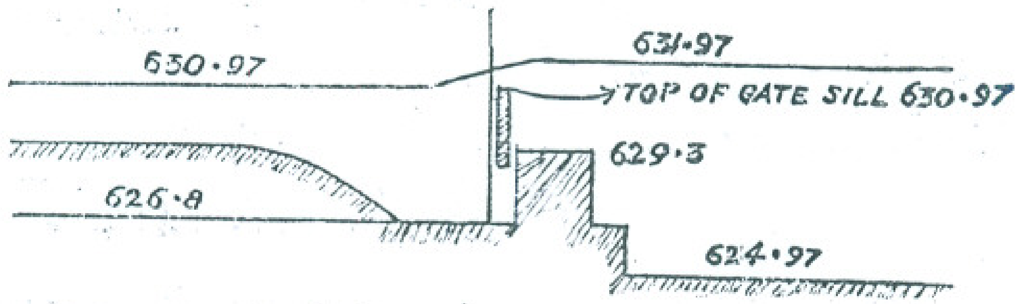
Suppose now we build a crest wall across the opening, so as to secure a free overfall :—

FIG. 15.



We then have :—

Discharge = 45 cusecs ; mean velocity = 5·6 ; elevation of crest = 6 feet ; maximum velocity = 8·4 ; silt index $= \frac{8 \cdot 4}{6} = 1 \cdot 4$.

If we give the regulator two spans of 8 feet, instead of one only, and design similarly, we get :—

Mean velocity = 2·8 ; maximum velocity = 4·2 ; elevation of crest = 6 ; silt index $= \frac{4 \cdot 2}{6} = 0 \cdot 7$.

It will be convenient to style this type of regulator, with gate-sill, the overshot type ; and the type which is at present in vogue, the undershot type.

The Raniwali Right Distributary.

The following data exhibit the silt index more precisely measured.

The Raniwali Right Distributary offtakes from the Lahore Branch, Upper Bari Doab Canal, at R. D. 94,000, about 2,000 feet upstream of a fall.

The hydraulic data of the canal were :—

Bed width 62 feet ; water depth 6 feet ; gradient 1 in 5700; critical velocity ratio 1·01 V_o.

The water flowed into the distributary through an undershot gateway six feet wide—the orifice being about 0·7 foot high—with a mean velocity of 8·4 feet per second, and a silt index of about 4·0. The distributary suffered severely from silt deposits.

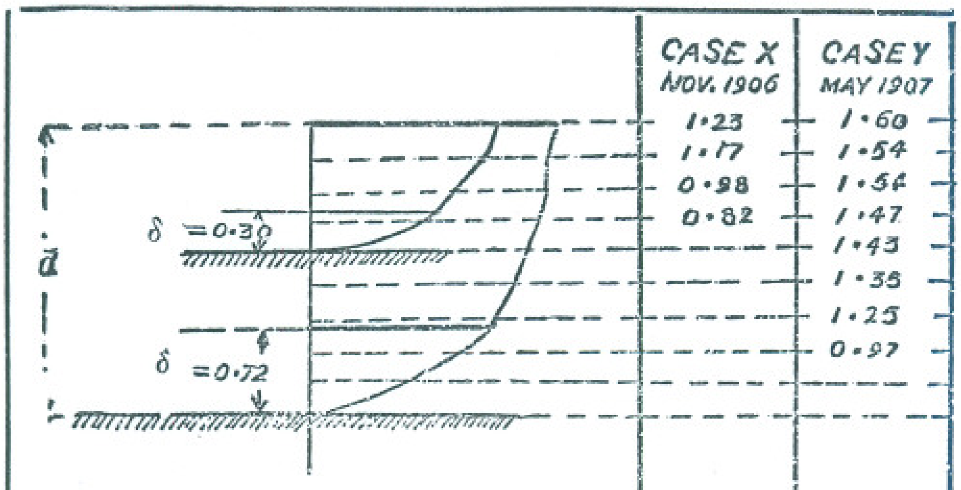
Plate VI exhibits the longitudinal section of its head reaches in 1906. The high bank represents mounds of silt excavated by manual labour from the channel. In November 1906 the hydraulic conditions of the distributary, a thousand feet below its head, were found to be thus :—

Discharge = 16 cusecs; gradient = 1 in 2380; mean velocity = 1·03 = 1·2 V_c.

With a gauge reading of 2·75 there was a depth of only one foot of water over the silted bed; and the channel was discharging less than half it should have discharged for that water level. The velocities of the stream were measured by the writer, with a Pitot tube, at three inch intervals from surface to bottom, on five verticals, *viz.*, one at midstream, and four others at points, respectively, two and four feet to the right and left of the centre vertical.

Six months later, *i.e.*, early in May 1907, the distributary was cleared of silt by manual labour; and again the surface and subsurface velocities were measured at three inch intervals on five verticals by Mr F. V. Elsden. The results are depicted in Plate VII; but a sketch of the conditions on the centre vertical is subjoined for convenience of reference.

FIG. 16.



	CASE X	CASE Y
v. MEAN VELOCITY ON THE VERTICAL	0·84	1·21
δ. ELEVATION OF v. ABOVE BED	·305	0 72
I. SILT INDEX $v. \div \delta$	2·75	1·68
RATIO $\delta : d$.	0·30	0 32
DISCHARGE	16	41
MEAN VELOCITY OF STREAM	1·03	1·44
GAUGE READING	2·75	2·62

LONGITUDINAL SECTION OF RANEWALI

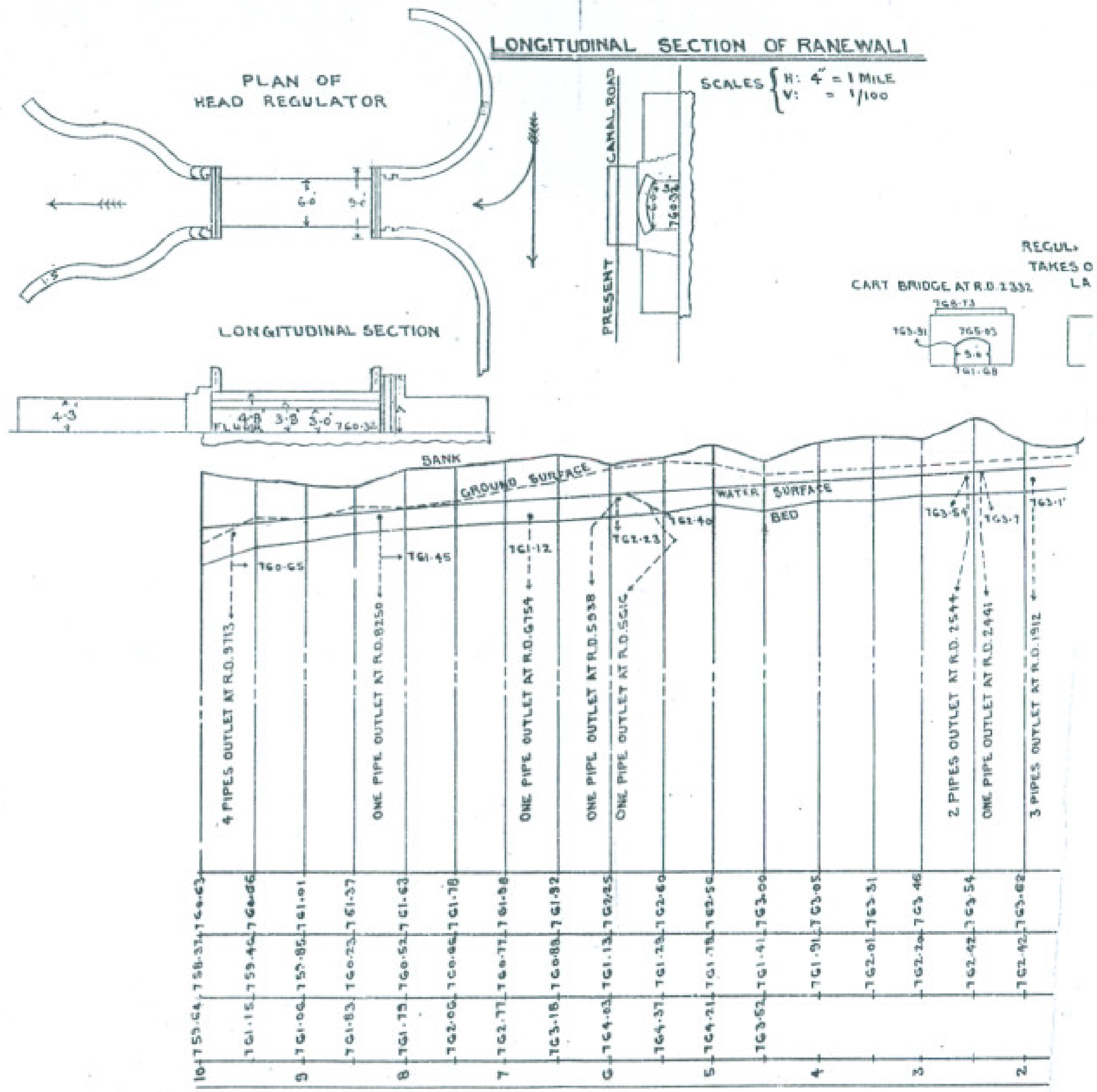


PLATE VII

EMBER 1906 BEFORE SILT CLEARANCE —HYD ULIC OBSERVATIONS—

— ON RA WALI RIGHT DISTRIBUTARY —

— UPPER B I DOAB CANAL AT R.D. 1000 —

CASE Y CROS S SECTION OF STREAM IN MAY 1907 AFTER SILT CLEARANCE

GAUGE READING 2.60

DISCHARGE 41 CU SECS

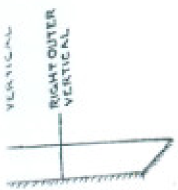
SLOPE 1 IN 4545

WATER SURFACE

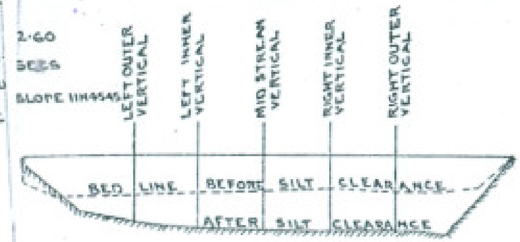
SCALE OF CH

SCALE VELOC NEL SECTIONS $\frac{1}{50}$

OBSERVATIONS { VELOCITIES $\frac{1}{10}$ FEET SECS; SOUNDINGS $\frac{1}{10}$



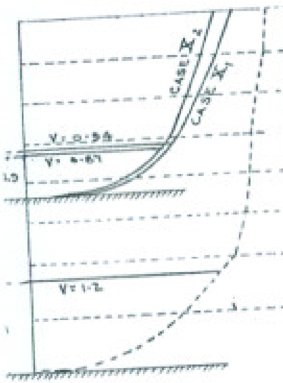
1.00	1.02	1.03	1.02	0.92



SOUNDINGS

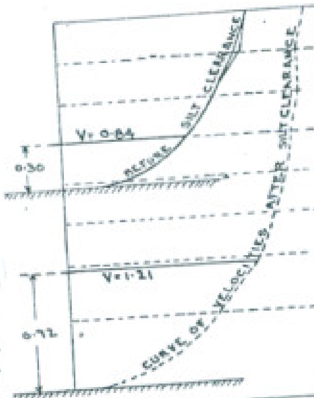
0.20	1.0	1.7	1.95	2.07	2.12	2.22	2.26	2.28	2.3	2.3	2.26	2.22	1.65	1.45

VELOCITIES ON LEFT INNER VERTICAL



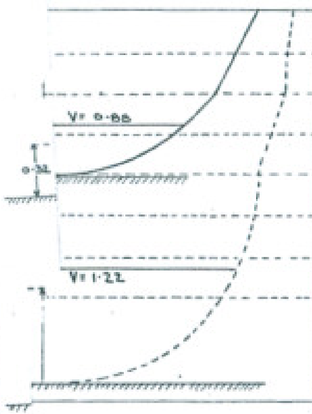
CASE	X_1	X_2	MEAN X	Y
WATER DEPTH	1.05	1.08	1.06	2.19
	1.34	1.21	1.27	1.55
	1.23	1.12	1.17	1.53
	1.10	1.03	1.07	1.48
	0.97	0.92	0.90	1.43
				1.42
				1.39
				1.30
				0.97
	0.94	0.87	0.90	1.20
	0.29	.25	.27	0.57
	3.24	3.48	3.33	2.1
	0.28	.23	.25	.26

VELOCITIES ON MID STREAM VERTICAL



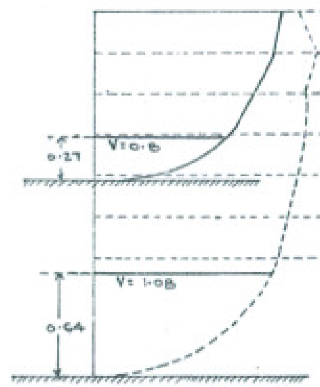
CASE	X_1	X_2	MEAN X	Y
WATER DEPTH	1.03	1.03	1.03	2.27
	1.23	1.23	1.23	1.60
	1.18	1.15	1.17	1.54
	0.98	0.98	0.98	1.54
	0.81	0.83	0.82	1.47
				1.43
				1.35
				1.25
				0.97
	0.84	0.84	0.84	1.21
	.31	.30	.30	0.72
	2.71	2.8	2.75	1.68
	.3	.3	.3	.32

VELOCITIES ON RIGHT INNER VERTICAL



CASE	X	Y
WATER DEPTH	1.02	2.3
	1.32	1.56
	1.21	1.53
	1.08	1.52
	0.83	1.44
		1.36
		1.32
		1.26
		1.12
	0.88	1.22
	0.32	0.73
	2.75	1.67
	.31	.32

VELOCITIES ON RIGHT OUTER VERTICAL



CASE	X	Y
WATER DEPTH	1.04	2.24
	1.12	1.22
	1.08	1.34
	0.96	1.29
	0.82	1.28
		1.23
		1.18
		1.11
	0.80	1.08
	.27	.64
	2.96	1.69
	.26	.29

Mr. Elsden also observed the following hydraulic data of the distributary in May 1907 :—

Discharge = 41 cusecs ; gradient = 1 in 4,545 ; mean velocity = 1·435 = V_o.

The silt clearance flattened the gradient of the channel, increased its mean velocity, and more than doubled its discharge, but although the new mean velocity was equal to that indicated by Kennedy's formula, the distributary could not retain those conditions for any length of time, *simply because of the excess of silt scoured into it through its head regulator.* It should be noted that the Pitot tube was not rated ; hence the velocities registered by it are not *absolutely* correct as to magnitude, though *relatively* correct, *inter se.*

Calling the conditions of November 1906, *i.e.*, those of the channel which was approaching stability of silt regime, Case X ; and those of May 1907, *viz.* those of the channel which was bound to silt up again, Case Y ; we see from Fig. 16 that in the non-silting channel, Case X, the mean velocity was only 0·84 ; yet, as it occurred at a point only 0·305 foot above bed, its silt index was 2·75, a high value. We see, also, that in the silting channel, Case Y, the mean velocity was fifty per cent. higher, *viz.* 1·21 ; and yet, because its elevation above bed was greater, *viz.*, 0·72 foot, its silt index was only 1·68.

The silt index, sixty-six per cent. higher in Case X than in Case Y, explains the difference, *qua* silt regime, between the two cases.

It is noteworthy that the mean velocity filament in both cases, occurs at three-tenths of the water depth above bed ; and not at mid-depth, as observed by Messrs. Humphrey and Abbott, and by M. Bazin.

The silt index of a stream may be expressed by the ratio of a function of any velocity to the elevation above bed of the filament possessing that velocity. It would of course have a different value for each filament considered, but that would involve no confusion, provided that in comparing the silt capacity of different streams we based our silt indices on filaments of velocity at the same relative elevation above bed ; *i.e.*, say at mid-depth in each case, or three-tenths depth in each case, or at surface in each case ; and so on.

If we seek to learn the silt-carrying power of the Raniwali Distributary by the formula, suggested by Higham, the product of Kennedy's and the writer's formulæ combined, we get :—

$$\text{Case } X \quad I_b = \frac{V_s^2 - V_d^2}{d} = \frac{1{\cdot}23^2 - 0{\cdot}82^2}{0{\cdot}75} = 1{\cdot}12$$

$$\text{Case } Y \quad I_b = \frac{1{\cdot}6^2 - 0{\cdot}\text{[illegible]}}{1{\cdot}75} = 0{\cdot}95$$

which shows a silt index higher by twenty-two per cent. in case X than in case Y.

If we consider the bottom velocity as zero, we get

$$\text{Case } X \quad I_b = \frac{V_s^2}{d} = \frac{1{\cdot}23^2}{1{\cdot}05} = 1{\cdot}47$$

$$\text{Case } Y \quad I_b = \frac{1{\cdot}6^2}{2{\cdot}27} = 1{\cdot}13$$

which shows a silt index higher by thirty per cent. in case X than in case Y.

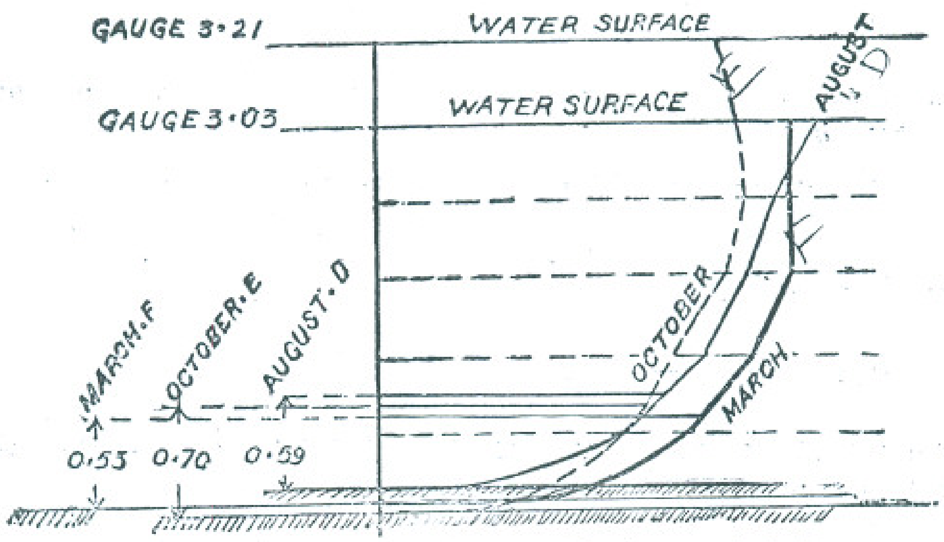
The Bamni Distributary, Lower Chenab Canal.

This is another illustration of the applicability of the silt index. The Bamni Distributary had a fall at R. D. 17,400, over which the water passed through a trapezoidal notch. At R. D. 9,000, *i.e.* 8,400 feet upstream of the fall, there was a rectangular flume of masonry in the channel. The declivity of the water surface of the stream, from the flume to the fall, averaged 2·58 feet in 8,400, or 1 in 3,250. The surface and subsurface velocities of the stream at the flume were measured with a Pitot tube on three verticals, *viz.*, one at midstream, and on two others, respectively two feet on either side of the centre line, at half-foot vertical intervals. These observations were repeated on three days, *viz.*, the 25th, 26th, and 27th August 1903. Then the level of the sill of the fall, and of its notch, was raised so as to reduce the declivity of the water surface, from flume to fall, to 2·07 feet in 8,400, or 1 in 4,060, and all the above mentioned velocity observations were repeated on three days at the end of October 1903.

Finally, the lip of the fall at R. D. 17,400 was lowered once more to its original level, and all the velocity observations were repeated, on the 27th and 31st March 1904. Thus, if we call the conditions of August, October and March, cases D, E and F, respectively ; we have cases D and F representing conditions under a declivity of 1 in 3,250, and case *E* those of a declivity of 1 in 4,060.

The results are depicted and compared in Plate VIII, the diagram of the midstream vertical being reproduced below for convenience of inspection :—

FIG. 17.



The full black lines represent cases *D* and *F*, the fine line being for August, and the thick one for March ; whilst the dotted line represents case *E* with its flatter gradient.

We see that in case *D* the mean velocity (the velocity curve being assumed to be parabolic below the level of the deepest velocity measurement and vanishing to zero at stream bed) was 0·90 at a level 0·59 foot above bed ; so that its silt index would be $\frac{90}{59} = 1{\cdot}53$. The corresponding silt index for case *F* would be $\frac{1{\cdot}00}{0{\cdot}55} = 1{\cdot}82$; and the mean silt index for these two cases, representing the hydraulic condition due to the slope of 1 in 3,250, would be 1·68 ; or about thirty-five per cent. in excess of the silt index $\frac{0{\cdot}87}{0{\cdot}70} = 1{\cdot}24$ of case *E* with its flatter gradient of 1 in 4,060. The discharge of the stream was the same, *viz.*, about twenty cusecs, in both cases *E* and *F* ; and yet the mean velocity was fifteen per cent. greater, and the silt index forty-seven per cent. greater in case *F* than in case *E*. In case *D* the discharge was only about eighteen cusecs, yet its mean velocity was slightly higher, and its silt index twenty-four per cent. higher than in case *E*.

If the silt index from the surface velocity and depth is calculated by a combination of Kennedy's formula and the writer's, as suggested by Higham; that is to say—

$$I = \frac{V_s^2 - V_d^2}{d}$$

Then, with bottom velocity vanishing to zero,

$$I = \frac{V_s^2}{d}$$

Which gives

For case D, $\frac{1 \cdot 4^2}{2 \cdot 3} = 0 \cdot 85$ } Average $= 0 \cdot 78$

For case F, $\frac{1 \cdot 32^2}{2 \cdot 45} = 0 \cdot 71$ }

For case E, $\frac{1 \cdot 08^2}{2 \cdot 87} = 0 \cdot 41$

Or a silt index nearly twice as great in cases D and F as in case E.

Plates VIII and IX afford data for exhibiting the application of the silt index to the velocities in the horizontal plane. The masonry flume at R. D. 9,000 of the Bamni Distributary was originally 8·8 feet wide, and velocity measurements were made on it in that condition by the writer, assisted by Mr. R. L. Colbourne, in September 1902. Afterwards the flume was reduced in width to 7 feet, and further observations were taken in August 1903 and March 1904, under conditions otherwise similar, except that the discharge was 30 cusecs in September 1902, as compared with only 18 and 20 cusecs, in August 1903, and March 1904, respectively. In September 1902 the mean velocity on the verticals, two feet on either side of the midstream, was the same as on the midstream vertical; *viz.*, 0·8 foot per second. These side verticals were 2·4 feet from the sides of the flume, so that their horizontal silt index (or force producing eddies) would be proportionate to $\frac{0 \cdot 80}{2 \cdot 4} = 0 \cdot 33$. In the August 1903 and March 1904 cases, the mean velocities on the verticals two feet on either side of midstream were 0·77, and that on the midstream vertical was 0·95. The horizontal silt index of the mean velocities on the side verticals would be $\frac{0 \cdot 77}{1 \cdot 5} = 0 \cdot 51$, as compared with only 0·33 in the case of the wider flume of

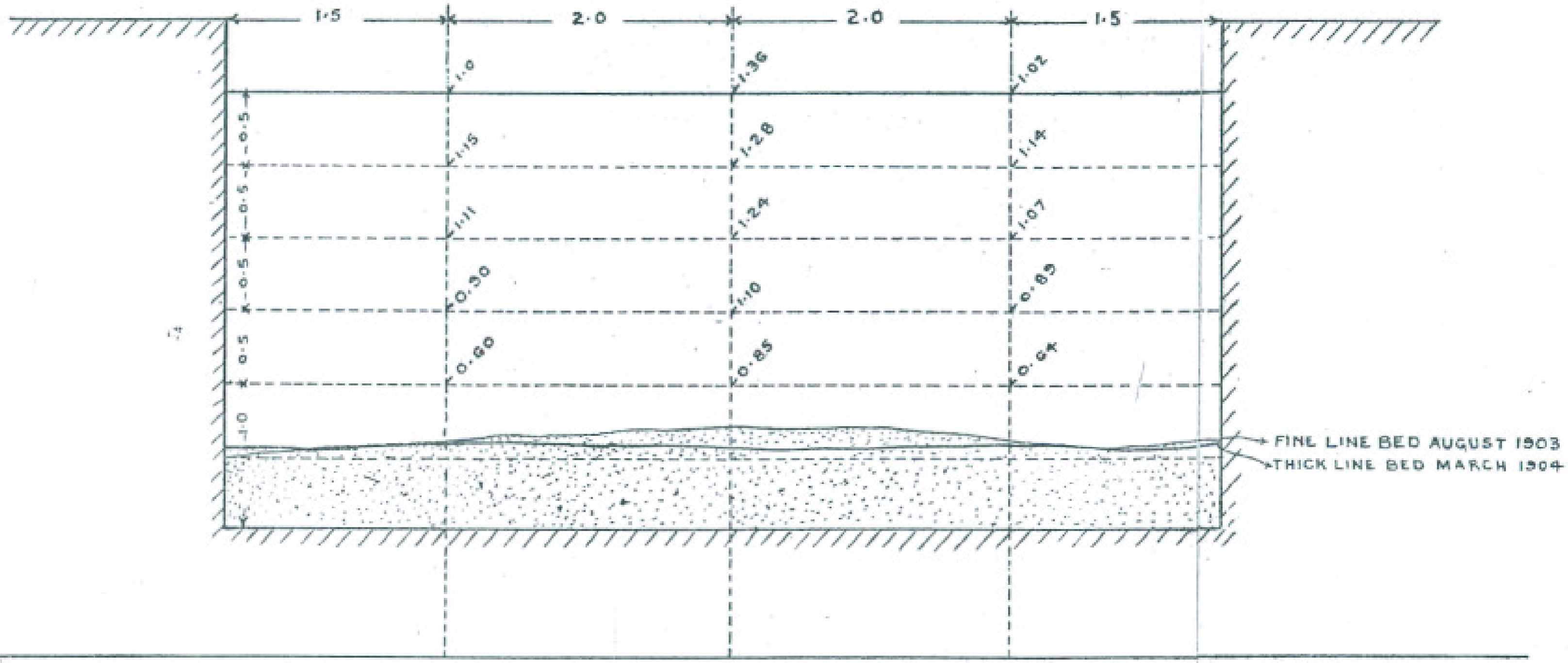
PLATE VIII

VELOCITY MEASUREMENTS, BAMNI DISTRIBUTARY, LOWER CHENAB CANAL

RECTANGULAR MASONRY FLUME, REDUCED IN WIDTH TO 7 FEET, AND IN DEPTH TO 3.5 FEET

MEASUREMENTS TAKEN WITH DARCY PITOT TUBE

SCALE 1:12·5



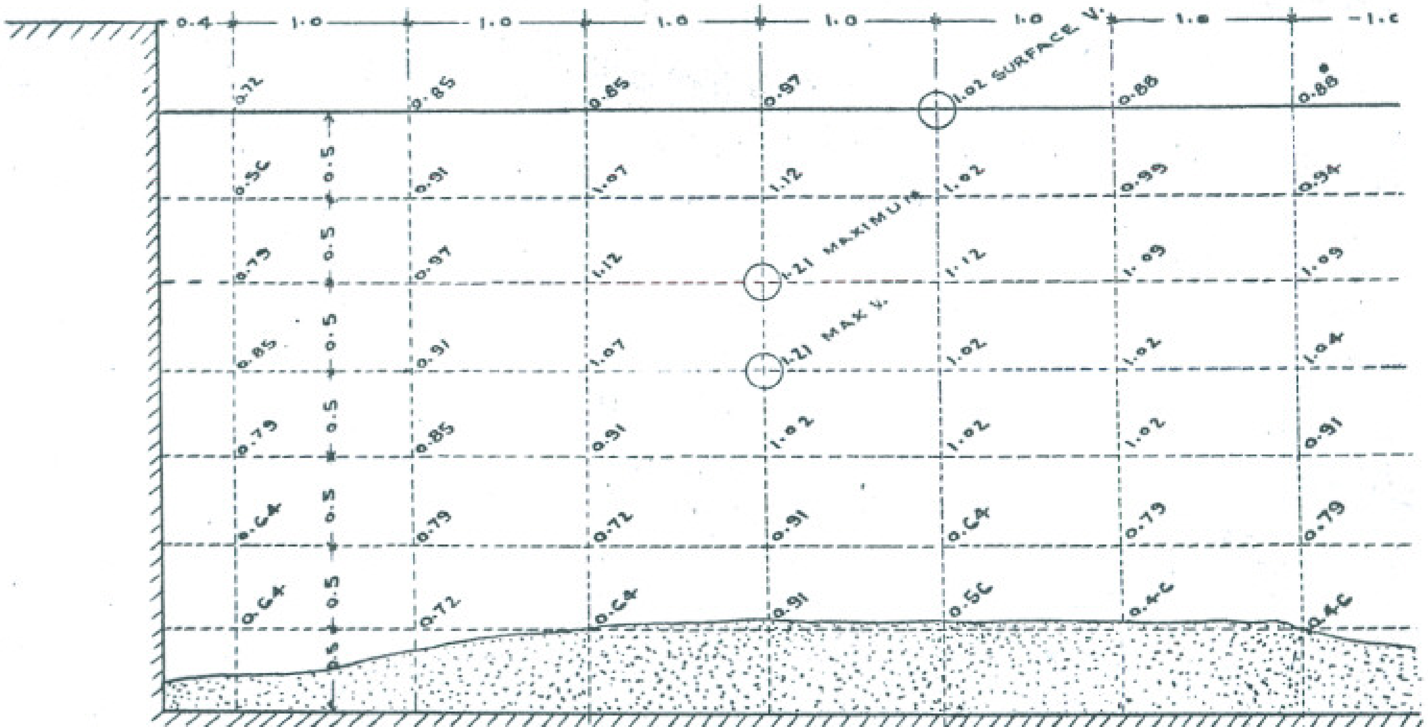
V MEAN VELOCITY ON THE VERTICAL	0.77	0·95	0·77
δ ELEVATION OF V ABOVE BED	0.68	0·60	0·66
I SILT INDEX V ÷ δ	1.13	1·60	1.17
RATIO δ:d	0.27	0·25	0·27

VELOCITY MEASUREMENTS BAMNI DISTRIBUTARY

TAKEN AT A RECTANGULAR MASONRY FLUME 8.8 FEET WIDE AND 4 F

MEASUREMENTS WITH DARCY PITOT HYDROMETRIC TUBE

SCALE-1:12.5



V	MEAN VELOCITY ON THE VERTICAL	0.81	0.81	0.80
δ	ELEVATION OF V ABOVE BED	0.8	.62	0.5
I	SILT INDEX V ÷ δ	1.0	1.31	1.6
	RATIO δ : a	0.27	0.21	0.27

SURFACE FLOAT MEASUREMENTS

SURFACE FLOATS WERE DISCS OF <u>KIKAR</u> WOOD, 1½" DIAMETER, ¾ INCH THICK.

TIMING OF SURFACE FLOATS 9.4, 9.0, 8.4, 9.0, 9.2, 9.0, 8.4, SECONDS.

LENGTH OF RUN = 10 FEET

VELOCITY OF SURFACE FLOATS = { FASTEST FLOAT =
AVERAGE FLOAT =

September 1902. In an earthen channel, this difference of fifty per cent. in lateral eddying force might mean the difference between side erosion or berm-silting.

If the horizontal eddying force of the mean velocity on the midstream vertical is regarded in the light of the formula :—

$I = \frac{V}{b}$ (where Vc is the mean velocity on the central vertical, and b the half width of the stream) we get, for the wide channel of September 1902 :—

$$I = \frac{0{\cdot}81^2}{4{\cdot}4} = 0{\cdot}15$$

and for the narrower channel of 1903-04

$$I = \frac{0{\cdot}95^2}{3{\cdot}5} = 0{\cdot}26$$

the horizontal silt index of the narrower channel being seventy per cent. in excess of that of the wider channel.

Examples of Distributary Heads, Lower Jhelum Canal.

Systematic hydraulic surveys of all the distributaries of the Lower Jhelum Canal have been carried out by the engineers employed on this canal during the years 1914 and 1915, by way of definitely exhibiting the nature of the silt troubles that prevail. In particular, hydraulic observations have been made in the vicinity of each head regulator ; a few hundred feet upstream of it, in the trunk, or parent, channel ; a few hundred feet downstream of it, in the branch or offtaking channel ; and at the head regulator itself. The results of some of these observations, fair samples of all, are exhibited in Appendices I, II and III. In these appendices are set forth the hydraulic data of the trunk and branch channels at each head regulator, and the conditions of discharge through the orifice of the regulator ; while the conditions governing the carriage of silt have been stated, in terms of the silt index applicable to each case, in the last three columns of each appendix.

In calculating the silt indices, it has been conventionally assumed that the filaments possessing velocity equal to the mean velocity of the entire cross section of each open channel are located at mid-depth of the current. This involves an error of defect ; because in these irrigation channels the mean velocity on the midstream vertical is usually found at an elevation of only a quarter to a third of the water depth above bed level ; and the mean velocity of the entire cross section is probably less than that of the midstream vertical, and consequently closer to the bed. However, the error involved is of no consequence, since it will apply equally to both channels, trunk and branch ; and it is only the *comparison* between the two with which we are concerned. In the case of the gateway orifice of each head regulator it has been assumed that the mean velocity filament is located at the centre of each submerged orifice ; and the silt index has been based on this mean velocity and the elevation of the centre of the orifice above the bed of the trunk channel. These silt indices are tabulated in the appendices, only as a very rough and ready reflection of the hydraulic conditions, *qua* silt carriage, of each offtake. The main function of these appendices is to exhibit, by dimensioned drawings, and by statistical data, the hydraulic conditions, which usually prevail on our irrigating distributary systems; and which are, it is thought, not sufficiently realized by, or known to, most of us.

Silt Indices of open and closed Channels compared.

The data exhibited in the appendices generally lend support to the ideas set forth in this paper ; in that they show that the majority of branch or offtaking channels, have higher critical velocity ratios (Kennedy's) and also higher silt indices (I_b) than their trunk, or parent, channels (I_t) ; and that these higher ratios, or indices, indicating heavier charges of silt in the branch than in the trunk channels are due to, or coincident with, silt indices for the gateway orifices of the head regulators (I_r) higher than those for the trunk or branch channels. If the current of entry through the orifice has a higher proportion of silt, or a higher capacity for silt carriage, than the trunk channel, it is easy to understand why the critical velocity ratio, or the silt index, of the branch channel should also be liable to exceed that of the trunk channel. Out of the five sets of observations by Mr. Yeaman, the silt index of the head regulator (I_r) is in every case greater than that of the trunk channel (I_t), and in every case, but one, greater also than that of the branch channel (I_b).

Out of the eight sets of observations by Sheikh Karim Baksh, (I_r) is in every case, but one, greater than either I_t or I_b; and in the one exceptional case, No. 7, the Massan Distributary, with its discharge of 238 cusecs, is really the tail extension of the canal—the gate of its head regulator is fully open, and the flow is merely that through a bridgeway.

Out of the twenty sets of observations by Lala Behari Lal Uppa, I_r is greater than either I_t or I_b in sixteen cases, and greater than I_t in eighteen cases. In the other cases, *viz.*, Nos. II, VIII, XI, XVIII, there is practically no head of pressure through the regulator (less than 0·1 foot) in three out of the four cases ; and the discharge is less than ten cusecs in three out of the four discordant cases. In the case of streams of such trifling discharge as less than ten cusecs with a depth of only one foot or less, a very slight error of observation may make a very material difference to the silt index deduced therefrom. In two out of the four discordant cases, also, the branch channel irrigates high land, uncommanded by flow ; a condition which tempts irrigators to dam the stream illicitly, thereby causing silt obstructions.

On the whole the writer thinks that the data in the appendices support his views as consistently as may be expected from such an unruly subject as practical hydraulics. The possibility of errors of observation must always be borne in mind. The obviously unlikely values which the data impute in cases Nos. VIII, XI and XV, to the co-efficient of discharge of the gateway orifices, indicate errors of observation in those cases.

The Principles of Design.

Assuming the case proved, that the present type of head regulator, with undershot gate, and a high velocity of entry through an orifice at a low level, tends to sweep into the branch channels more than their fair share of the silt carried by trunk channels ; and that, taking into account the lesser silt-carrying capacity of branch channels, due to their relatively small discharges, loss of momentum due to "shock" in alteration of direction of flow, etc., etc., it will be advisable, as a rule, to pass water into branch channels with relatively low velocities at relatively high levels, over crest walls, or overshot gates ; we have next to consider the design of the waterway of entry in accordance with this idea.

Plates X and XI, exhibit the design proposed by the writer, which he has prepared with the help of Mr. Gemmell, Principal of the Engineering School at Rasul, and Mr. Wilkinson, Mechanical Engineer. The main feature of this design is the discharge of water through the regulator, by a "free" overfall, ver a movable gate-sill, which can be raised so as to completely it off the supply from the distributary ; and also lowered till s masked by the masonry crest wall provided in the design.

As a rule the discharge will be by a free fall over the gate-sill, with a constant velocity at a constant level above the bed of trunk channel; implying a limited silt index (I_r).

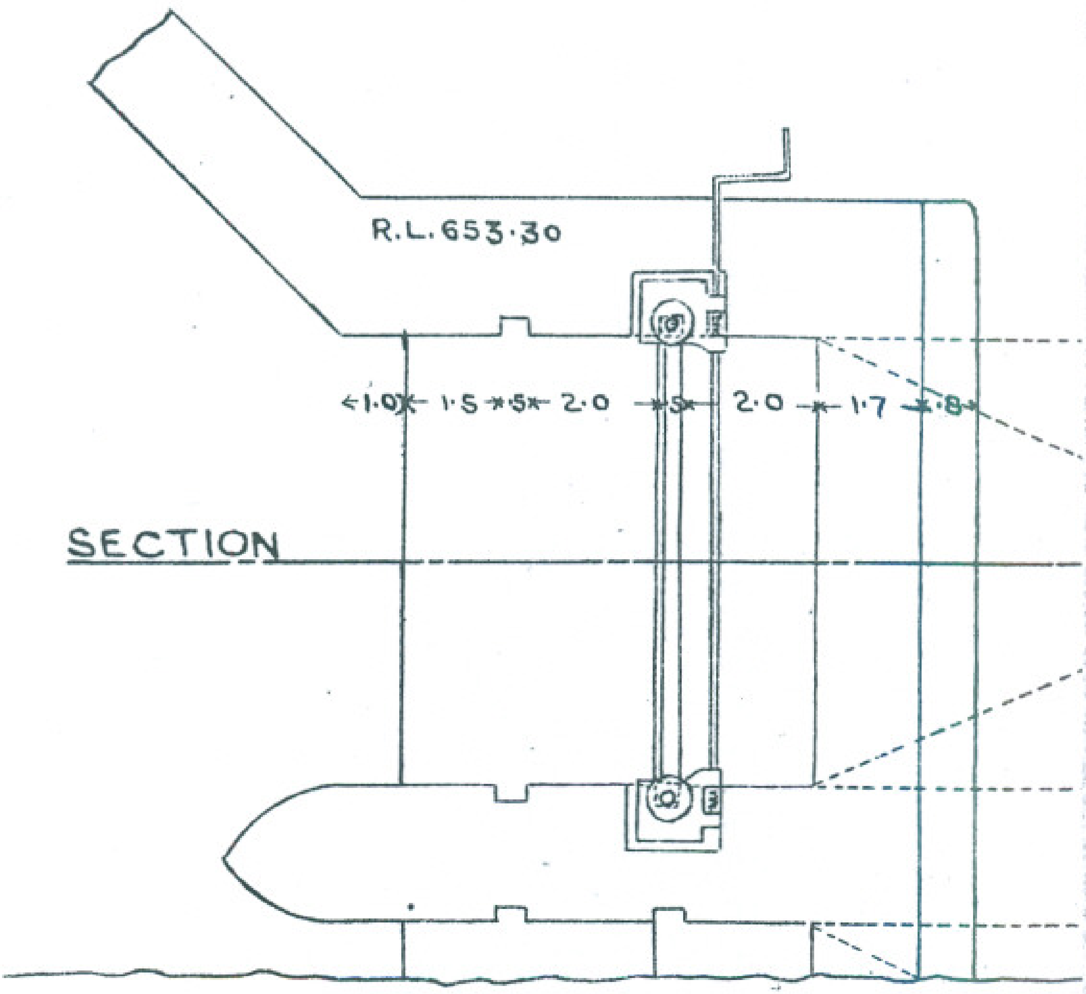
One feature of the design is the staunching bar; merely a metal pipe, resting on the masonry sill; and pressed by water pressure, so as to close the space between the gate and the crest wall. This keeps the gate water-tight, and bars silt entry through that space. It can be arranged so as to rest on the top of the gate, masked by the masonry crest wall, when the gate is fully down.

Another feature is the provision of a single flat-bar, three inches wide by half an inch thick, on the down-stream cheek of the grooves, for the gate to slide against, instead of the cast-iron grooves at present in general use which involve waste of material on two sides of the groove where it is not needed.

The lifting gear shown in Plate XI has been designed by Messrs. Gemmell and Wilkinson. It will be cheaper than the pattern at present in vogue, and probably at least as effective, but the present pattern can also be applied to the design without alteration.

An investigation of a large number of cases on the Lower Jhelum Canal leads the writer to believe that, in most cases occurring on Punjab perennial canals, it will be possible to feed major, branch and minor distributaries by "free" overfalls over movable gate-sills, as designed in Plate X. In this way the flow of silt into branch channels can be controlled to almost any extent that may be desired. Silt exclusion must not, however, be overdone. If we passed into branch channels less than their proportionate share of the silt carried by their trunk channels, the latter would, in their lower reaches, become overcharged with silt. We must, in the first instance, design the canal head, at the offtake from the river, on these principles; so as to admit only the lowest possible silt-charge, consistent with reasonable economy or convenience of design; and thereafter we must design each branch channel with the I_r and I_b most likely to accord with I_t. Branch channels usually offtake from just upstream of a vertical fall on the trunk channel. By furnishing this fall, as well as the head regulator of the branch channel, with a crest wall and movable gate-sill, we can easily arrange to design both fall and regulator with the same value of I_r.

PLAN



The Regulator as a Meter.

So far, the design of the head regulator has been considered from the point of view merely of regulation of the flow of silt-laden water from one channel to another. It remains to consider its function as a means of measuring the discharge passing through it, whether that discharge be constant or variable. In this connection it is a favourable circumstance that, for reasons connected with economy of supply in irrigation practice, it has been found advisable to keep distributaries in flow up to their full authorized capacity whenever water is sufficiently in demand for irrigation, or to periodically close them altogether. Thus, in the case of a distributary with a full authorized capacity of, say seventy cusecs, if the demand for water at a particular season, amounted to not more than, say fifty cusecs, it would be correct irrigation practice to run the full supply of seventy cusecs in the channel for five days in the week, and to close it altogether for the remaining two days, rather than to keep it flowing throughout the week with fifty cusecs only. Taking advantage of this circumstance, it will usually be possible to supply most distributaries throughout the year by a "free" fall over a sliding gate-sill, according to the design exhibited in Plate X, which provides for the maintenance of a free fall within a reasonable range of working conditions. By giving the top of the gate-sill a sharp edge, we can ensure a constant and known co-efficient of discharge over it ; and we could, if necessary, furnish sharp-edge side contractions to the overfall waterway. We might even arrange to bell-mouth the orifice, or to give it the Venturi meter shape throughout the regulator, in order to secure a constant co-efficient of discharge with a minimum loss of head.

The push-and-pull rods working in the grooves at the sides of the gate-sill might be arranged so as to abut at the top against a buffer, or stop-plate, when the top of the gate-sill was flush with the authorized full supply of the trunk channel. When raised to this limiting level, the gate-sill would completely close off the distributary unless the canal water surface happened to exceed its authorized full supply level, in which case there would be a spill over the top of the gate, and the distributary would act usefully as an escape for excess of flow. When lowered below this limiting level the side rods of the gate sill could be arranged so as to mark off, by the reading of an index finger on a vertical float gauge, the depth of water passing over the gate-sill, and the discharge due to that depth of overflow,

The Flume Meter.

Cases would, however, occur, in which a free fall over the gate-sill would not be obtainable, and the overfall would be partially drowned, with an uncertain co-efficient of discharge. To meet the requirements of such cases, each distributary should be furnished, a few hundred feet downstream of its head regulator, with a cheap masonry flume, designed so as to pass the flow of the distributary without silt deposit. This flume should be at least a hundred feet long, with a cross sectional area of waterway, compared with that of the earthen channel, in the inverse ratio of their respective velocity co-efficients, $V \div \sqrt{R\ S}$ Midway down its length, the flume should be furnished with a piezometer gauge, the readings of which would correspond to known discharge values. Such a flume, in length not less than ten times the width of the channel of the distributary, and free from risk of silt deposits, would register the discharges of the distributary without appreciable error ; and might be used for this purpose, either in supersession of the gate-sill meter of the head regulator, or by way of supplementing it whenever the gate-sill gauge indicated drowned conditions of overfall.

Summary.

The principal features of this paper may be summarized now, as follows :—

(*a*) The theories of Dupuit on the subject of silt carriage (1860).

(*b*) The Ganges Canal experience and theory of Login (1867).

(*c*) The investigations of Kennedy (1883—1896).

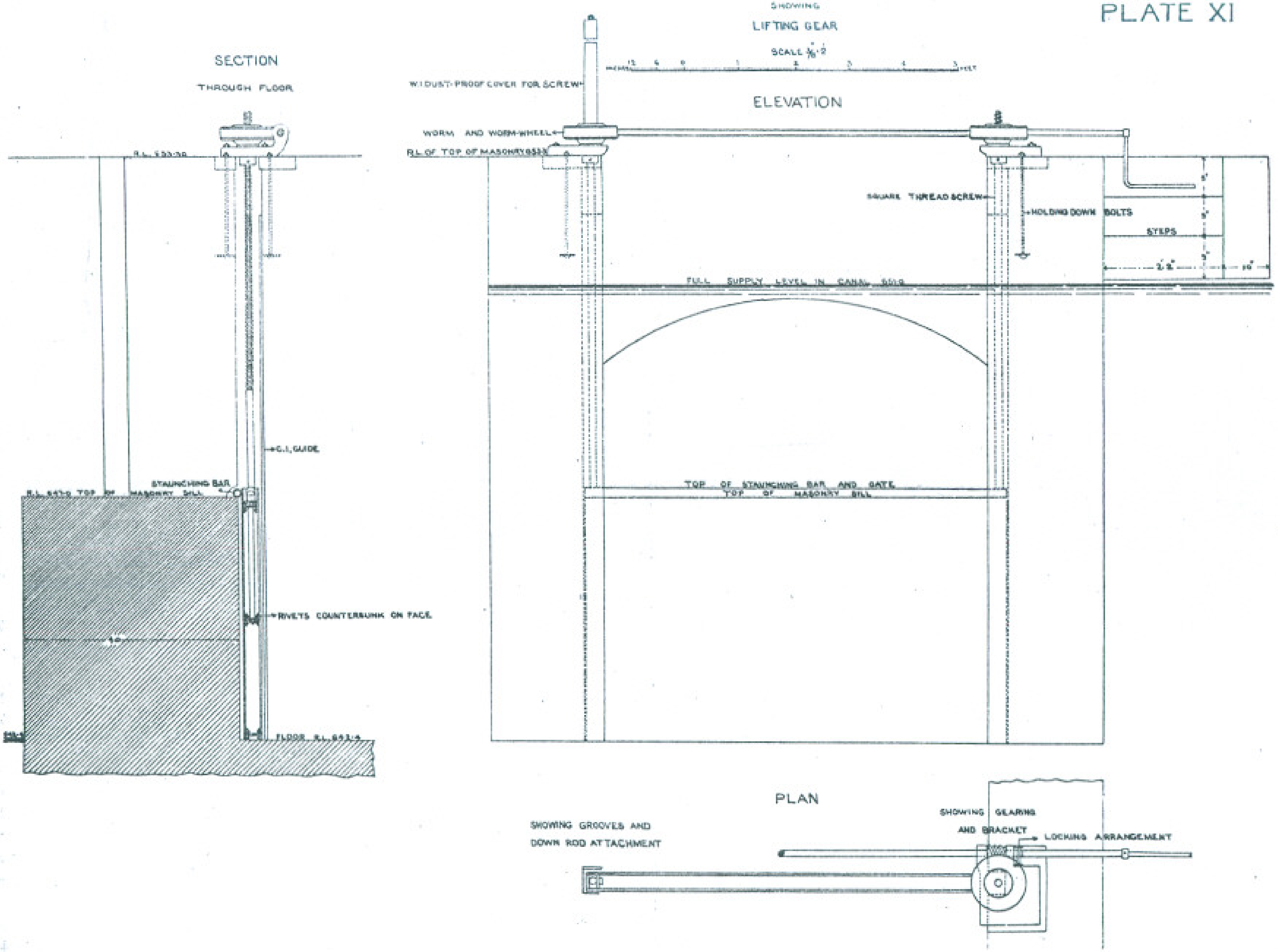
(*d*) The Gudha Minor experiments, suggesting the dependence of silt flow on *differential* water velocities.

(*e*) The erosion phenomena of the Jhang Branch, Lower Chenab Canal, suggesting that flow through an undershot gateway has the same hydraulic effect *qua* erosion of bed, as flow over an excessively steep declivity. Inferentially an excess of silt is carried through the undershot gateway into the channel downstream of it.

(*f*) The Raniwali experiments, illustrating the variation of silt carriage power with the magnitude of the silt index, $v \div \delta$

DESIGN FOR DISTRIBUTARY GATE

PLATE XI



(*g*) The Bamni experiments, demonstrating the application of the silt index in the horizontal, as well as in the vertical, plane.

(*h*) The silt history of the Mithalak and Luddewala distributaries of the Lower Jhelum Canal.

(*k*) The data of hydraulic observations near distributary head regulators, by Messrs. Yeaman, Karim Bakhsh and Behari Lal Uppal.

(*l*) The design of the head regulator gate-sill proposed by the writer, having the functions of a meter as well as of a silt control.

Conclusion.

The author has enunciated no new theory of silt carriage by currents of water, nor has he propounded any precise formula that will save the perfunctory engineer the trouble of thinking out his designs. He has endeavoured merely to establish a scientific connection between the phenomena of recorded observations, and the theory of Dupuit, which is entirely in accordance with common sense. In view of the fact that numerous cases exist of irrigating distributaries in the tail reaches of a canal system, a hundred miles or more distant from the canal head, which suffer from deposits of silt finer than four thousand meshes to the square inch, in spite of their having been designed according to Kennedy's very useful formula, it has become necessary to go behind that formula, to its essential basis in natural laws, in order to carry the science of design another step forward.

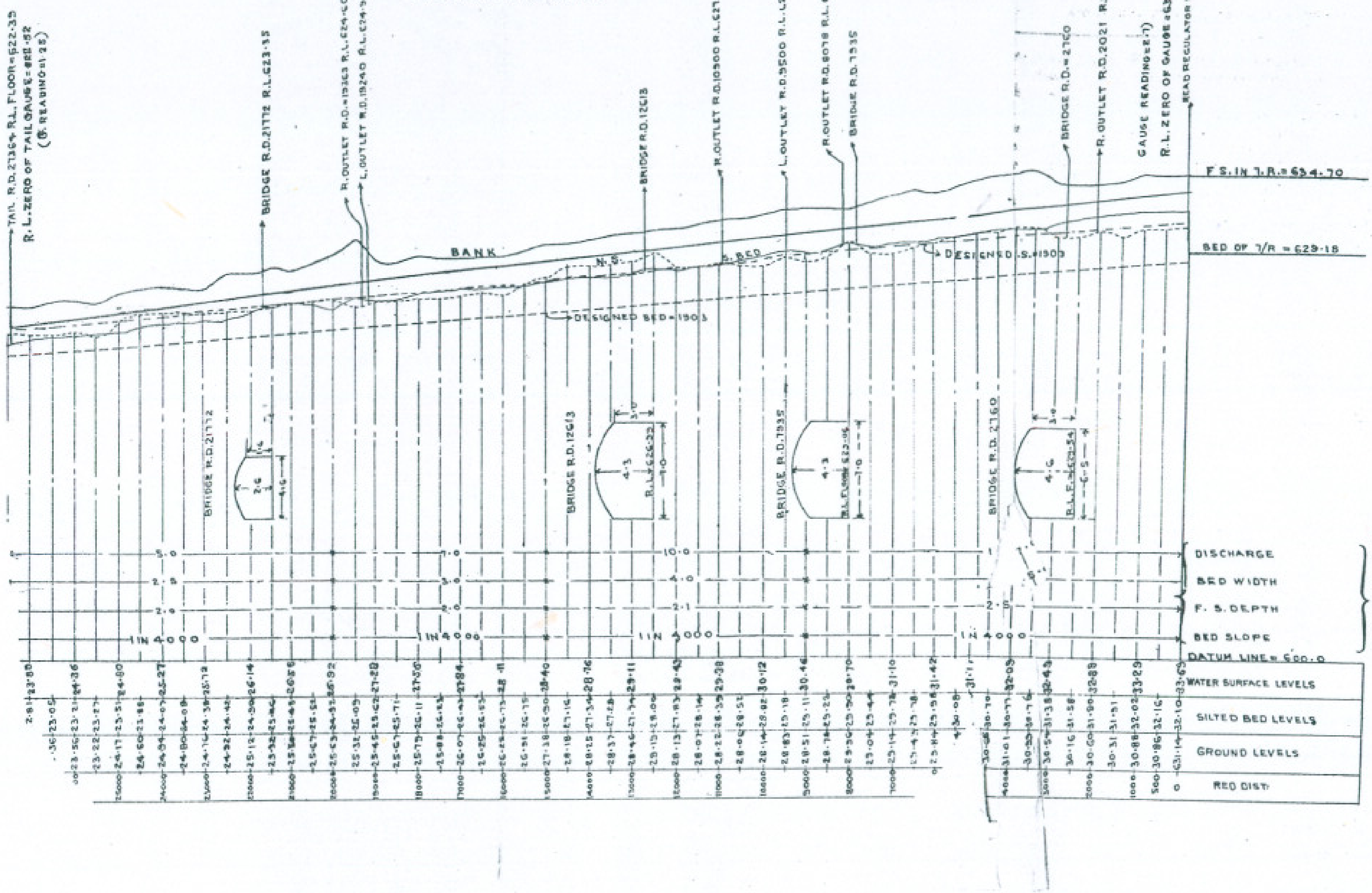
Plate XII is typical of the state of these distributaries. It shows the longitudinal section of the Daria Minor (case No. VII of Appendix III) with its bed silted up to, and above the natural ground surface, three feet and more above its original levels. It is only under such conditions that its irrigating outlets are enabled t scour out on to the fields the excess of silt swept into the distributary from its parent channel, through the undershot gate of its head regulator.

Ever since Kennedy's principles of design were accepted by the profession in this province, some eighteen years ago, we have supposed that the channels of a canal system will naturally tend to seek a stable regime in accordance with Kennedy's formula ; the ratio of mean velocity to depth, in all channels, naturally conforming to that formula ; subject only to the consideration that channels nearer to canal head will have higher values for V_0 than those towards the tail of the canal system. We find, however, that this does not hold good generally. In the thirty-three cases of pairs of channels on the Lower Jhelum Canal system, which are tabulated in Appendices I to III, we find that the average value of the mean velocity of branch channels is thirteen per cent. ($1{\cdot}13\ V_0$) in excess of Kennedy's critical velocity, although they offtake from channels whose mean velocity is on the average seven per cent. ($0{\cdot}93\ V_0$) less than his figures; while in several cases of branch channels, from fifty to a hundred miles distant from a canal head, the mean velocities are from thirty to sixty per cent. in excess of Kennedy's figures ($1{\cdot}3\ V_0$ to $1{\cdot}6\ V_0$). If these inequalities in distribution of silt-charge in different channels be due to the defective design of the head regulators of the branch channels, it is very desirable that such defects of design should be avoided in future.

II DIVISION LOWER JHELUM CANAL

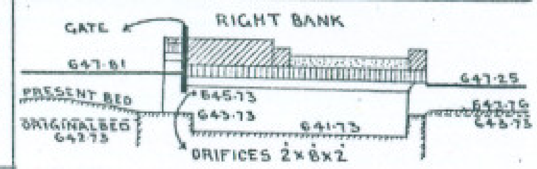
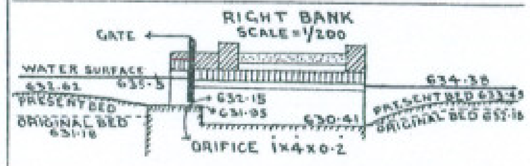
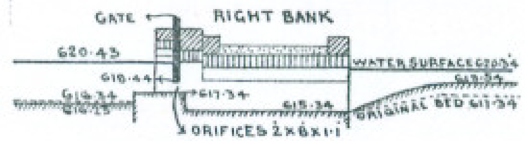
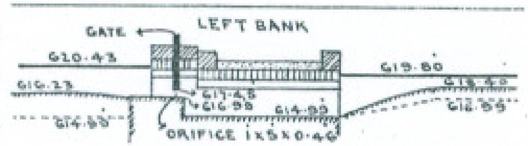
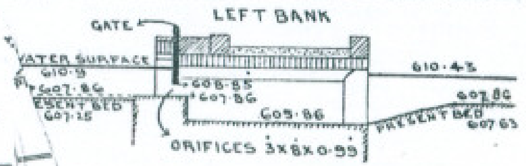
LONGITUDINAL SECTION OF DARYA MINOR

FROM HEAD TO TAIL R.D. 27364



APPENDIX I

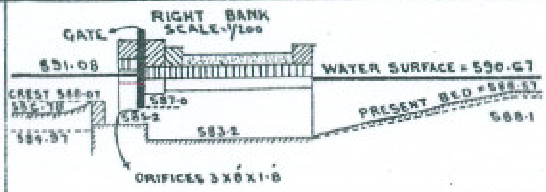
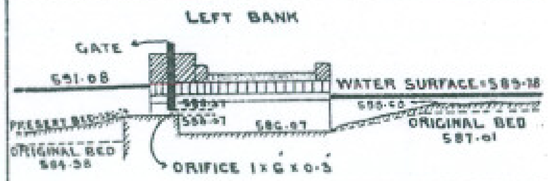
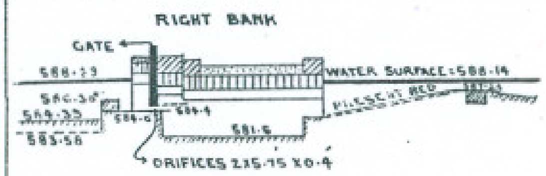
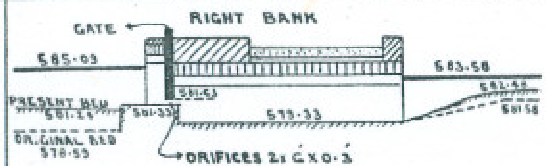
HYDRAULIC DATA OF DISTRIBUTARIES ABOVE AND BELOW OFFTAKES OF BRANCHES OBSERVED BY MR. W. G. YEAMAN EXECUTIVE ENGINEER

	STATISTICS OF OBSERVATIONS IN THE OPEN CHANNELS												CONDITIONS GOVERNING THE CARRIAGE OF SILT.			
CASE No.	NAMES OF CHANNELS	DATES OF OBSERVATION	SITES OF OBSERVATION R.D.	AREAS OF WATER SECTION	HYDRAULIC MEAN DEPTHS	SLOPE	DISCHARGE	KUTTERS N	MEAN VELOCITY	AVERAGE MIDSTREAM DEPTH	CRITICAL VELOCITY VO	CRITICAL VELOCITY RATIO	MEAN VELOCITY	ELEVATION ABOVE BED	SILT INDEX I	SECTION THROUGH REGULATOR SHOWING THE CONDITIONS OF INFLOW
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	KIRANA D.S.B | G.R	30.5.14	8800	168.6	3.42	·0001	305	·018	1·81	4·2	2·11	0·86	1·81	2·1	0·86	
1	CHUKERA MINOR	"	500	46.6	2.09	·00025	66	·023	1·42	2·5	1·51	0·94	1·42	1·25	·14	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·33)											2.06	1·9	2.06	
	KIRANA D.S.B | G.R	29.5.14	49500	126.2	3.97	·0001	224	·021	1·77	3·7	1·94	0·91	1.77	1·85	0·96	
2	SARAULI MINOR	"	300	4·5	0·85	·0004	4	·026	0·89	1·0	0·84	1·06	0·89	0·5	1·78	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·60)											5·0	0·87	5·75	
	KIRANA D.S.B | G.R	28.5.14	104500	108·5	3·26	·00005	165	·016	1·54	4·5	2·2	0·70	1·54	2·25	0·68	
3	MALKANA MINOR	"	500	22·6	1·33	·00023	29	·020	1·30	1·9	1·26	1·03	1·3	0·95	1·37	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·66)											1·65	1·66	1·0	
	KIRANA D.S.B | G.R	28.5.14	104500	108·5	3·26	·00005	165	·016	1·54	4·5	2·2	0·70	1·54	2	0·68	
4	SHARKAN M | I.A.L	"	500	10·2	1·13	·0004	10	·033	·085	1·5	1·08	0·79	0·85	15	1·13	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·69)											4·35	0·23	1·89	
	KIRANA D.S.B | G.R	15-6-14	151000	70·3	2·81	·00005	89	·016	1·25	3·1	1·73	0·72	1·25	1·55	0·81	
5	BARHANA MINOR	"	300	47·7	1·41	·00017	73	·019	1·51	2·5	1·51	1·0	1·51	1·25	1·21	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = ·54)											3·04	0·5	6·08	

APPENDIX II

HYDRAULIC DATA OF DISTRIBUTARIES ABOVE AND BELOW OFF TAKES OF BRANCHES

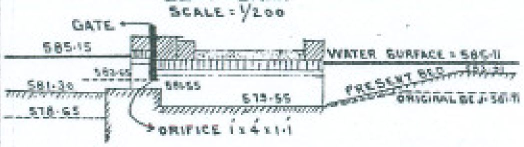
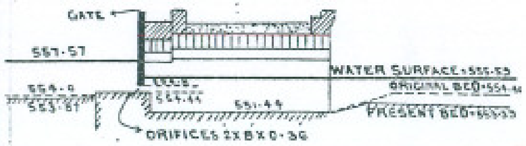
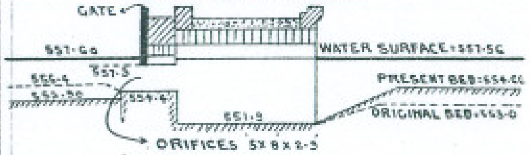
OBSERVED BY SHEKH KARIM BAKHSH SUB ENGINEER

CASE No.	STATISTICS OF OBSERVATIONS IN THE OPEN CHANNELS												CONDITIONS GOVERNING THE CARRIAGE OF SILT			SECTION THROUGH REGULATOR SHOWING THE CONDITIONS OF INFLOW
	NAMES OF CHANNELS	DATES OF OBSERVATION	SITES OF OBSERVATION R.D.	AREAS OF WATER SECTIONS	HYDRAULIC MEAN DEPTHS	SLOPE	DISCHARGE	KUTTER'S N	MEAN VELOCITY	AVERAGE MIDSTREAM DEPTH	CRITICAL VELOCITY V0	CRITICAL VELOCITY RATIO	MEAN VELOCITY	ELEVATION ABOVE BED	SILT INDEX I	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	NORTHERN BRANCH	21.6.14	307200	183·9	3·71	·0002	436	·021	2·37	4·4	2·17	1·09	2·37	2·2	1·77	
	NAURANGWALA 11.R.	"	500	56	1·76	·0004	112	·021	2·0	2·0	1·31	1·53	2·0	1·0	2·0	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·51)											2·6	1·0	2·6	
2	NORTHERN BRANCH	21.6.14	307200	183·9	3·71	·0002	436	·021	2·37	4·4	2·17	1·09	2·37	2·2	1·77	
	RAMDANA MINOR	"	500	9·7	1·04	·00035	10·9	·0236	1·12	1·1	0·89	1·25	1·12	0·55	2·0	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·66)											6·0	1·48	4·0	
3	NORTHERN BRANCH	22.6.14	317500	147	3·48	·0002	303	·0235	2·05	4·3	2·14	0·96	2·05	2·05	1·0	
	SOBHIWALA 12.R.	"	500	10·9	0·83	·0004	11·3	·023	1·05	1·0	0·84	1·25	1·05	0·5	2·1	
	GATEWAY ORIFICE	COEFFICIENT OF DISCHARGE = 0·625											2·5	0·5	5·0	
4	NORTHERN BRANCH	20.6.14	331500	146	3·3	·00018	280	·023	1·92	3·8	1·97	0·97	1·92	1·9	1·0	
	JHANDA DISTY: 13.R.	"	100	16·9	0·97	·00036	18·4	·023	1·09	1·3	0·99	1·1	1·09	0·6	1·82	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·52)											5·1	0·65	7·9	

HYDRAULIC DATA OF DISTRIBUTARIES ABOVE AND BELOW OFF TAKES OF BRANCHES

OBSERVED BY SHEKH KARIM BAKSH SUB ENGINEER

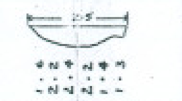
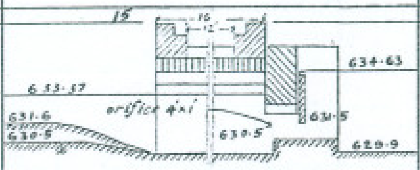
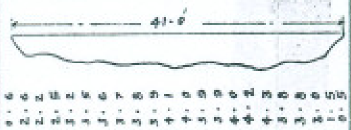
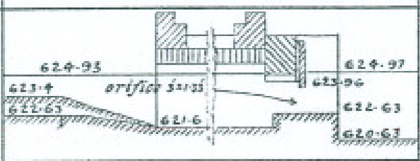
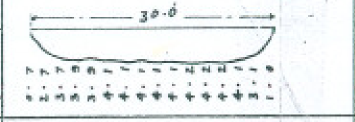
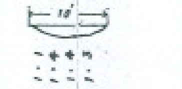
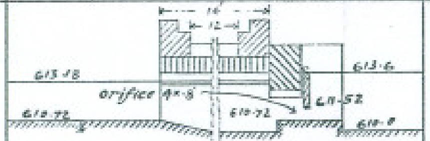
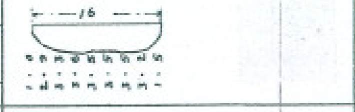
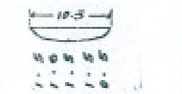
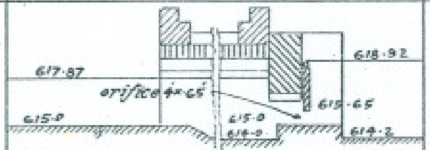
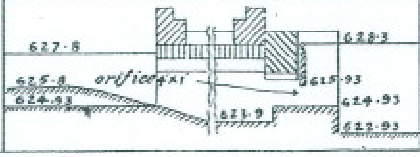
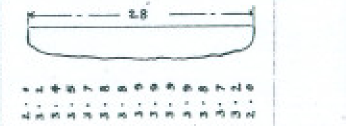
APPENDIX II (CONTD:)

CASE No.	NAMES OF CHANNELS	STATISTICS OF OBSERVATIONS IN THE OPEN CHANNELS: DATE OF OBSERVATION	SITES OF OBSERVATION R.D.	AREAS OF WATER SECTIONS	HYDRAULIC MEAN DEPTHS	SLOPE	DISCHARGE	KUTTER'S N.	MEAN VELOCITY	AVERAGE MIDSTREAM DEPTH	CRITICAL VELOCITY Vo	CRITICAL VELOCITY RATIO	CONDITIONS GOVERNING THE CARRIAGE OF SILT: MEAN VELOCITY	ELEVATION ABOVE BED	SILT INDEX I	SECTION THROUGH REGULATOR SHOWING THE CONDITIONS OF INFLOW
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	NORTHERN BRANCH	20.6.14	331500	146	3·3	·00018	280	·023	1·92	3·8	1·97	0·97	1·92	1·9	1·0	LEFT BANK SCALE = 1/200 
5	THATTA UMRA MINOR	"	70	4·8	0·81	·0003	4·3	·023	0·9	1·3	0·99	0·91	0·9	0·6	1·5	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·625)											1·0	0·65	1·5	
	NORTHERN BRANCH	23.6.14	351500	125	3·13	·0002	238	·0235	1·9	3·7	1·94	0·97	1·9	1·85	1·03	RIGHT BANK 
6	KOT SULTAN DISTY: 14.R	"	500	32·4	1·76	·0003	45	·026	1·45	2·2	1·39	1·04	1·45	1·1	1·3	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·70)											7·8	1·1	7·1	
	NORTHERN BRANCH	22.6.14	351500	125	3·13	·0002	238	·0235	1·9	3·7	1·94	0·97	1·9	1·85	1·03	TAIL OF NORTHERN BRANCH 
7	MASSAN DISTRIBUTARY	"	500	91·9	2·57	·0002	151	·0236	1·64	3	1·7	0·97	1·64	1·5	1·1	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·75)											1·21	1·5	0·8	
	MASSAN DISTRIBUTARY	29.9.14	96250	50·8	2·34	·0002	54	·034	1·06	3·4	1·84	0·58	1·06	1·7	0·62	RIGHT BANK 
8	MINOR 3.R	"	500	18·9	1·51	·00028	21	·028	1·1	2·1	1·34	0·82	1·1	1·05	1·05	
	GATEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·35)											3·4	1·6	2·1	

STATISTICS OF HYDRAULIC MEASUREMENTS MADE BY LALA BEHARI LAL UPPAL, ASSISTANT ENGINEER P. W. D.

APPENDIX III

DATA OF OBSERVATIONS IN OPEN CHANNELS

NAMES OF CHANNELS	DATES OF OBSERVATION	SITES (REDUCED DISTANCES)	SECTIONAL AREAS OF STREAMS	HYDRAULIC MEAN DEPTHS	WATER SURFACE SLOPES	DISCHARGES	KUTTER'S N	MEAN VELOCITIES	AVERAGE MID-STREAM WATER DEPTHS	KENNEDY'S V/V_0	CRITICAL VELOCITY RATIOS	CROSS SECTIONS OF STREAMS OF BRANCH CHANNELS SCALE 1/200	SECTIONS THROUGH HEAD REGULATORS OF BRANCH CHANNELS SCALE = 1/100	CROSS SECTIONS OF STREAMS OF TRUNK CHANNELS SCALE 1/200	CONDITIONS AFFECTING SILT CARRIAGE: MEAN VELOCITY	CONDITIONS AFFECTING SILT CARRIAGE: ELEVATION ABOVE BED OF TRUNK CHANNEL	CONDITIONS AFFECTING SILT CARRIAGE: SILT INDEX COLUMN 17 / COLUMN 18
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
..DIR FEEDER	11-9-14	116500	140·2	3·16	·0001	231	·019	1·64	3·8	1·95	0·83				1·64	1·9	0·86
..DA BRANCH	11-9-14	200	23·5	1·6	·00025	30	·0245	1·26	2·2	1·39	0·91				1·26	1·1	1·15
..TEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·84)														7·5	1·1	6·8
..DIR DISTRIBUTARY	12-9-14	28200	111·2	3·25	·000125	187	·0213	1·69	4·0	2·04	0·82				1·69	2·0	0·84
..TNAJA MINOR	12-9-14	200	5·2	0·70	·000375	4·7	·0223	0·9	0·9	0·8	1·12				0·90	0·45	2·00
..TEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·73)														1·17	2·66	0·44
..IAN DISTRIBUTARY	8-6-14	136500	50·6	2·56	·0001	77	·018	1·63	3·45	1·86	0·82				1·53	1·75	0·87
..RI MINOR	8-6-14	200	11·3	1·04	·00035	11·4	·0254	1·01	1·4	1·04	1·00				1·01	0·7	1·44
..TEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·68)														3·56	1·12	3·18
..LIAN DISTY:	8-6-14	123000	68·3	2·75	·000125	104	·0213	1·62	3·6	1·91	0·80				1·52	1·8	0·84
..LEWALA BRANCH	8-6-14	200	13·7	1·15	·00025	16	·0212	1·16	1·5	1·09	1·06				1·16	0·75	1·55
..TEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·77)														6·15	1·12	5·5
..LIAN DISTY:	7-6-14	89200	100	3·04	·0001	167	·0193	1·67	3·8	1·98	1·84				1·67	1·9	0·88
..NDIWALA MINOR	7-6-14	200	15·9	1·39	·0003	18	·026	1·1	2·0	1·30	0·85				1·1	1·0	1·10
..TEWAY ORIFICE	(COEFFICIENT OF DISCHARGE = 0·8)														4·5	2·5	1·8

…ONS IN OPEN CHANNELS

WATER SURFACE SLOPES	DISCHARGES	KUTTER'S N	MEAN VELOCITIES	AVERAGE MID. STREAM WATER DEPTHS	KENNEDYS V_0	CRITICAL VELOCITY RATIOS	C… BR…
7	8	9	10	11	12	13	
·000125	258	·028	1·56	6·0	2·64	0·6	
·00025	67	·021	1·7	2·5	1·51	1·12	
…ARGE = 0·83)							
·00011	284	·019	2·0	4·8	2·29	0·87	
·000375	20	·0255	1·21	1·6	1·13	1·07	
…ARGE = 0·7)							
·0001	180	·018	1·82	4·[illegible]	2·11	0·86	
·00025	6	·019	1·0	1·2	0·89	1·06	
…ARGE = 0·55)							
·000125	140	·021	1·62	3·9	2·01	0·8	
·0004	9·3	·024	1·12	1·5	1·08	1·04	
…ARGE = 0·9)							
·00015	113	·020	1·53	2·8	1·63	0·94	
·000425	7·8	·018	1·31	1·1	0·89	1·47	
…ARGE = 0·83)							

CASE No.	NAMES OF CHANNELS	DATA OF OBSERVAT			
		DATES OF OBSERVATION	SITES (REDUCED DISTANCES)	SECTIONAL AREAS OF STREAMS	HYDRAULIC MEAN DEPTHS
1	2	3	4	5	6
	LALIAN DISTY	4-6-14	58500	165·4	4·3
VI	MALKEWALA BRANCH	4-6-14	200	39·5	1·9
	GATEWAY ORIFICE	(COEFFICIENT		OF	DISCH
	LALIAN DISTY:	29-8-15	58600	141·6	3·8
VII	DARIA MINOR	29-8-15	300	16·5	1·26
	GATEWAY ORIFICE	(COEFFICIENT		OF	DISCH
	KHADIR DISTY:	23-10-14	89400	98·8	3·2
VIII	THATHA CHANDU Mr.	23-10-14	200	6	0·85
	GATEWAY ORIFICE	(COEFFICIENT		OF	DISC
	KHADIR DISTY:	30-11-15	108000	86·3	3·0
IX	AHMAD NAGAR MINOR	30-11-15	200	8·25	1·02
	GATEWAY ORIFICE	(COEFFICIENT		OF	DISC
	KHADIR DISTY:	21-9-15	137000	74·1	2·32
X	PILOWAL MINOR	21-9-15	200	6	0·8
	GATEWAY ORIFICE	(COEFFICIENT		OF	DISC