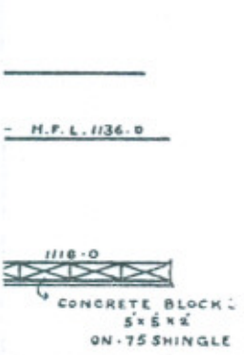
IULLAH AQUEDUCT AT R.D. 157,000

MACHAI BRANCH

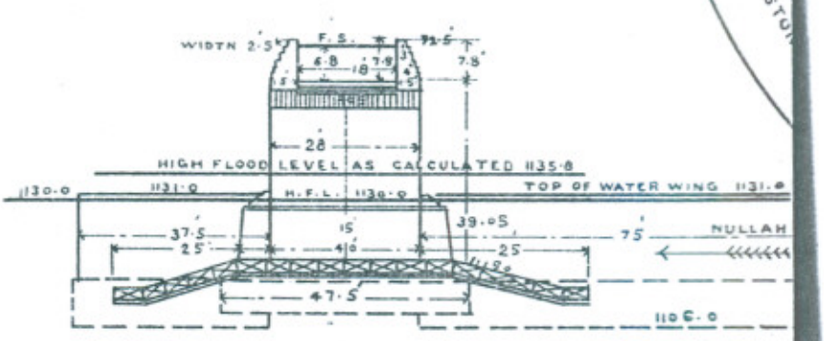
SCALE 1/720



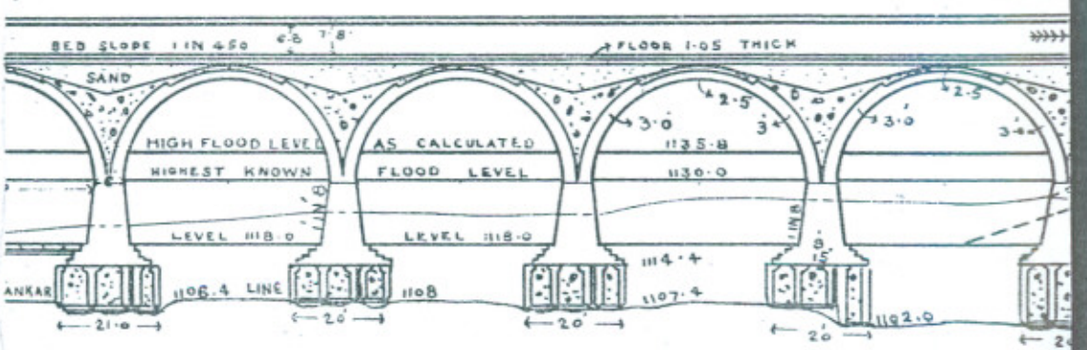
TERWING



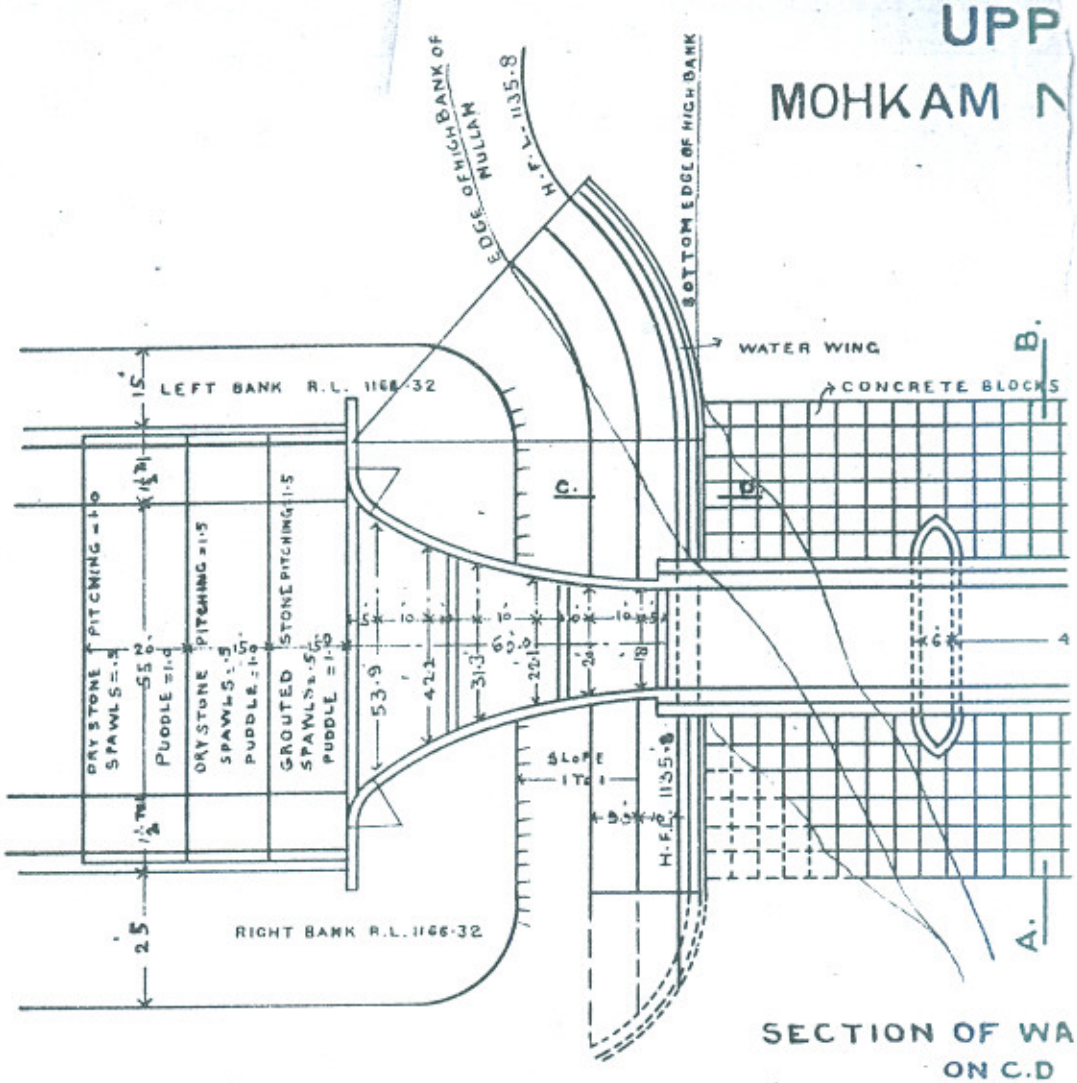
CROSS SECTION ON A.B.



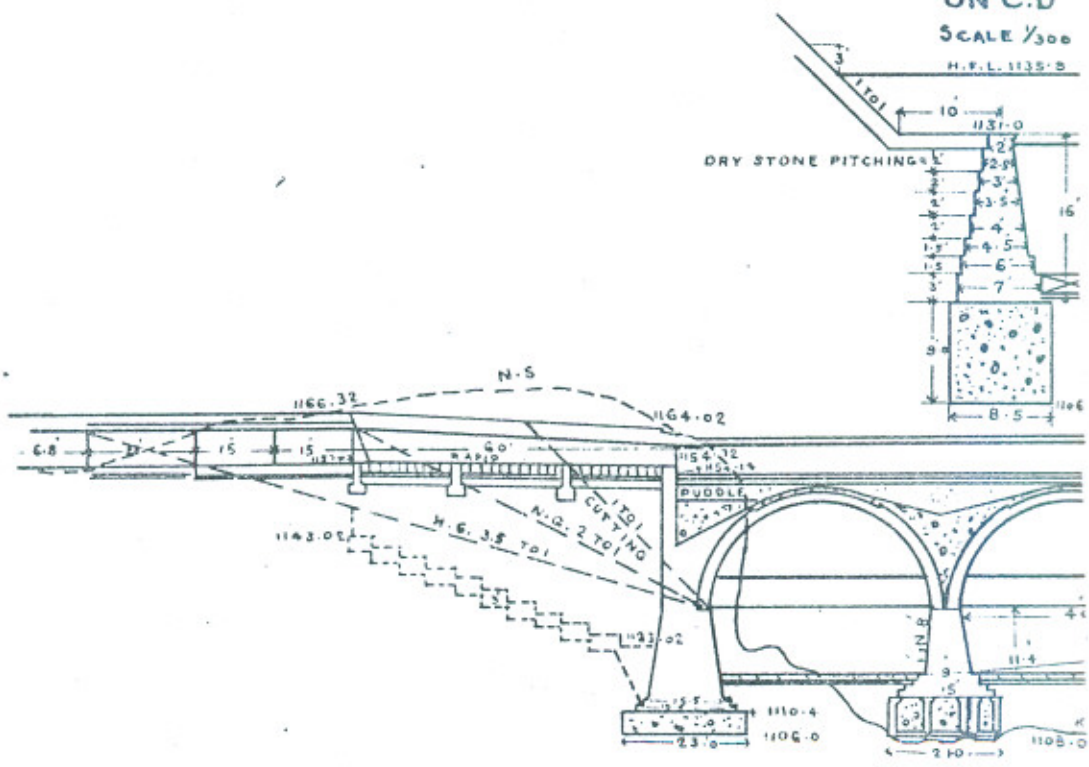
LONGL SECTION THROUGH CENTRE LINE OF CANAL



UPP
MOHKAM N



SECTION OF WA
ON C.D
SCALE 1/300



DISCUSSION.

MR. WADLEY, in a written communication, expressed his regret that arrangements in connection with the opening ceremony of the canal, which was to take place on the 14th instant, did not permit his attending the Congress, and submitted the following introductory note.

The Upper Swat Canal, with a discharge of about 2,200 cusecs, was not a large one in point of volume, but its construction had involved the solution of many novel difficulties. Like its big brother, the Upper Jhelum Canal, it has been carried over country which was scored by deep ravines, and enlivened by torrents which demanded a quick way out when they were in flood. The irrigable area lay in miniature *doabs* between these numerous ravines, so that in every case the question of diverting a torrent, or of providing a drainage work for it, had to be weighed in the scales of economy and prudence.

Having decided upon the provision of a drainage work, the next question was to ascertain the kind of design best adapted to the local conditions. He had indicated in his paper the results of some investigations and experiences under these circumtances, as, there being very little easy country now left in the Punjab or North-West Frontier Province, in which canals could be constructed, their energies in the future were apparently destined to be directed to the solution of such complex problems as the carrying of water through ranges of mountains, across the faces of hills, down steep slopes, and over or under deep chasms. There was a distributary on the Upper Swat Canal under design at present which passed through country the longitudinal section of which somewhat resembled the rise and fall diagram of one of their Punjab rivers during the flood season.

With regard to steel tube syphons, it was rash to design a tube of less diameter than $3\frac{3}{4}$ feet, because no one could get inside to paint it annually. The author was inside one recently, and could therefore speak feelingly. At the same time such a diameter would often be wasteful in the case of a distributary, and that was one reason why the author had recommended the reinforced concrete tube in preference to the steel tube, but he gave the palm to the masonry or concrete aqueduct, as being, wherever possible, the best design.

With regard to the matter of increasing the velocity in the canal when circumstances were favourable, he was not sure that full advantage had been taken of such circumstances in the

past, and in fact he could recall instances on the older canals, in which hard *putt*, capable of standing a velocity of four feet per second, had barely been given one of three, and where the excavation in several miles of main line might have been reduced by twenty-five per cent. with a very small sacrifice of head.

The author had drawn attention to the need for having a reserve of head available when laying down the project alignment, as it gave the designer more scope for economy.

The following table, showing the resistance of various soils to erosion by flowing water, had been prepared from a diagram* by Mr. W. A. Burr.

Material.	Velocity in feet per second.
Pure sand	1·1
Sandy soil 15 per cent. clay	1·2
Sandy loam 40 per cent. clay	1·8
Loamy soil 65 per cent. clay	3·0
Clay loam 85 per cent. clay	4·8
Agricultural clay 95 per cent. clay	6·2
Clay	7·35

MR. FOY said that Mr. Wadley's paper dealt with the designs of works on the Upper Swat River Canal, and was of particular interest to him because four out of the five designs described were some with which as Executive Engineer he was personally intimately connected. He might say that the question of crossing six big nullahs in the Mardan Division had been contested in a pitched battle between "Aqueducts" *v.* Syphons, a further bone of contention being whether masonry or steel aqueducts should be adopted. The battle raged for three years, and finally resulted in a compromise; three aqueducts and three syphons being finally adopted.

As the proposer and designer of the masonry aqueduct it was scarcely necessary to say the speaker fought on the side of the masonry aqueduct, and his only regret was that that type of crossing had not been adhered to throughout.

* "Engineering News," Feby. 8th, 1894.

In the six nullahs referred to, the widths varied from about 300—500 feet and the depth from 40 to 100 feet below canal bed. Splendid building stone was available on the spot, and imposing handsome structures were possible, especially as good hard foundations were to be found at each site. It seemed a pity to have buried the canal under ground in a pipe. A reference to Plate No. 4 showed that in crossing the nullah the bed width of the flume of the aqueduct was reduced to 19 feet against a canal bed width of 58 feet. This required an increased velocity of ten feet against a velocity of about three feet in the canal. Consequently sufficient head was required at the entrance to generate this velocity. This brought the speaker to the point to which he wished to draw attention. On page 142 Mr. Wadley said a special form of entrance was not adopted, but if some such form had been adopted he thought considerable saving would have been effected at some sites. The question was however a complicated one, and could only be mentioned there in passing, but if the speaker's views had been adopted, the width of the flumes could have been considerably reduced. The view taken however was that the available heads at each site could only generate certain velocities, and from this the width of the flume was fixed. The speaker thought they would have generated more, and probably in all cases it would have resulted in narrower flumes, costing less than steel tubes. With lower velocities and wider flumes in one or two cases steel syphons became cheaper.

Mr. Wadley had noted that perforated spandrels had not been adopted. In the original design however the haunches of the arches were perforated with a trefoil of rings, one eight feet wide and the other two three feet running right through each spandrel. The advantages of such openings were a reduction of weight on the foundations, greatly improved architectural effect and provision of an escape for seepage water. The reason given for the non-adoption of the perforations *viz.*, that the concrete was not sufficiently water-tight was not convincing.

These openings would have drawn off the water leaking through the concrete. The probable result now would be the saturation of the haunches, with a green and mouldy appearance of the masonry. He did not think it was yet too late for the openings to be made, as he believed the arches were only now being turned.

The water wings which had been added were not in the original designs and were a decided improvement.

It was proposed in the event of all six aqueducts being sanctioned, to get light steel centerings for forty feet spans and use them successively on each work, by which means their cost, spread over six large works totalling in cost not less than twelve lakhs of rupees, would have been trifling per work. This however was not done in the end, as all six aqueducts were not sanctioned.

MR. SCHONEMANN remarked that Mr. Wadley's paper was much too wide in its scope. It consisted of a series of comments on the main features of design of a large number of different works scattered over the Upper Swat Canal, any one of which might have suitably formed, by itself, the subject of a complete paper for discussion at the Congress. It was quite impossible to adequately discuss the paper ; especially as the speaker had only five minutes at his disposal for doing so. He could only gallop rapidly over the course, commenting in the briefest possible manner on one or two points, as he went. Mr. Wadley had fallen into a common error in writing of the problem of scour as though it depended upon the absolute velocity of a current. That was not correct. Scour, or silt deposit, depended, not on absolute velocity, but on the distance of the filament of maximum velocity of the current from the surface eroded or deposited on. Any given velocity of current, say x feet per second, occurring in a water depth of say y feet, above the bed of a channel, might erode material of a given coarseness, weight or cohesion, from that bed ; and yet it might not do so if the water depth were increased to, say $(y+z)$ feet ; or it might scour still more severely if the water depth were say $(y-z)$ feet, the velocity remaining the same. It was true that Mr. Wadley had erred in common with the compilers of many treatises and manuals of civil engineering ; but that did not alter the fact of the error.

Mr. Wadley had referred to the design of the pitched channel of the Upper Swat Canal, with its gradients of 1 in 250, its numerous rapids, and its velocity of nine feet per second ; but he had omitted to mention the reason why that design had been adopted. This pitched channel, under Sir J. Benton's original design, was to have had a bed width of 130 feet, a water depth of 1·73 feet, a gradient of 1 in 60, and a mean velocity of nine feet per second. These conditions

involved the production of waves, according to Bidone's formula for the standing wave :—

$$V^2 > gd$$

For, with $g = 32{\cdot}2$, and $d = 1{\cdot}73$, and $\sqrt{gd} = 7{\cdot}5$ the wave condition would be set up as soon as the mean velocity exceeded 7·5 feet ; and it was exceedingly doubtful whether dry stone pitching would safely withstand such wave action in a channel of such dimensions and discharge. But under the revised conditions of design, with bed width 47 feet, water depth 4·33 feet, gradient 1 in 250, and the mean velocity nine feet per second, the wave condition would not occur with a mean velocity of less than 11·8 feet per second, for :—

$$\sqrt{gd} = \sqrt{32{\cdot}2 \times 4{\cdot}33} = 11{\cdot}8 \text{ feet per second.}$$

CAPT. ANDERSON, referring to the expansion in reinforced concrete syphons, said that he had recently completed some reinforced concrete platforms, in which they had had a good deal of trouble with expansion cracks. These cracks appeared in spite of the introduction of specially designed joints to give the calculated allowance for the expansion, and the cracks were only eliminated in later work by giving nearly double the allowance. Apparently it was necessary to allow for at least double the calculated amount of expansion in a reinforced concrete structure, if such cracks were to be entirely eliminated.

MR. PURVES said that the Paper contained a mass of information in a small compass, which would be of great use to other engineers required to consider similar problems in the future. The paper showed the care and consideration devoted to the selection of the design best suited to the locality. Owing to the great variety of conditions on this material, it appeared that the adopted designs had been as varied as the material brought into use.

It was probable that when designs in reinforced concrete were more developed in India to meet climatic conditions, when greater skill was attained in execution, and when cheaper concrete was available, they would adopt more freely this material in their designs of such works. Under existing conditions the cost combined with the difficulties of execution, deterred engineers generally from going boldly for reinforced designs.

It was to be earnestly hoped that papers dealing with single works would find a place in future congresses, which presented a good field for advancing their knowledge in the best designs for works under such very varied conditions. Engineers writing such papers would be doing a useful service for the profession.

MR. WADLEY, in reply, said that it was extremely doubtful whether a special form of entrance would have justified the additional expense involved in its construction. The velocities being dealt with did not appear sufficiently high to warrant a special entrance, considering that the sides of the flume were plastered, and that there was no sudden change of sectional area at the entrance, in the design adopted. With regard to Mr. Foy's second point, the non-adoption of perforated spandrels, the author thought that they should be used with caution where semi-circular arches were concerned. The theoretical contour of the backing necessary in such cases, showed that if it were desired to economise in the arches, and by obtaining a uniform distribution of pressure, to keep the line of resistance as near as possible to the centre line of the arch, it was not desirable to perforate the backing, unless the perforations could be located clear of the theoretical contour of the backing. The drainage of the spandrels could be equally well arranged for by inserting six inch pipes. The author agreed that perforated spandrels were economical, useful, and architecturally desirable, wherever stability was not likely to be impaired by their use. With regard to the light steel centerings which Mr Foy advocated, he doubted whether less than three sets would have been found sufficient in practice, without causing considerable delay. The method which had been adopted had proved both expeditious and economical. In the case of the aqueduct at R. D. 95,500, three of the spans were provided with earth centres, and three with wooden centres resting upon pillars made of dressed stone in mud. The dressed stone was that destined to be laid later in the walls of the flume. In the span reserved for the passage of freshets the stone in mud pillars were pointed with lime mortar.

In the case of the aqueduct at R. D. 157,000 only four sets of centres were used, although the aqueduct consisted of seven spans. Four of the spans were first arched, but only three centres were struck, the central span being left unstruck, and the three available centres were then moved to the remaining three spans. It would thus be seen that by careful management it was not costly to give each large work its own wooden centering, by which means each Sub-divisional Officer was given a free hand, and had not to wait upon any one else's *bandobast*.

Mr. Schönemann had made some remarks about scour and deposition to the effect that, in his opinion, these results were dependent on the distance of the filament of maximum velocity from the bed. The formulæ in use at present were based upon

experiments ; those by Bazin (1897 new formula) ; Manning, Kutter and Kennedy finding most favour, and the author would await the results of any experiments made by Mr. Schönemann before criticising his remarks, for obviously results obtained by careful and extensive experiment, could only be compared with results similarly based.

It would be of general interest if Capt. Anderson would give further particulars regarding the kind of expansion joints which he used. Their re-inforced concrete tubes were buried, which made a great difference, but it would be instructive to all concerned if the best proportions for cement concrete in India, and the allowances to be made for expansion under various conditions, could be formulated.

PLAN OF BEAS BRIDGE

Scale 2400 Ft = 1 Inch

JULY 1913

