PAPER No. 205.

A REGULATION GAUGE FOR HEADLESS CANAL METERS.

By A. N. Wilson, B.Sc., A.M.I.C.E.

Introduction.

Headless Canal Meters have been fully described by F. H. Burkitt, O.B.E., in his paper No. 125 of the Punjab Engineering Congress (1929), and in principle Headless Meters are Venturi meters adapted for use in open channels with a silted bed, and provided reasonable care is taken in design, such meters are fundamentally sound discharge meters, the Venturi meter being generally recognized as one of the most reliable means of measuring a discharge in pipes and small channels.

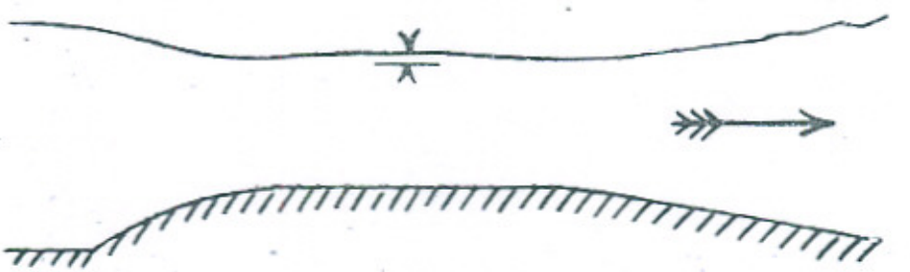
Headless Meters in Practice.

Existing Headless Meters have been subjected to much criticism, and in fact their reliability has been so much suspected that in many cases the meters are abandoned for all practical purposes. It is true that there are a number of possible causes of failure in practice:—

(1) Due to shock or eddy formation between the upstream and throat gauges there may be a slight loss of energy. In a reasonably good design such loss of energy would be extremely small, but the theortical co-efficient is probably not quite correct on this account.

(2) Due to gauge wells not recording true average water levels and other minor defects of construction a slight error may arise; this is probably negligible, as usually several gauge wells are used, and errors tend to cancel out when averaged.

(3) Due to peculiarities of design or construction or other reasons unknown, there is often if not usually, a slight wave in the throat of the meter so that the gauge reading recorded is dependent on the position of the opening into the gauge well; thus the theoretical co-efficient of a Headless meter is probably slightly and possibly considerably out from the truth.



SKETCH I

The sketch shows the type of water surface obtaining on the Eastern Canal Meter, the wave in the throat being quite stable. It is not easy to measure the dimensions of such a wave with any accuracy but the wave is clearly visible and its height of the order of 0·05 feet; assuming half that departure from the mean, the possible error at 2,000 cusecs is 50 cusecs or 2·5 per cent., though the likely error is considerably less.

The net result of the above three sources of systematic error may be nil, or on the other hand may be considerable, hence in the Author's opinion it is not safe to rely entirely on the theoretical co-efficient of a Headless meter. None of these errors is erratic, and provided the meter is properly calibrated against observed discharges and the co-efficient adjusted accordingly, the meter has no error from these sources. There are, however, other sources of inaccuracy.

(4) Errors in reading and noting of gauges may be a source of naccuracy, as the arrangements for reading gauges are not usually simple and accurate, especially if there is any pulsing of the gauge wells or of the supply in the canal. Considerable care is necessary in reading gauges, as the discharge is dependent very largely on the small difference in the readings of the upstream and throat gauges. The usual gauge system might well be improved and simplified as has been done in some cases.

(5) Although such an error should never arise, in actual practice the calculations of discharge are a common source of inaccuracy in Headless meters. The average Overseer either will not or cannot use logarithms properly, and it is very easy to introduce considerable error when calculations are made by any other method, owing to the nature of the discharge formula. Actually, a series of calculations were subjected to a double check by ordinary methods, and when re-checked by logarithms, errors were found in nearly every case often amounting to as much as 30 cusecs in calculation alone. Hence for reliability all calculations should be made with great care, preferably with the systematic use of logarithms.

(6) A deposit of silt on the upstream floor of the meter reduces the sectional area at the upstream gauge, and such a deposit would entirely vitiate the meter and make it quite unreliable. However, the designs given by Burkitt allow for a reduction of section in the approach flume, so that velocity is considerably greater than in the normal section of the silted channel, and no silt deposit should occur. There is, however, a possibility of a temporary silt deposit during the flood season, when regular probings should be made before reading the meter, to ensure that such reading is reliable. Actually, daily probings of the Headless meter on the Eastern Canal and occasional probings on othermeters were carried out during the flood season of 1936. No deposit was found on the Eastern Canal head meter except for an odd day or two after heavy

floods, and after a short period of open flow regulation. The Dipalpur Canal meter was regularly silted in one bay or more during the flood season, while no silt was detected on the Bikanir, Main Branch Eastern, or Jalalabad Branch on the days when tried. Thus the Dipalpur Canal meter as it exists is practically useless during floods, while all Headless meters are liable to give incorrect results when there is heavy silt movement, unless precautions are taken to make sure that there is no silt deposit on the upstream floor of the meter. Silt is undoubtedly a difficulty during floods, but this can be overcome by careful design and precautions, whereas in freefall or standing wave meters silt deposits also affect discharge, though to a lesser degree, but an error occurs in nearly all existing designs and may amount to as much as 3 per cent. due to the change of velocity of approach. The question of design to avoid silting is dealt with in Appendix I.

Thus all errors in Headless meters can be avoided or allowed for and such meters can be reliable measures of discharge, but the elaborate observation and calculation required render them practically useless for regulation purposes.

The Principle of the Double Gauge.

For regulation purposes, it is essential to have a simple direct reading corresponding to a definite discharge, and as the discharge formula for a Headless meter is very complicated, an arrangement is made whereby a pointer moves over a series of equi-discharge curves on a plate, from which the discharge is read directly. The actual mechanism is extremely simple, vertical movement of the pointer being given by a float in the upstream gauge well and horizontal movement by the difference in level of floats in the upstream and throat gauge wells (Plate No. 1). The reading at the tip of the pointer indicates the discharge according to the pair of gauge wells used.

Headless meters usually have two or more pairs of gauge wells and the average is utilised to obtain the discharge of the meter as a whole. The double gauge is fitted in its own pair of gauge wells with an hydraulic connection with all the upstream and throat gauge wells respectively, so as to give an automatic average. Thus one simple mechanism indicates the discharge of the meter as a whole by one direct reading, and can, therefore, be used for regulation purposes, and also avoid the usual continuous revisions of discharge tables and correction factors so common on many canals.

The Double Gauge on Eastern Canal.

The Headless meter at R. D. 2,500 of Eastern Canal consists of three bays exactly similar and of the raised crest type. There is a pair of gauge wells in each abutment and in each of the two piers. The existing pairs of wells are too far apart for fitting a double gauge, and a

fresh pair separated by a waterproof wall 5 inches thick has been built. The hydraulic connection with the original wells is maintained by 1 inch diameter G. I. pipe arranged as syphons above the water surface. This arrangement is necessary as an underground connection would silt up and could not be cleaned out. Priming of the syphons is carried out by priming tanks of ample capacity. The tanks being at the highest part of the syphons the pipes are kept full of water, and any air in the system enters the tanks and is replaced with water daily.

The two gauge wells each have a copper float supporting brass tubes held vertical by roller guides. The two brass tubes are connected by a link 1 ft. 4 inches long, with a pointer 2 ft. long fixed at right angles to the link at the upstream end; the upstream end of the link has a fixed pin while the downstream end has a roller pin working in a horizontal slot, fixed to the brass tube. Thus the pointer moves horizontally by $1\frac{1}{2}$ times the difference between the two gauge levels; a correction is made in the discharge curves to allow for the fact that the tip of the pointer moves in an arc. The arrangement is such that the pointer is almost parallel to the curves at all positions, to facilitate accurate reading.

The equi-discharge curves are calculated and plotted on paper and fixed to the plate and protected with waterproof varnish. Curves at 20 cusec intervals from 200 cusecs to 3,500 cusecs are plotted for an ample range of difference of level.

The readings of the double gauge are compared with current meter discharge observations in Table I and Plate No. 2. In making comparison it should be noted that during floods particularly, there is a very considerable fluctuation in supply in the Eastern Canal and that the double gauge indicated all the fluctuations, so that close agreement can hardly be expected in such conditions. Actually, on 4th September, 1936, the double gauge indicated a variety of discharges between 2,420 and 2,620 cusecs in the course of two hours due to fluctuations of supply. In spite of varying silt and slope conditions as indicated by the changing correction factor of the ordinary discharge table, the general agreement between the double gauge and observed discharge is so close, that the double gauge can be safely used for regulation purposes without the introduction of variable correction factors. Excluding the days when the river was in flood and supplies fluctuating, the double gauge on Eastern Canal may be taken as requiring a constant correction factor of +0·1 per cent. as against current meter discharge, from which there is a mean variation of 0·7 per cent. and a maximum of 1·5 per cent. These differences are within the likely error of the current meter discharge, so that the double gauge is probably as accurate as the current meter, and the discharge is indicated day and night for regulation purposes.

Design and Setting of Double Gauge.

The essentials of design of the mechanism are to have the floats as close together as is consistent with their size and length of link, and the pointer should be of sufficient length to give reasonable magnification without being flimsy. It is simple and convenient to make the link horizontal and the pointer vertical when the gauge wells are at the same level.

In construction care and accuracy are essential to ensure well fitting joints and guides and to avoid friction; for this reason and to avoid any variation of weight due to rust or paint, the construction is entirely of brass and copper.

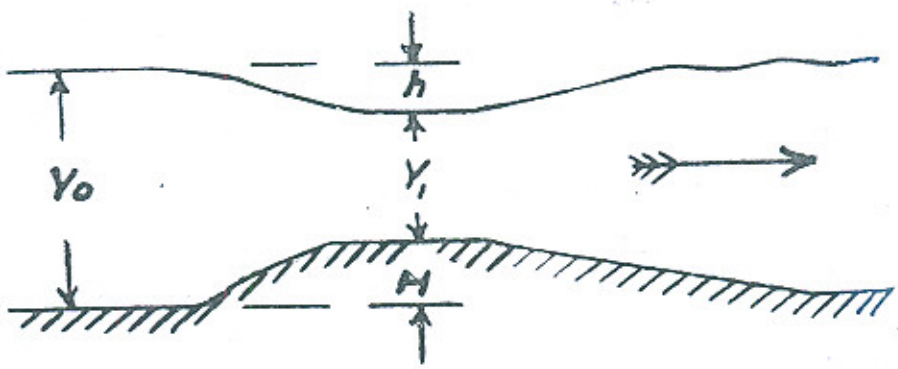
Calculation and plotting of the discharge curves is the most tedious part of the design. It would be laborious and unnecessary to calculate each of the 1700 points plotted for the curves, and actually only 150 were calculated for the Eastern Canal, the remainder being graphical interpolations.

The discharge formula for the raised crest type of Headless Meter is of the form—

$$Q = KY_0 Y_1 \frac{\sqrt{h}}{\sqrt{Y_0^2 - Y_1^2}} = KY_0 Y_1 \frac{\sqrt{h}}{\sqrt{(Y_0 - Y_1)(Y_0 + Y_1)}}$$

where

- Q = discharge.
- K = constant for the meter.
- Y_0 = upstream gauge.
- Y_1 = throat gauge.
- h = difference of level in gauge wells.
- H = height of crest.



SKETCH 2

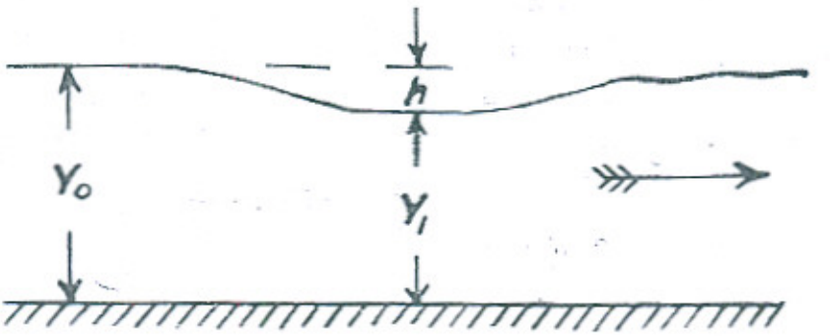
For purposes of design it is necessary to eliminate Y_1 as the mechanism only deals with Y_0 and h, but substitution is possible as $Y_1 = Y_0 - (H+h)$. Thus for any given value of 'h' it is fairly simple to calculate the values of Q for various values of Y_0 especially if done with logarithms. An example is given in Table 2.

For each value of 'h,' discharge is plotted against Y_0, giving almost straight discharge curves from which intermediate values can be interpolated, it being convenient to plot Y_0 to full size (Plate No. 3). The interpolated values of discharge are then carried across to the vertical on the gauge plate graph corresponding to the value of 'h': that is, to a vertical $1\frac{1}{2} \times h$ distant from the centre of the pin on the upstream gauge. The process is repeated for other values of 'h' until sufficient number of points are plotted to draw the equi-discharge curves. Actually before plotting, the values of Y_0 are corrected for each value of 'h' by the addition of the rise of the tip of the pointer, to allow for its circular motion.

For a laterally contracted Headless meter a similar procedure would be followed, the discharge formula being of the form—

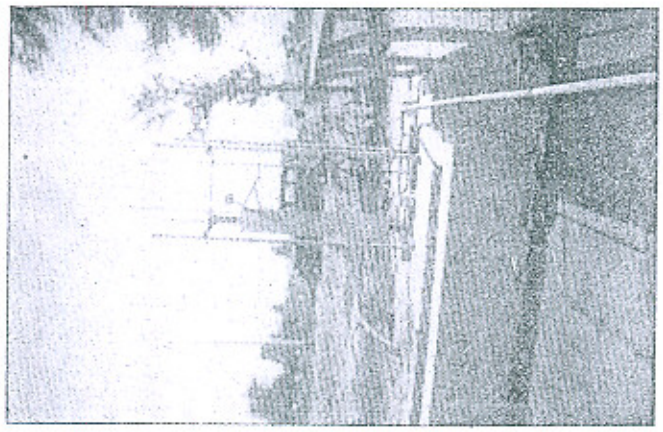
$$Q = KY_0Y_1\sqrt{\frac{h}{Y_0^2 - k^2Y_1^2}} = KY_0Y_1\sqrt{\frac{h}{(Y_0 - kY_1)(Y_0 + kY_1)}}$$

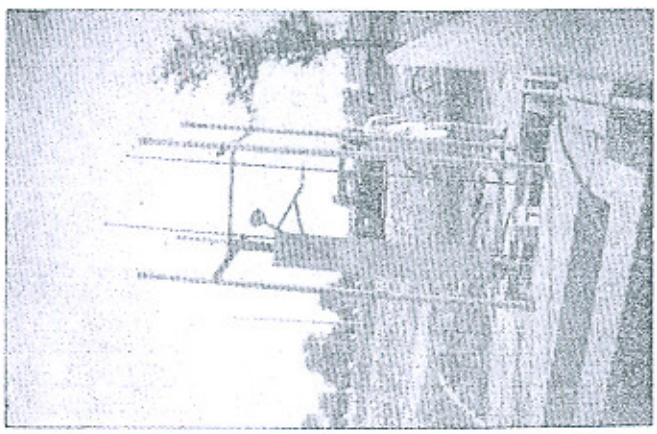
and in this case $Y_1 = Y_0 - h$



SKETCH 3

The Double Gauge on Eastern Canal was erected by R.T. Gardiner, I.S.E., whose attention to mechanical detail made it a sensitive and reliable regulating gauge.





APPENDIX I.

Silting in Approach Flumes of Discharge Meters.

Burkitt in his design of Headless Canal Meters (P. E. C. Paper No. 125, page 11) determines the width of approach flume " which will certainly remain clear of silt " from a formula $q = \cdot 75D^{\frac{5}{3}}$ (or $V = \cdot 75D^{\frac{2}{3}}$), and having done so, reduces the width still further without calculation. The formula $V = \cdot 75D^{\frac{2}{3}}$ is very little different to Kennedy's $V_0 = \cdot 84D^{\cdot 64}$ and is clearly not a safe formula for the purpose, and in fact silting takes place during floods on flumes so designed. The Dipalpur Canal meter silts very badly, while the Eastern Canal meter silts slightly during floods and cannot be regarded as quite immume from silt troubles, though, very nearly so.

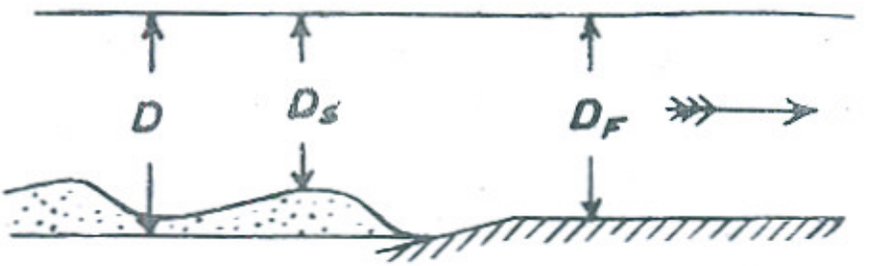
Meter.	Increase in velocity in flume.	Reduction in width.	Depth of silt on bed to give equal scour action.
Dipalpur ..	15 %	10 %	0·8 ft. or 9 % of depth.
Eastern ..	47 %	40 %	1·5 ft. or 18 % of depth.

The above figures indicate the main reason for the difference of silting of the two meters, the last column being worked out, taking Kennedy's scour formula as correct.

It is clear that to be always free of silt, a flume near the head of a canal must be designed to allow for a wave of silt at least as high as 18 per cent. of the depth of the canal, and to be on the safe side 20 per cent. or preferably 25 per cent. of the depth should be allowed for. This may sound a very big allowance to make, but in normal conditions the height of silt dunes averages about 15 per cent. of the depth, while floods produce abnormal conditions in the head reach of canals. Average bed levels on a cross section of the Upper Jhelum Canal showed a variation of 1 ft. or about $12\frac{1}{2}$ per cent. of the depth in the course of a few months, while the height of silt dunes observed at various sites in flow conditions are given below ; it should be noted that the observations are on the maximum

variation in normal conditions and do not necessarily represent the maximum possible.

Canal.	Height of dune.	Depth.	Per cent. of depth.
U. J. C.	1·4	8·0	17·5
N. B. (L. J. C.)	0·8	5·8	13·8
M. B. L. (U. B. D. C.) ..	1·4	6·0	23·4
U. G. B. (L. C. C.) ..	1·6	10·5	15·7



SKETCH 4

To calculate the required flume section to be free of silt, take D_s the silted depth as 75 per cent. of the designed depth D.

D_F = depth of flume.

W_F = width of flume.

V_F = mean velocity in flume.

D_s = silted depth of channel.

W_s = width of silted channel.

V_s = mean velocity of silted channel.

From Kennedy's scour formula $V_0 = K D^{\cdot 64}$

$$\frac{V_s}{V_F} = \frac{K D_s^{\cdot 64}}{K D_F^{\cdot 64}} = \left(\frac{D_s}{D_F}\right)^{\cdot 64}$$

and $$\frac{V_s}{V_F} = \frac{W_F D_F}{W_s D_s}$$

hence $$\frac{W_F}{W_s} = \left(\frac{D_s}{D_F}\right)^{1 \cdot 64} \quad \text{or} \quad W_F = W_s \left(\frac{D_s}{D_F}\right)^{1 \cdot 64}$$

(1) Assuming depth in flume to be the same as designed depth $D_s = \cdot 75\ D = \cdot 75\ D_F$

and $$\frac{W_F}{W_s} = (\cdot 75)^{1 \cdot 64} = 0.62$$

or 38 per cent. reduction in width.

(2) Usually it will be more convenient or cheaper to raise the bed of the flume by, say, 10 per cent. of the depth.

when $D_s = \cdot 75\ D$ and $D_F = \cdot 9\ D$

and $$\frac{W_F}{W_s} = \left(\frac{\cdot 75}{\cdot 9}\right)^{1 \cdot 64} = 0 \cdot 74$$

or 26 per cent. reduction in width.

TABLE I.

Discharge of Eastern Canal.

Date.	Regulation gauge.	Corrected tabular discharge.	Correction factor in use.	Current meter discharge.	Double gauge discharge.	% difference from current meter.	Discharge in river.
1-9-36 ..	17·04	2215	Nil	2206	2090	—5·3	54,528
2-9-36 ..	7·32	2188	..	2451	2420	—1·3	66,631
3-9-36 ..	7·30	2175	..	2486	2430	—2·2	62,518
4-9-36 ..	7·15	2313	..	2469	2605	+5·5	1,50,345
5-9-36 ..	7·12	2290	..	2448	2420	—1·1	93,076
6-9-36 ..	7·21	2363	..	2569	2685	+0·6	1,23,780
7-9-36 ..	7·16	2329	..	2421	2570	+0·2	1,18,282
8-9-36 ..	7·11	2297	+5%	2339	..	..	97,500
9-9-36 ..	7·18	2452	..	2331	..	..	70,304
10-9-36 ..	7·18	2452	..	2263	2360	+4·3	75 401
11-9-36 ..	7·21	2481	..	2451	2320	—5·3	85,979
12-9-36 ..	7·21	2481	..	2406	2410	+0·2	69,145
13-9-36 ..	7·23	2507	..	2361	2340	—0·9	70,765
14-9-36 ..	7·08	2368	..	2139	2100	—1·8	50,358
15-9-36 ..	7·08	2368	..	2122	2095	—1·3	51,797
16-9-36 ..	7·01	2070	—3 %	2039	2010	—1·4	45,080
17-9-36 ..	6·99	2059	..	2040	1940	—4·9	42,765
18-9-36 ..	7·06	2123	..	2018	2020	+0·1	38,224
19-9-36 ..	7·06	2123	..	2004	1980	—1·2	30,472
20-9-36 ..	7·16	2201	..	2078	2080	+0·1	27,286
21-9-36 ..	7·23	2269	..	2181	2160	—1·0	26,314
22-9-36 ..	7·20	2115	—10%	2104	2100	—0·2	26,346
23-9-36 ..	7·18	2101	..	2063	2070	+0·2	25,986
24-9-36 ..	7·16	2088	..	2049	2065	+0·8	25,359
25-9-36 ..	7·25	2172	—10%	2215	2208	—0·3	24,617
26-9-36 ..	7·42	2306	..	2296	2265	—0·9	24,362
27-9-36 ..	7·40	2286	..	2327	2320	—0·3	23,274
28-9-36 ..	7·39	2280	..	2269	2275	+0·3	23,660
29-9-36 ..	7·25	2172	..	2153	2165	+0·5	24,018
30-9-36 ..	7·19	2108	..	2146	2135	—0·5	22,213
1-10-36 ..	7·05	2002	..	2113	2140	+1·3	20,491
2-10-36 ..	7·07	2020	..	2095	2100	+0·2	18,554
3-10-36 ..	7·06	2011	..	2074	2080	+0·3	17,309
4-10-36 ..	7·08	2097	—7%	2117	2130	+0·6	17,348
5-10-36 ..	7·03	2051	..	2071	2110	+1·9	16,659
6-10-36 ..	7·03	2051	..	2089	2100	+0·5	15,183
7-10-36 ..	7·03	2051	..	2060	2050	—0·8	13,881
8-10-36 ..	6·82	1879	..	1965	1980	+0·8	13,932
9-10-36 ..	6·46	1660	-5%	1408	1415	+0·5	13,006
10-10-36 ..	6·40	1501	-10%	1542	1520	—1·4	12,151
11-10-36 ..	6·31	1478	..	1335	1340	+0·4	11,075
12-10-36 ..	6·31	1478	..	1362	1345	—1·2	11,022
13-10-36 ..	6·66	1705	..	1864	1890	+1·4	10,773
4-10-36 ..	6·44	1698	2%	1457	1460	+0·2	10,582
-10-36 ..	6·36	1784	..	1753	1770	+1·0	10,642

TABLE 9.

Example of Calculation h = 0.30

$Q = 62{\cdot}6\, Y_2 Y_1 \sqrt{\frac{100\ h}{(Y_2 - Y_1)(Y_2 + Y_1)}}$

$100\ h = 30 \qquad H = 2{\cdot}76$

$H + h = 2{\cdot}76 + 0{\cdot}30 = 3{\cdot}06 = Y_2 - Y_1$

$\log 100\ h = 1{\cdot}4771$

$\log\ Y_2 - Y_1 = 0{\cdot}4857$

$\log \frac{100\ h}{Y_2 - Y_1} = 0{\cdot}9914$

	Y_2 ..	3·0	3·5	4·0	4·5	5·0	5·5	6·0
$Y_2 - (H + h)$	$- Y_1$ ..	0·24	0·74	1·24	1·74	2·24	2·74	3·24
	$Y_2 + Y_1$ ..	5·94	6·94	7·94	8·94	9·94	10·94	11·94
	$\log \frac{100\ h}{Y_2 - Y_1}$ ..	0·9914	0·9914	0·9914	0·9914	0·9914	0·9914	0·9914
Subtract	$\log Y_2 + Y_1$ ..	0·8114	0·8409	0·8513	0·8591	0·8650	0·8699	0·8739
Divide by 2		0·1500	0·0916	0·0401	$\bar{1}$·9323	$\bar{1}$·9264	$\bar{1}$·9215	$\bar{1}$·9175
		0·0250	0·0458	0·0200	$\bar{1}$·9979	$\bar{1}$·9782	$\bar{1}$·9572	$\bar{1}$·9337
	$\log Y_2$ ..	0·4990	0·7404	0·7782	0·8129	0·8451	0·8751	0·9031
Add	$\log Y_1$ ..	0·2878	0·3874	0·4683	0·5368	0·5965	0·6474	0·6937
	$\log 62{\cdot}6$ ..	1·7966	1·7966	1·7966	1·7966	1·7966	1·7966	1·7966
	$\log Q$ ..	2·8584	2·9702	3·0631	3·1431	3·2134	3·2763	3·3331
	Q ..	721·8	933·7	1156·5	1390	1635	1889	2153
Corrected value of Y_2 ..		3·025	3·525	4·025	4·525	5·025	5·525	6·025

PLATE I
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DOUBLE GAUGE FOR HEADLESS METER
EASTERN CANAL
SCALE = 1/20

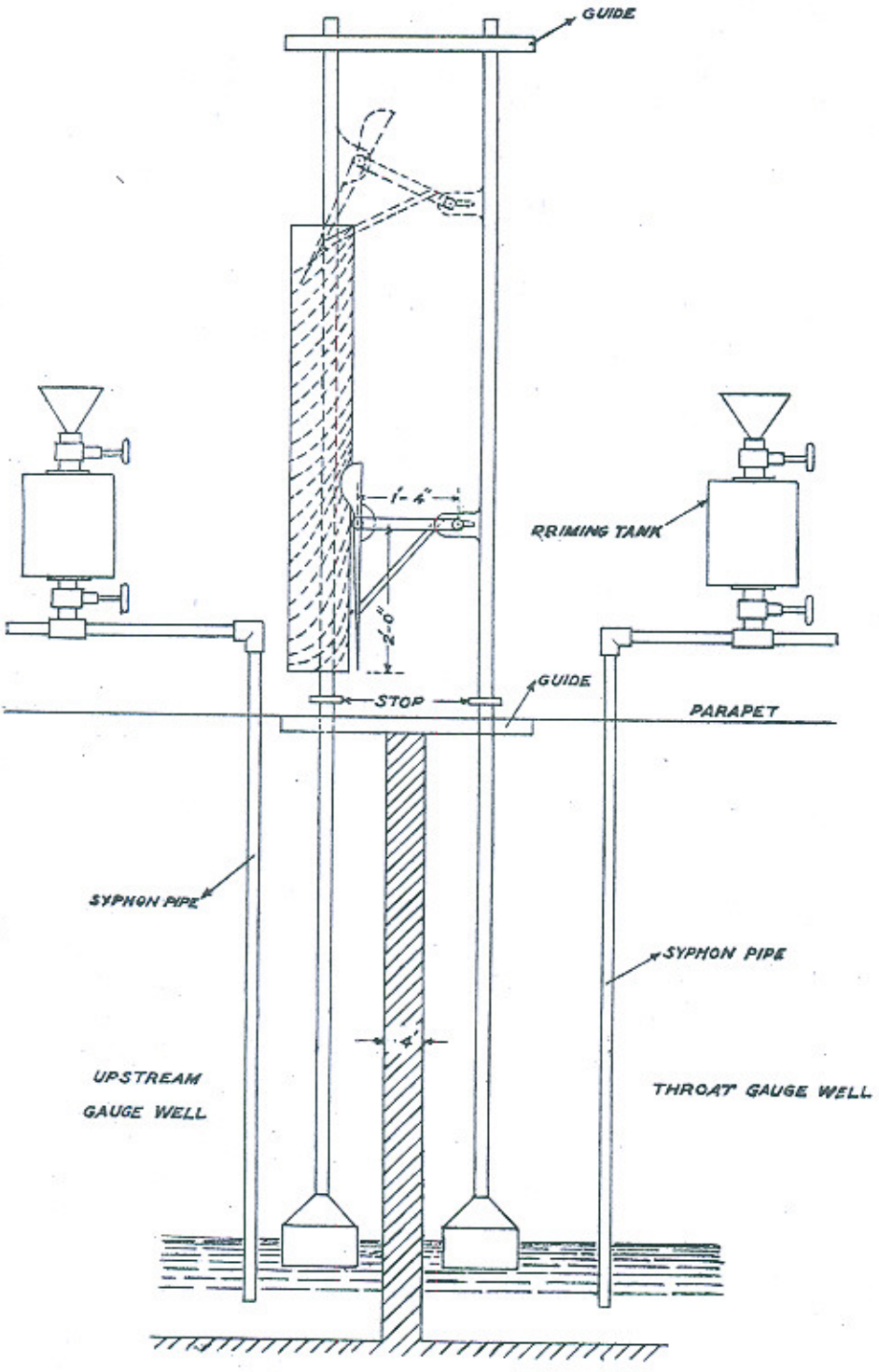
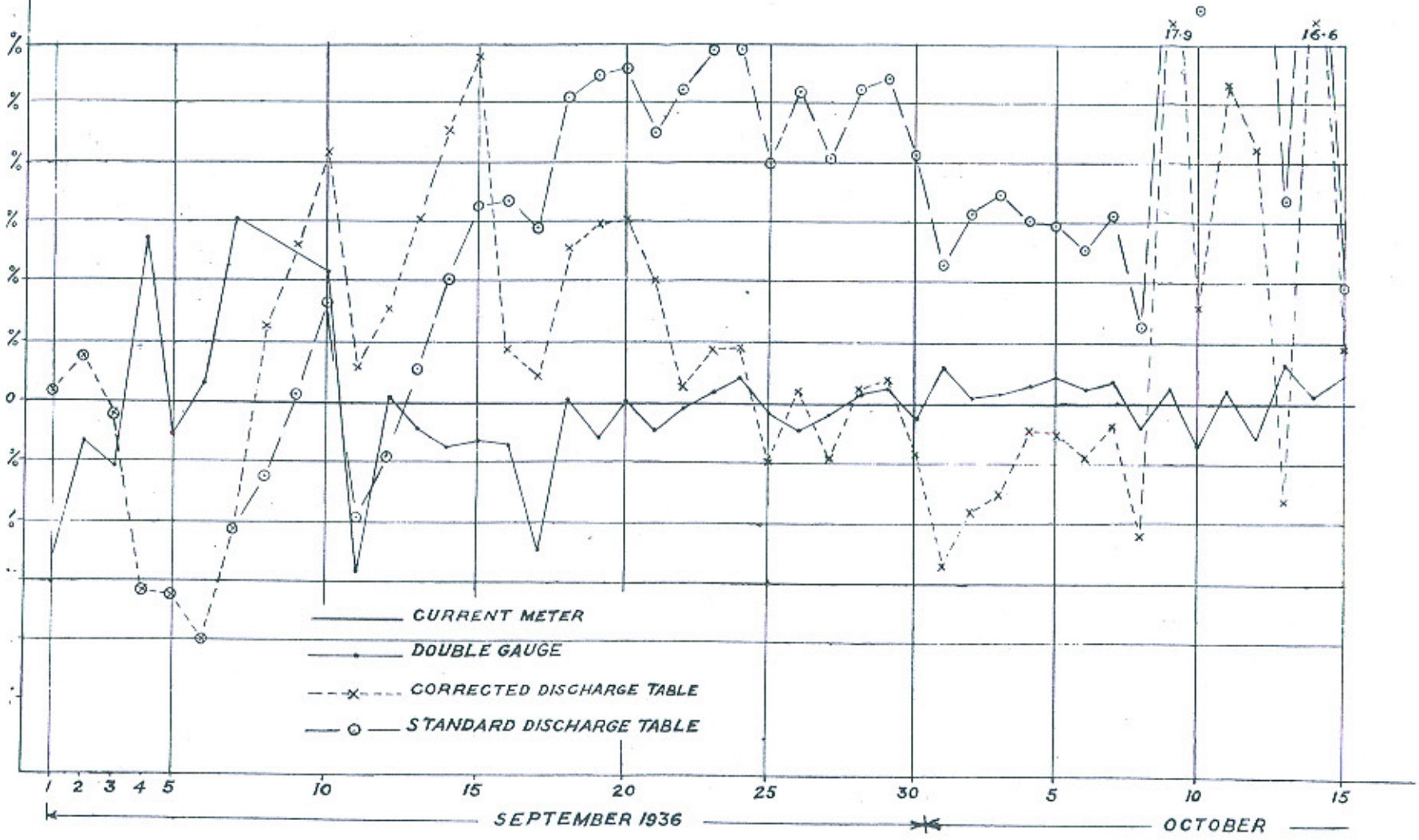


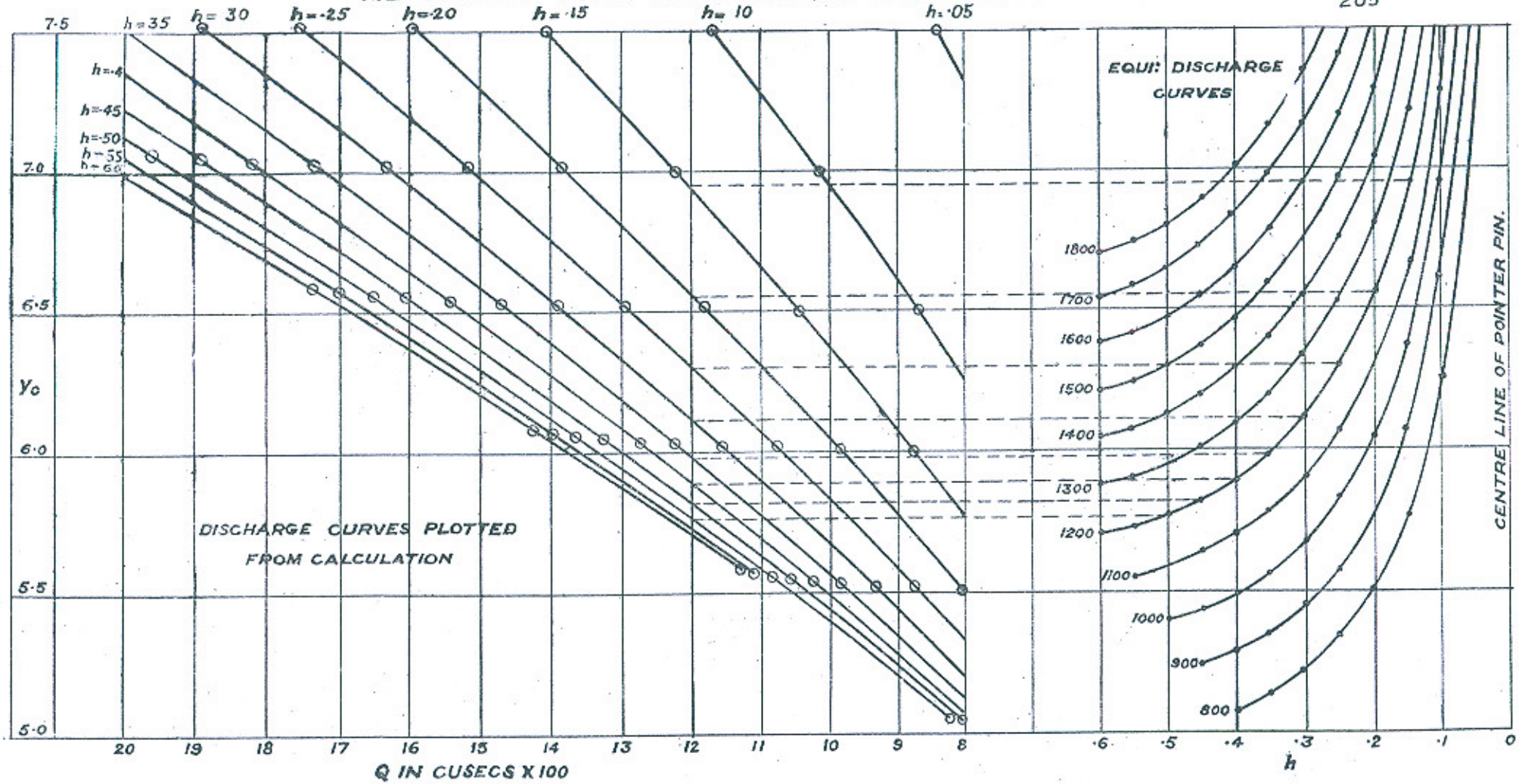
PLATE 2
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GRAPH SHOWING VARIATION FROM CURRENT METER DISCHARGE



METHOD OF PLOTTING EQUI-DISCHARGE CURVES

PLATE 3
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DISCUSSION.

MR. **Wilson,** in introducing his Paper, stated briefly the following circumstances that led up to the design and construction of the Double Gauge on the Eastern Canal Headless Meter. He said that he was in charge of the Eastern Canal and found that although the Headworks Division took great care to comply with indents as nearly as possible, there was always uncertainty as to the discharge that would actually enter the canal. Consequently indenting officers were very cautious about increasing indents where there was any danger of breaching channels. As the canal was not " paying " and maximum discharge was well below the authorized limit it was necessary to create confidence in the regulation of the canal, so that indents might be increased when water was available, and thereby increase irrigation and the revenue from the canal, the running expenses having been cut to the absolute minimum already.

Confidence could only be created when it was certain that indents would be complied with exactly, and fluctuations avoided, and this was impossible so long as regulation was dependent on a gauge in a silted channel, as the fine silt of the Sutlej River entered the canal in relatively fast moving waves which created a varying relation between gauge and discharge. The canal had an Headless Meter available, but this was not used for regulation as there was no certainty that it was reliable and computation of discharge was too involved for regulation purposes.

To convert the Headless Meter into a weir seemed the obvious solution, but this would have involved a higher pond level in the river which was most undesirable, apart from the objection of abandoning works on which much thought, time and money had been spent. The alternative of designing some contrivance to make regulation possible from the Headless Meter did not seem practical, especially when it was known that many incorrect figures had been obtained from such meters. The Author had been informed by more than one person that Headless Meters were most unreliable and regulation from them quite impossible. The task was a double one of ensuring correct functioning of the meter and eliminating complicated readings and calculations.

The arrangement finally adopted gave the discharge by one direct reading, but to be sure that the figure so read was correct, it was necessary to see that there was no silt deposit anywhere in the approach flume.

MR. **Som Nath Kapur** remarked that there were a few points in the Paper where the Author had found some difficulties but had left them unsolved. He referred to paragraph 3 on page 143 where mention was made of a small wave in the throat of the meter. This was a vitiating factor and required to be eliminated. Could it not be avoided? The upstream entry was generally an arc of a circle. How were the approaching streamlines affected?

The various laminae thinned out and in doing so, apart from the curvature of entry, there was circular motion obtained on account of thinning down and consequently each stream of water was under the action of a centrifugal force with its centre slightly displaced from the centre of the entry curve. When it reached the horizontal portion, the circular motion had to be replaced by a translatory one and where was the force for the change in direction to come from? Apparently there was the impact on the crest; there was another thrust on the waterlines; there was also a loss due to restitution which gave rise to the small wave noticed. The discussion on this might or might not be outside the scope of this Paper, but this side issue was a very important one which ought to be gone into. What was therefore required was a transitional curve at the upstream end of all measuring weirs and the exact shape was a question which needed mathematical treatment, supplemented by actual laboratory experiments on different curves. Similarly, the downstream sloped glacis had to be joined to the horizontal portion by another transitional curve instead of an abrupt kink or else it was not difficult to see that an eddy would form as water could not suddenly cling to the surface when changing direction without impinging on it. This curve would probably be a parabola, fitted between two tangents. It would certainly be interesting to find the effect of these curves on streamlines.

Before coming to the question of the gauge itself the speaker thought that next to a weir, the current meter was the next best thing to be depended upon for measuring discharges and anything which gave a lesser percentage of error than a current meter deserved patronage.

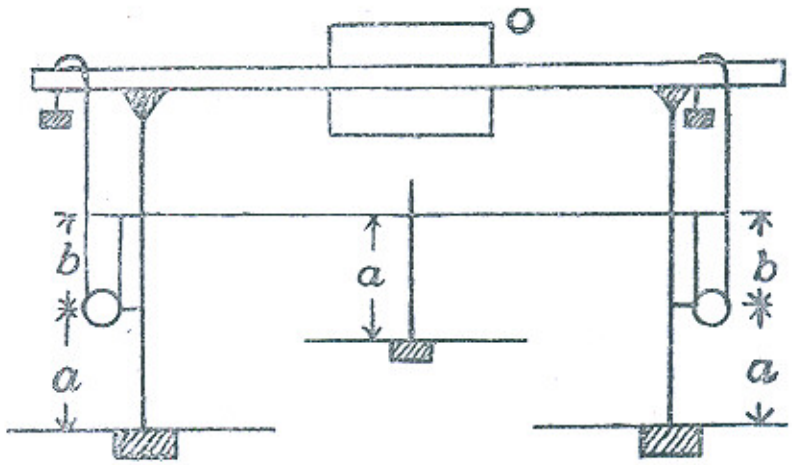
Mr. Kapur continued that Mr. Wilson had admitted that with a silt deposit on the upstream floor, the discharge reading became unreliable and hence a solution had to be found to make the discharge independent of the upstream gauge, if possible.

The design of headless meters was based on Julian Hind's ideas, where it was assumed that in the throat, velocity over the whole of the section was constant. Hence if the depth and velocity in the throat were known, the rest was simple. He asked what happened if a pressure and pitot tube were fitted in one of the bays. The difference in the two would register the velocity head. The problem was then reduced to adjusting the floats so that the depth was represented by the ordinate and velocity by the abscissa and the discharge could then be read from the table. The depth would usually be considerable but the velocity head would require magnification which could be obtained by converting the vertical movement of the floats into a rotary one by making it work a spiral screw, the pitch of which would determine the magnification. There were two simple ways of doing this.

There could be, for example, two independent floats each with a

counterpoise one of which was in the pressure well and the other in the pitot tube well, the float of each working different screws (one screw being inside the other) and worked in opposite directions so that the backward and forward movements would give a nett horizontal propulsion depending on the difference between the two water levels. A board with divisions could be mounted at the end which by its lateral motion would register velocity head on the X-axis. Another float could work in vertical guides so that its pointed top showed the depth of water along the Y-axis. If, therefore, the board had divisions both ways, the discharge under each point would equal X×Y which could be written on the board and read straight away.

If two screws were not desirable the apparatus could be simplified still further, the Author stated. The float in the pitot well could have a cross at a height "a" the arms passing through slots in the two pressure well floats. The pressure floats would support the spiral and the board.



These arms could be connected by a string over a pully at height "a" to the spiral by counterpoise. The vertical movement of this would represent the velocity head and be translated into spiral motion, the board itself forming a part of the depth-recording float and hence if a lamp or slot were fixed at zero point, when there was no water, the board could always move the exact discharge figure in front of the lamp which could be read immediately.

The speaker had assumed that the magnification of depth was not needed, but if it was required, the principle of extensiometers could be used to attain this. A floating cork hinged at the top and fitted with a mirror would reflect a beam of light and the distance of the screen would fix the magnification. This beam of light could be controlled

horizontally by the spirally translated velocity head but if so, the discharge table board would have to be read in a dark chamber.

The alternatives proposed (which were capable of improvement, the Speaker said,) would have the advantage of being simpler and be independent of silt movements. No curves would have to be dealt with but only simple arrangements which everybody would be able to follow.

Referring to the curves on plate 3, it would be found that with a small "h" the computation of exact discharges was very difficult and an error due to interpolation in this region would be of considerable magnitude. Again, if the total depth of the graph be one third of designed "H" on the crest, apart from the congestion of the curves, the thickness of lines drawn here would be a significant error in discharge.

It was however time that correct metering received the attention it deserved and the Author was to be complimented on bringing out various avenues of investigation.

Mr. **R. K. Gupta** said that on page 145 it was mentioned that Headless Meters usually had two or more pairs of gauge wells and that the average was utilized to obtain the discharge of the meter as a whole. Thus, the average of the upstream and downstream gauge wells was automatically obtained with an hydraulic connection by means of a syphon connecting the various gauge wells to the new pair of gauge wells on which the Regulation Gauge for Headless Canal Meters was fixed. This was not necessarily correct as the discharge calculated for the meter for average values of Yo, Y and H was not the same as would be obtained if the discharge were worked out for each bay separately with its own values of Yo , Y and H. This was tested with the observations taken on one date, *viz.*, 25th August, 1926, when the discharge was 2,180 cusecs, obtained by summing up the discharges of the three bays as against 2227 cusecs obtained by averaging the values Yo, Y and H used in each separate bay. This would seem to indicate a source of error.

Mr. **Vidya Rattan** remarked that Mr. Wilson began by cataloguing the various defects of existing Headless Meters such as the loss of energy between upstream and throat gauges, gauge wells which were not recording true water levels, a wave in the Venturi-Section, incorrect distance of the throat Gauge well, a deposit of silt on the upstream floor, etc. So far one found himself in complete agreement with the Author but where one differed was when the Author wound up by saying that all these errors paled into insignificance when compared with the supreme difficulty of calculating the discharge from the formula. To the irrigation engineer, all too familiar with discharge formulae for weirs, notches, channels, falls, etc., the expression for discharge through a Headless Canal Meter did not appear particularly cumbersome.

Regarding the Double Gauge itself the Author had said on page 145 that "there is a pair of gauge wells in each abutment and in each of the two piers. The existing pairs of wells are too far apart for fitting a Double Gauge and a fresh pair separated by a water-proof wall 5 inches thick has been built. The hydraulic connection with the original wells is maintained by 1 inch diameter G. I. pipe arranged as syphons above the water surface." The pipe connection between the original wells and the fresh wells set up important sources of error, and it was some of these that the speaker proposed to discuss.

(*a*) It was common knowledge that the flow through an overhead syphon was regulated by the difference of air pressures on the two surfaces which the syphon connected. As the syphon worked, this difference went on gradually diminishing until a stage was reached when this difference was so small that it was unable to overcome the resistance in the syphon and the friction at entrance. Then the flow stopped. Applying this to the arrangement of the Double Gauge, it was easy to see that the level of the water in the fresh pair of wells would not be the same as in the original pair. It would be less. The discharge being proportional to Y_1 and Y_0, the Double Gauge discharge would be less than actual.

(*b*) A second source of error—and this was more important than the rest—would arise from the water level in the gauge wells where the Double Gauge was installed, being not in phase with the water-level in the stream because of the syphon pipe. This difference in phase would depend on the relative positions of the original pair of wells and the fresh pair of wells and also on the length and diameter of the connecting pipes. The effect of this phase difference would manifest itself in the Double Gauge indicating a discharge corresponding to distorted values of the discharge elements Y_1, Y_6 and h. While the error in Y_1 and Y_0 may be small, the error in "h" which was of the order of 0·2, 0·3, or 0·4, would account for an appreciable percentage difference in discharge. It would also be seen that this error was considerably more when the supply was fluctuating than when it was steady. That explained why on the 4th of September the Author got very divergent results from his Double Gauge. Some of this may have been due to the actual fluctuation in supply but there appeared no doubt that this divergence was perhaps in an equal measure to the water levels in the gauge wells being out of phase with those of the channel.

(*c*) There was also a third source of error and that was, that

the actual oscillations in the water level due to wind, wave and turbulence were damped in the gauge wells. The extent to which the amplitude of these oscillations was diminished depended on the length of the pipe, its diameter and the diameter of the gauge wells; the smaller the diameter of the pipe the higher the damping ratio. With the arrangement adopted by the Author there were two distinct changes in amplitude of oscillations, first as between the actual water surface and that in the original wells, secondly as between the original gauge wells and the fresh pair of gauge wells. The effect of this resultant damping of the oscillations was to cause the average heads Y_1, Y_0 as recorded in the gauge wells to be less than the average values of Y_1 and Y_0 which were effective in producing the discharge. Thus the discharge as registered by the Double Gauge was less than the actual.

3. A word about the discharge curves on which the pointer of the Double Gauge moved. These discharge curves were plotted by calculating values of Q as given by the formula :—

$$Q = KY_0 \, Y_1 \sqrt{\frac{h}{Y_0^2 - Y_1^2}}$$

On the one hand the Author gave it as his definite opinion (see page 144) that it was not safe to rely entirely on the theoretical co-efficient of a Headless meter and on the other he asked us to accept the discharge which had been calculated using the same theoretical co-efficient. This was somewhat inconsistent.

In conclusion, the speaker said that the Double Gauge was without doubt a useful device inasmuch as it saved calculation. Its usefulness, however, was confined to steady conditions of flow. It was by no means an answer to the various criticisms against the Headless meters in their role as meters of supply. While the accuracy of Headless canal meters themselves was questionable, the discharge as given by the Double Gauge on account of errors due to phase difference, damping ratio, loss of head in friction through the syphon pipe, expansion and contraction of the paper on to which the discharge curves were plotted, was even less accurate.

Mr. **T. Blench** commented that Mr. Wilson's Paper was very valuable, in that his direct reading gauge could be easily adopted to give a far more accurate discharge than obtainable from current meter observations. In fact he said he would use the headless meter properly designed, to calibrate the current meters. And for Mr. Wilson's dictum on headless meters " the elaborate observation and calculation required render them practically useless for regulation purposes " he would substitute " the simple calculations, combined with the use of

Mr. Wilson's direct reading gauge, render a properly designed meter most valuable for regulation."

He was aware that Mr. Wilson had a poor opinion of the reliability of flume measuring devices, so he (Mr. Blench) tabled the graphs of the results obtained at Rasul, and published in *The Engineer*, July 31st 1936, showing that a current meter could go by 1 p. c. wrong for 6°C change in temperature; and he brought to the notice of this Congress that Mr. Wilson had taken his discharge observations for his Paper by "the standard methods of the Discharge Division" with the meter at 0·6 depth. All authoritative books condemned this practice, and it was prohibited in para. 5 of Article 2A of A and C slip No. 6 to the Irrigation Handbook of Professional Orders, under date 15th January 1927, where instructions were given to find the filament of mean velocity and not to assume it. Disobedience of these orders may be expected to result, usually, in an error of 2 to 3 per cent. and in extreme cases to well over 5 p.c. In criticizing a masonry meter from the records of the Discharge Division it was essential to remember not only the temperature error, but that the mean velocity was not observed.

To assess the degree of accuracy of a headless meter there was the frictionless equation :—

$$Q = \sqrt{2g\ B Y_0\ Y_1} \sqrt{\frac{h}{Y_0^2 - Y_1^2}} \qquad (1)$$

which should become :—

$$Q = \sqrt{2g\ B Y_0\ Y_1} \sqrt{\frac{h - h_f}{Y_0^2 - Y_1^2}} \qquad (2)$$

where h_f, is the loss of head due to friction and shock between the gauge sections. If the bed and side approaches were properly designed there should not be the shock loss indicated by the irregularity of surface of Mr. Wilson's Sketch I, and only friction remained, which was easy to assess.

Equation (2) could be written in the approximate form

$$Q = \left(1 - \tfrac{1}{2} \frac{h_f}{h}\right) \sqrt{2g\ B Y_0\ Y_1} \sqrt{\frac{h}{Y_0^2 - Y_1^2}} \qquad (3)$$

showing that the frictional difference in discharge from frictionless discharge was one half the ratio of friction loss to water surface depression assuming that the meter had no shock loss.

From an old Congress Paper it appeared that the Eastern Canal Meter flume had two intermediate piers, a clear water-way of about 80 feet, about 15 feet of crest upstream of the lower gauge slit, and about

15 feet of low floor upstream of the crest to the upper gauge slit. This being so it was easy to work out h_f, for the 15 feet of crest. For example if Q=1100, Y_0=5·75 and h=0·35 from Plate 3,

Then $Y = 5{\cdot}75 - 2{\cdot}75 - 0{\cdot}35 = 2{\cdot}65$ feet.
$R_1 = 80 \times 2{\cdot}65 / (80 + 6 \times 2{\cdot}65) = 2{\cdot}21$ feet.
$V_1 = 1100 / (80 \times 2{\cdot}65) = 5{\cdot}2$ feet/sec.

Using Basin's γ of 0·55, the nomograms show that energy is being lost against friction at a rate of 1 foot in 1,050.*

Therefore the discharge would be less than theoretical friction-less by $(\frac{1}{2}) \times 15/1050) \times (100/0{\cdot}35)$ per cent *i.e.*, 2·05 %. There would be a further loss of discharge due to the friction in the upper 15 feet of about one-fifth of 2·05 % which would be worked out in exactly the same manner.

If now Q=1800 Y_0=7·0 feet and h=0·4 feet the percentage discharge drop due to the 15 feet of crest would work out at 1·44 % and to this must be added the bit from the upper 15 feet. On the whole, friction would produce about 0·75 % more drop in discharge at the low discharge than at the high.

The figures of Y_0 and h had been taken to fit what Mr. Wilson's data suggested actually occurred, and the result explained why his double-gauge curve of Plate 2 had a slight upward trend,—by taking a constant co-efficient he had made the lower calculated discharges (of October) greater than they should be in relation to the greater discharges of September.

The simplicity of the friction calculations, and the labour required to plot Plate 3 made it well worth correcting the latter plate.

In a design without shock loss, which could not be assessed, even if the friction drop were assessed wrongly by as much as 30%, the discharge correction would only err, in this example, by about 0·15 of 2·5 %, say 0·4 % at the very most. Compared with a current meter with a temperature error of several per cent. and held at the wrong depth there was no question which metering device was the better.

If all discharges were assumed to occur from the same "h" it would be found that friction was more important at high discharges. Actually "h" would not be the same, so this was merely a warning to choose practical values for discussion.

A meter flume was merely the limiting case of a headless flume, in which "h" was known without measurement, and it had, of course, the

*See Parker's "The Control of Water," 2nd edition, Diagram No. 8.

great advantage that the gauge to be measured was conveniently large, apart from other advantages.

As regulation could be done with accuracy of about $\frac{1}{4}$ per cent. it was obviously desirable that it should be measured by meters of the same degree of accuracy.

If, as the speaker hoped, Headless Meters took the position that they deserved and could now attain, due to Mr. Wilson's direct reading device, it would be necessary to consider the various errors in reading, etc., very carefully. One possible error mentioned by Mr. Vidya Rattan was that the fluctuation, if any, in the gauge wells might be out of phase if the syphon pipes were not identical. As a Headless Meter might suffer from "hunting" this error might be important. It might also be wise to have separate gauges for separate bays, and to have pipe gauges in midstream.

The **Author** in replying to the discussion said that Mr. Kapur had suggested a theory to explain the wave in the throat of a headless meter, while Mr. Blench mentioned shock as the cause, and though these explanations seemed reasonable yet the Headless Meter had extremely well designed gentle curves, and it would not be easy to eliminate such slight irregularity of surface as existed.

Mr. Kapur suggested the use of Pitot gauges to replace the upstream gauges and thus avoid the difficulty of silt deposits, but the alternative mechanisms suggested did not seem to simplify matters at all. On the contrary they were so complicated that they could not have been made locally as was the Double Gauge, and the accuracy of the alternative mechanisms seemed doubtful on account of backlash of the screw threads and the unbalanced changes of load on floats due to the use of wire ropes. As the use of pitot gauges did not simplify the Double Gauge mechanism it did not seem worth changing the existing gauge wells, but pitot gauges did simplify the discharge formula and eliminated silt difficulties so that they might be worth while on a new work. In fact with pitot gauges it became possible to indicate discharge on a linear scale with quite a simple mechanism by working out the formula $Q=KY_1\sqrt{h}$ mechanically, so that a discharge recorder was within the bounds of possibility, and the Author was investigating the practical application of such a recorder as distinct from a regulating gauge.

As the curves on Plate 3 were plotted to full size there was practically no error in interpolation; nor was there congestion of curves, the minimum spacing for 20 cusecs being $\frac{1}{8}$ inch and the indicator could be read to the nearest 1/16 inch.

Mr. Gupta pointed out that the calculation of discharge of each bay

separately did not give the same result as from the average of upstream and downstream gauges respectively, but unfortunately the example he gave was for a date prior to the Author's records. However the difference was probably due to the pulsation of gauge wells, particularly as the recorded head in the central bay was double that of side bays, and seemed most unlikely to be a true average reading.

Mr. Vidya Rattan did not seem to agree that calculation was any great difficulty, but the actual fact was that it took a trained Overseer about one hour to record all the gauges and complete the calculations, and it would be quite impossible for an illiterate Jamadar of a Headworks to regulate a canal without some device to indicate discharge without calculation, however simple. The Author could not agree that there was any more source of error due to the syphon connection than with a direct pipe connection; nor that there was any appreciable error due to difference of phase of gauge wells, as the upstream and downstream syphons were of the same size and almost exactly the same length. Nor could the Author agree that there was any error due to damping of fluctuations; in fact the damping of oscillations in the gauge wells was intentional and essential for obtaining an accurate average discharge over a period of 5 to 10 minutes, which was necessary for proper regulation. In nearly all the hydraulic work it was usual to use a theoretical co-efficient and to apply a further correction or practical co-efficient, and this did not seem inconsistent provided only that the final result was correct and reliable.

Mr. Blench suggested that Headless Meters were far more accurate meters, but the fact remained that the five Headless Meters under observation were abandoned for all practical purposes on account of their unreliability, in spite of the great care taken in their design: as suggested in the Paper, precautions were necessary on all of them, while at least one was useless in its present form. It had also been mentioned that even free fall and standing wave weirs were subject to an error up to 3 p.c. due to silting of approaches, so that, for the present at least, current meter and rod discharges were a convenient and reliable check.

As regards the observations at Rasul it might be mentioned that the Discharge Division had rated current meters by an extremely accurate electrically recorded method, over a very wide range of temperatures and that not the slightest variation of rating was detected. It was true that the current meter should be held at the filament of mean velocity, but numerous observations showed that this position varied from time to time at the same site, and for different positions on the same cross section, and that as far as canals were concerned 0·6 of the depth was a very good average position and caused very little error on the whole. Admittedly, current meter discharges were not perfect, but on the average they were very reliable, even at a very bad discharge site such as at Rasul. The curves given by Mr. Blench were very interesting in that

they showed that in spite of the defects of the current meter discharge there was no appreciable difference between the actual observed discharges and the discharges from the meter flume during the period of observation. In fact the observations demonstrated very clearly that if the current meter was at 0·6 of the depth, and no correction was applied either for temperature or anything else, the results agreed very well with a meter flume. It was unfortunate that Mr. Blench did not observe discharges with rods, or calibrate his current meter in the canal at various temperatures, to check his conclusions.

As regards error due to friction losses it was pointed out that Mr. Blench's equation (2) was an approximation, as any variation in "h" affected the relation between Y_0 and Y_1, and that equation (3) was a further approximation. Accepting his value for loss against friction and applying it without approximation the effect on discharge was less than 1·3 p.c. and the change of error due to friction was correspondingly less than that given by him and worked out to 0·4 p. c. only. In any case the change of error due to friction was very small and as there were other sources of error apart from friction, it did not seem worthwhile allowing for it in calculations, as the alleged upward trend of the results on Plate 2 was apparently not of great importance. Due to proper damping there was absolutely no tendency to "hunting" on the Double Gauge, while the suggestion of separate gauges for separate bays would render the device useless for regulation purposes.

In conclusion the Author said whatever errors there might be in the Double Gauge the actual results showed that their combined effect was very small and within the probable error of the current meter discharges, and in the case of the Eastern Canal at least, the correction factor required was negligible.