

4.4 Measurement of flow of water and the limitations of velocity area method (CBIP, 1978)

Systematic observations of river gauges and discharges have been practiced in some parts of the country for several decades. In Punjab, Sind, Tamil Nadu, Karnataka, Andhra Pradesh, Uttar Pradesh, West Bengal and some other states, rivers have been regularly gauged. Ganga Basin Water Resources Organization under the administrative control of Central Water Commission is observing gauges, discharges, sediment charges in entire of Ganga Basin which is one of the largest basins in Asia. The work has also been carried out in other river basins such as Mahanadi, Krishna, Cauvery, Brahmaputra.

4.4.1 Relation between Surface Velocity and Mean Velocity

When surface velocities are measured by surface floats or current meters, a coefficient is applied to obtain the mean velocity on the vertical. Earlier experiments on different streams have indicated that this coefficient is not constant and lies between 0.79 to 0.9. In the Punjab and Sind a large number of observations gave a value of 0.89. This value was in use in other parts of India. The studies conducted under Research Scheme sponsored by Government of India, on 24 sites of different canal reaches in Karnataka, the analysis of a set of 46 observations indicated that the ratio of mean velocity to surface velocity works out to.

4.4.2 Point of Mean Velocity

Experiments carried out on Sind canals showed that in 79 percent of the cases the mean velocity occurred between 0.51 and 0.75 of depth on each vertical. Data collected on 43 sites on the Sukkur Barrage canals was similarly examined. Five verticals were selected out of a cross-section for purposes of study. Analysis showed that the average position of mean velocity on the two and verticals was obtained at 0.67 depth, for the intermediate two verticals at 0.63 depth and for the central vertical at 0.61 depth.

Data of velocity distribution on 951 verticals on the River Indus during the years 1916 to 1932 yielded the following statistical relationship

$$\bar{V} \text{ (m/s)} = 0.3048 (1.004 v_{0.6} + 0.041)$$

in which $v_{0.6}$ is the velocity at 0.6 depth in fps (foot per second).

Velocity observations made on an equally large number of verticals during the years 1936-38 on the various Sukkur Barrage canals gave the following relationship between the velocity observed at 0.6 depth and the mean velocity over the vertical

$$\bar{V} \text{ (m/s)} = 0.3048 (1.010 v_{0.6} - 0.059)$$

in which $v_{0.6}$ is the velocity at 0.6 depth in fps (foot per second).

4.4.3 Velocity by Float Rods

Cunningham in his Roorkee experiments showed that velocity of the float rod (V_r) would be equal to the mean velocity of a vertical (\bar{V}) when the submerged length of the rod was 0.95 to 0.927 depth of water, the exact value depending on the position of the maximum velocity on the vertical. The Indian practice has been to use rods having submergence of 0.94 depth to account for variations of stream depth along the float track, the following relation between (\bar{V}) and (V_r) has been used.

$$\bar{V} \text{ (m/s)} = 0.3048 \left(V_r \left(1.012 - 0.116 \sqrt{\frac{y-L}{y}} \right) \right)$$

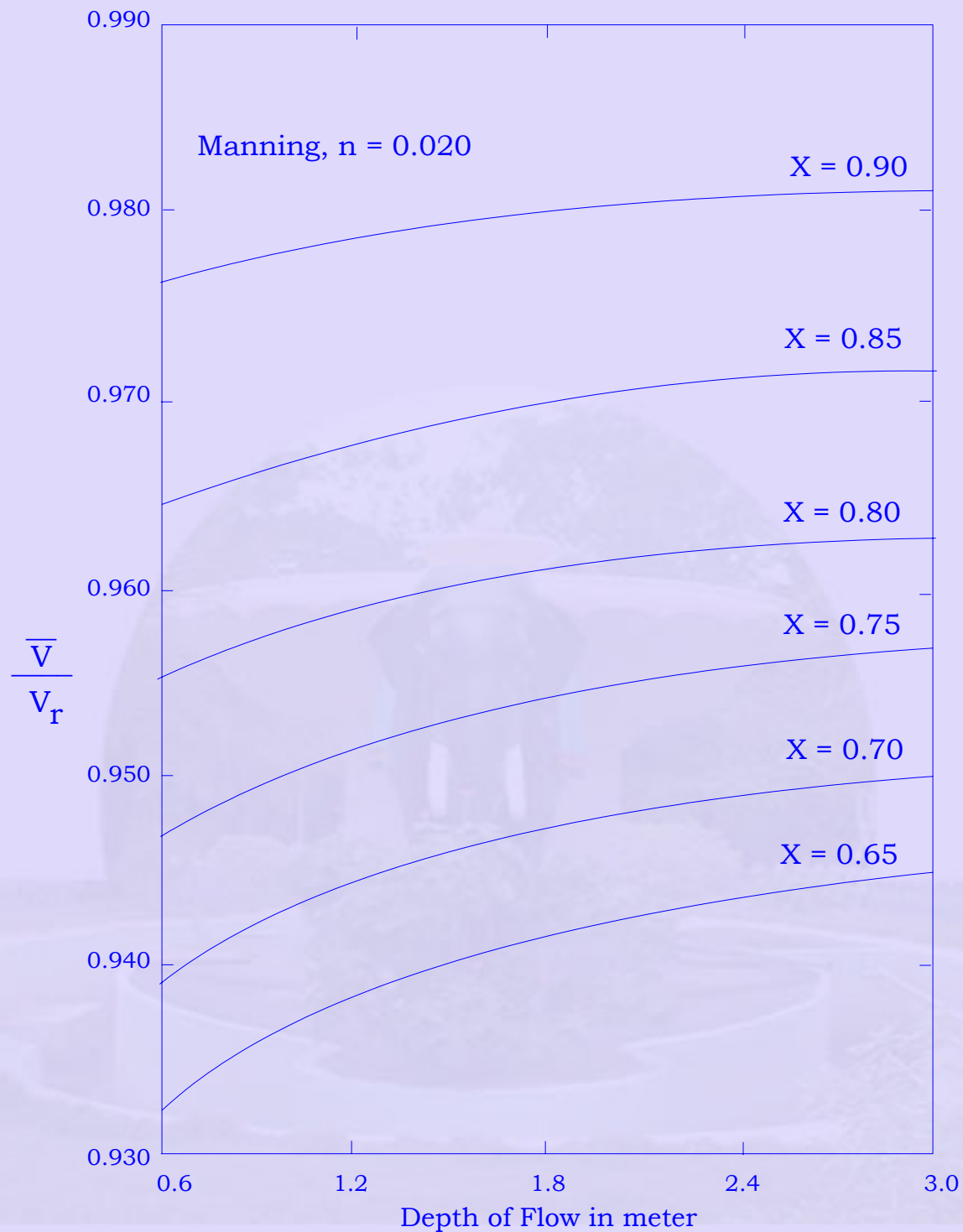
in which V_r is in FPS.

where, y is the depth of water in feet and L is the submerged length of the rod in feet.

Lacey proposed the use of a special tabular rod which was named after him. He suggested that the following formula could be used:

$$\bar{V} \text{ (m/s)} = 0.3048 \left(2v_{0.80y} - v_{0.4y} \right)$$

in which $v_{0.80y}$ and $v_{0.4y}$ in FPS at 0.8 and 0.4 depth of flow respectively.



X is the ratio of Length of the measuring rod to Depth of water
 Typical Correction factors for velocity rods for log velocity distribution (This depends on Manning, n value)

4.4.4 Errors in Discharge Measurements in Large Rivers by the Velocity Area Method

Accuracy of discharge measurement in natural and artificial channels depends upon a particular method being selected. Out of many practical methods, the one which has found wide applicability and use in field and project studies is the "Area Velocity Method". [ISO/BIS](#) have brought out standards for adopting this method. Detailed investigations have been carried out in the past as well as recently for evaluating, the errors in discharge measurement by the area velocity method.

Measurements of flow in open channels by the area velocity method are subjected to systematic errors in the measuring instruments and random errors caused by their lack of sensitivity in the range in which they are used. Random errors can also be due to pulsations and personal errors during observation. The total error in discharge measurement by area velocity method comprises components of errors due to width and depth and velocity measurements which are subject to random and systematic error of observations, besides the one due to using finite number of verticals along the entire cross-section.

4.4.5 Error in Width

In the Pivot-point method, which is the standard practice in India for positioning of the boat at various observation points in a wide river, the position of the station at which the depth or velocity is to be observed is located by a geometrical layout of points on the bank or banks of the river. The distance from the bank is not measured, but the boat is brought to the desired position by aligning it against the cross-section line pegs and prefixed pivot-point flags on the bank. The error in positioning has been determined by comparing the distances with those determined by the angular method with the help of a precise theodolite. The latter method is presumed to yield true distances. Observations taken on 10 days for a total of 154 verticals have been statistically analyzed and the mean standard deviation determined. The results are summarized below

Range of width observed (m)	Absolute error (m)	Mean standard deviation (%)	Remarks
300 to 600	2.34	± 0.386	From one bank
600 to 1200	6.72	± 0.564	From each of two banks

It would appear that with increase in width, the percentage error increases in magnitude with the same equipment.

Errors due to measurement in width could be minimized by taking segments at equal distances and the total surface width could be measured with more sophisticated instruments available now.

4.4.6 Error in Depth

Depth is usually measured by a rigid sounding rod up to a depth of 6 m and by a log line beyond this depth.

To work out the error in depth, two readings are taken with the same sounding rod at the same place. The average of these two readings are used for comparison with the individual readings to work out the standard deviation.

Observations for 10 days for a total of 80 verticals have been statistically analyzed and the following results are obtained.

Range of width observed (m)	Absolute error (m)	Mean standard deviation (%)
0.41 to 6	0.039	± 0.65
6 to 14	0.049	± 0.35

The percentage standard error would appear to decrease with depth, though the absolute error increases.

4.4.7 Error in Mean Velocity at Verticals

The normal Indian practice is to measure the velocity at 0.6 depth and take it as the mean velocity, unless the point of mean velocity is observed by preliminary observations to be at different depth. This is compared with the mean velocity obtained by the six-point method, i.e., observing velocities at 0.2, 0.4, 0.6 and 0.8 of the depth below the surface and as near as possible to the free surface and at the bottom. The mean velocity was worked out from the following equation

$$\bar{V} = \frac{1}{10} (V_s + 2V_{0.2} + 2V_{0.4} + 2V_{0.6} + 2V_{0.8} + V_{bottom})$$

Observations for 21 days at different sites for a total of 390 verticals yielded the following results

Range of velocity	Mean standard deviation (%)
0.087 to 1.3 m / sec	± 4.75%

Error due to Limited Number of verticals:

Investigations by the Rijkswaterstaat show that the standard error reduced progressively with the increase in the number of verticals, as given in the Table

Table: Progressive reduction in the standard error with the increase in the number of verticals

Number of verticals	Standard error in percent of discharge
8	2.35
10	1.35
12	0.90
15	0.60
20	0.38
25	0.30

4.4.8 Components of Error in ISO/ISI Specifications

When equidistant verticals spaced at 'b' unit apart in a water surface width 'T' are used.

The systematic part of the error in discharge measurement dependent on the number of verticals was found to be

$$X_m(b) = \frac{50b}{T} \text{ or } \frac{50}{m+1}$$

in which, $X_m(b)$ is systematic error in discharge due to 'm' number of verticals. Random

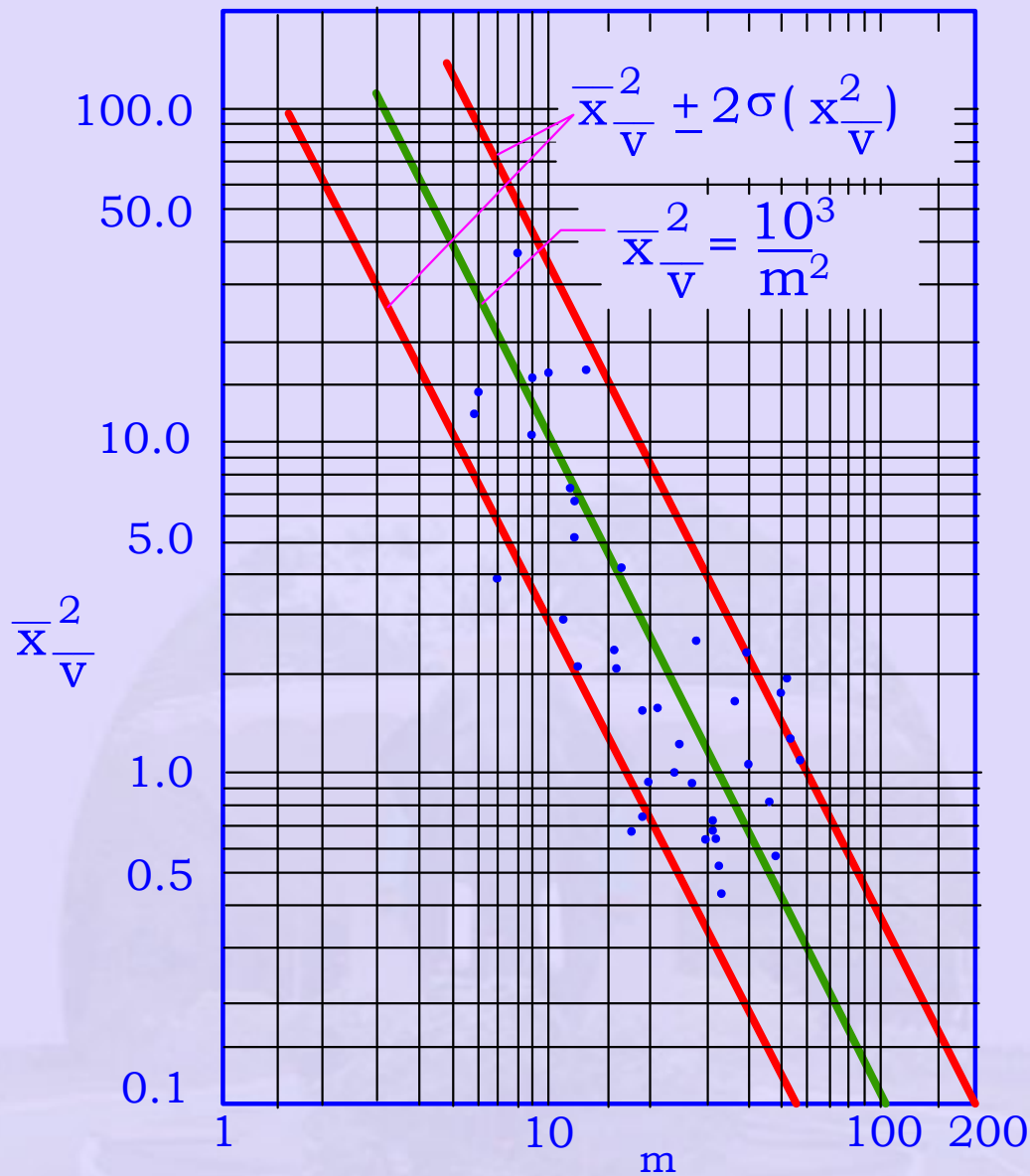
errors $X_{\bar{v}}^2$ and $X_{\bar{y}}^2$ due to velocity and depth after analyzing 43 sets of observations

having approximately 100-200 number of velocity observations on the Maharashtra

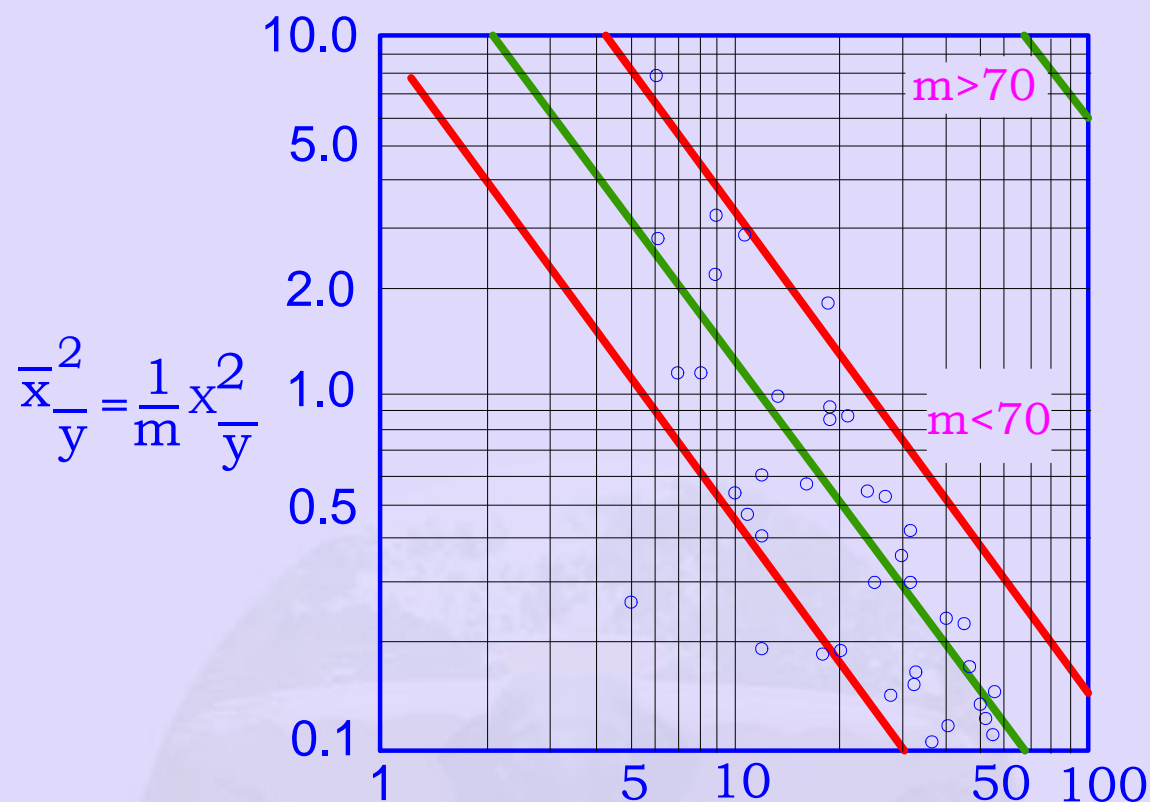
canals, Gole et al. (1973) have suggested the following two equations: $X_{\bar{v}}^2 = \frac{10^3}{m^2}$

$$\text{and } X_{\bar{y}}^2 = \frac{28}{m^{4/3}}$$

The average coefficient of variation for horizontal distribution of velocity was obtained as 32 and for mean depth as 5.3 percent.



Variation of \bar{x}^2/v with $m = [\frac{T}{b_1} - 1]$



m is the Number of verticals)

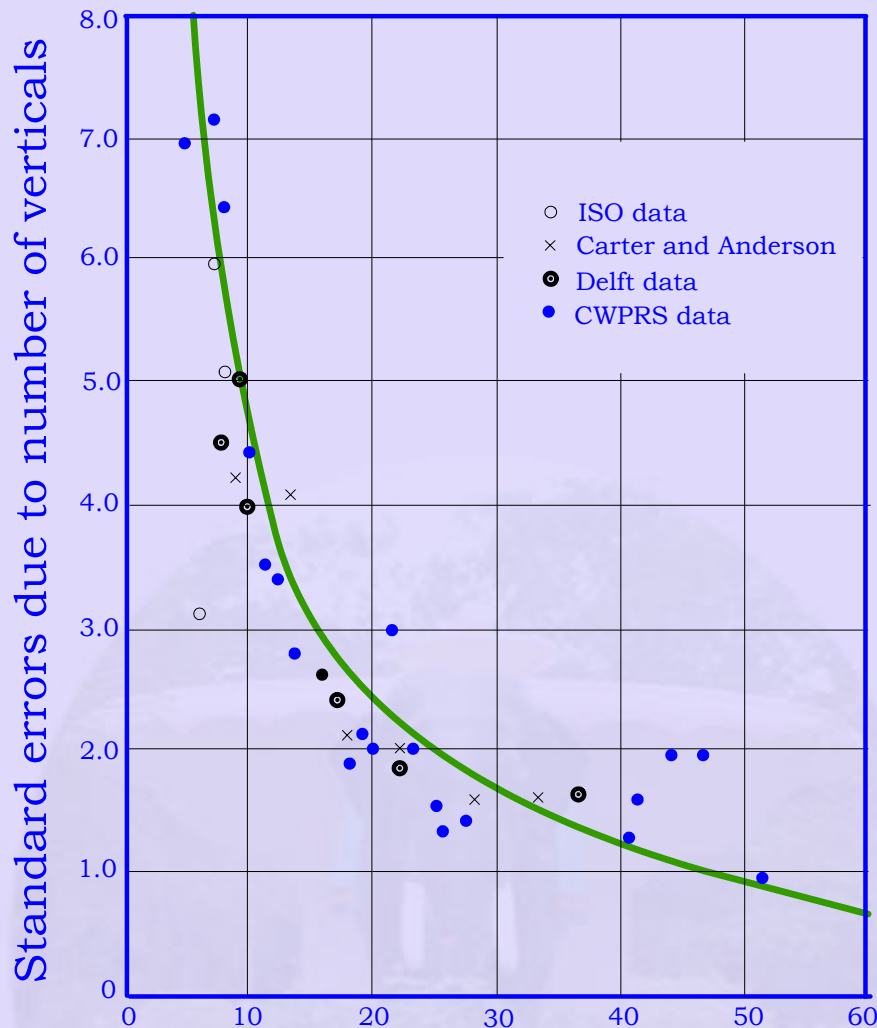
Variation of $\frac{\overline{x}^2}{\overline{y}}$ with the number of verticals

The total error could thus be worked out as

$$X_Q = \left[X_m^2(b) + \frac{1}{m} \left(X_v^2 + X_y^2 \right) \right]^{0.5}$$

4.4.9 Intrinsic Error in ISO/ISI Specification for 15/50 Verticals

ISI have recommended 15/50 equidistant verticals for computation of discharge in channels. It is found that intrinsic errors in discharge due to number of verticals being 15 and 50 are +3.12 and +1.0 percent respectively. The total root mean errors due to velocity and depth measurements works out to be 3.8 and 1.4 percent respectively.



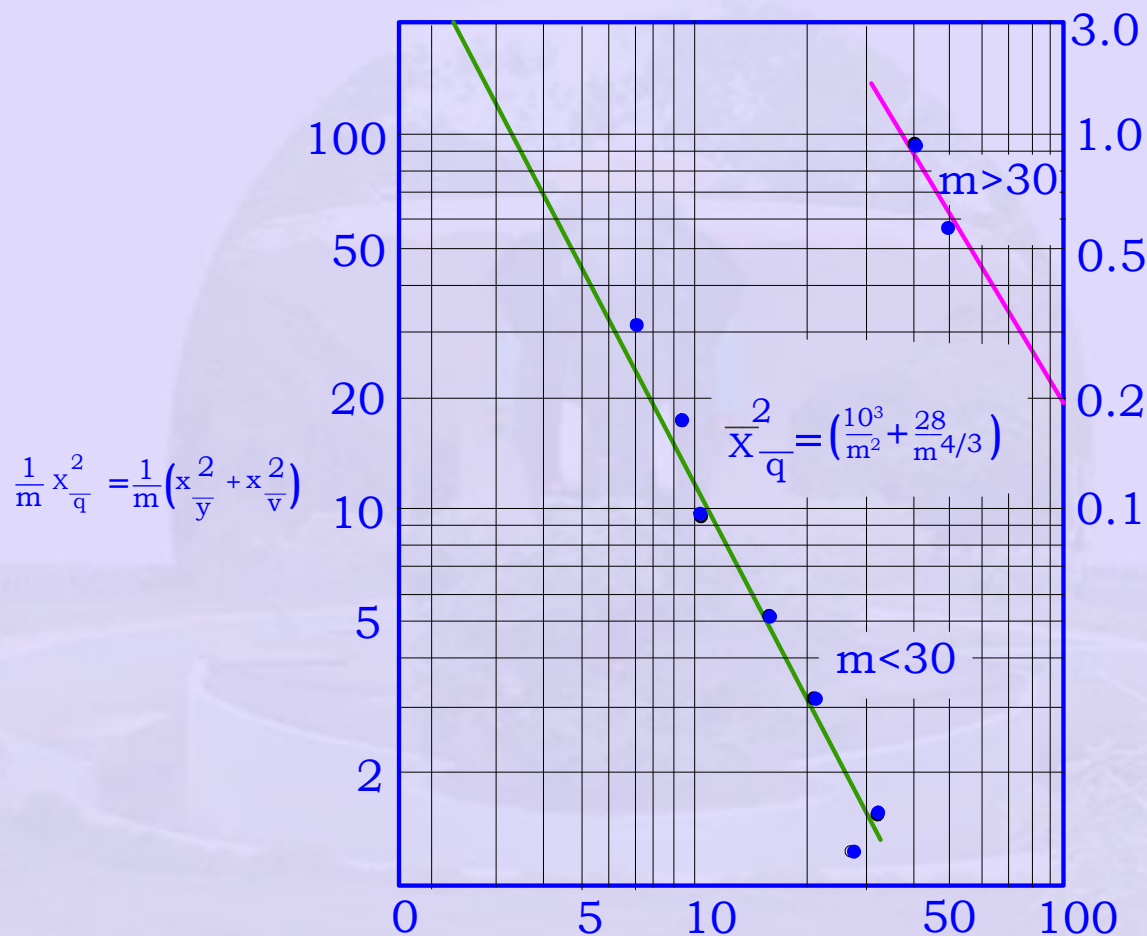
$$\text{Number of verticals } m = \frac{W}{b} - 1$$

Showing theoretical curve for X_m and experimental data as a function of number of verticals

4.4.10 Effect of Deployment on Random Errors X_v^2 and X_y^2

When the 'm' number of verticals are deployed according to a particular scheme for precisely locating the depth (cross-section) profile, it is expected that it would have some effect on the estimate of X_v^2 and X_y^2 . Since deployment help in getting the nearest estimate of the representative profile and hence coefficient of variation in velocity and depth over a cross-section, it will affect the contribution to the random error in so far as the estimate of the coefficient of variation in error are compared to the true value. But errors are inversely proportional to \sqrt{m} and hence the difference is not

significant unless 'm' is very small. To verify the above hypothesis $X_{\bar{v}}^2$ and $X_{\bar{y}}^2$ were estimated for different deployment of vertical and the total contribution against the mean function for $\frac{1}{m}(X_{\bar{v}}^2$ and $X_{\bar{y}}^2)$ (See Figure). It is found that the difference in the $X_{\bar{Q}}^2$ for different deployments from the mean curve for equidistant verticals are not significant and for all practical purposes the theoretical curve may be utilized to get the contribution of random errors due to sources velocity and depth.



m number of verticals

Variation of $\frac{1}{m} X_{\bar{Q}}^2$ with m

Table Shows computation of X_m from experimental data (CBI&P)

Sl.No	% error with reduced number of verticals, $E_m = 8$	Number of verticals for standard discharge	X_m Intrinsic error in standard discharge due to verticals (%)
1	3.74	11	4.17
2	8.17	11	7.17
3	4.76	10	4.55
4	5.68	16	2.94
5	0.99	16	2.94
6	5.21	16	2.94
7	1.22	20	2.38
8	0.82	21	2.27
9	0.89	41	2.19
10		18	3.06

Computation done by CBI & P (Central Board of Irrigation and Power)

Average $\bar{E} = 3.30$

(Set Error) $\sigma = 2.93$

$$\left(\frac{1}{2}\bar{E}\right)^2 + \sigma^2 = (1.15)^2 + (2.93)^2$$

$$\text{or } (\hat{X}_m - \bar{X}_m)^2 = 11.3125$$

$$(\hat{X}_m - \bar{X}_m) = 3.36 \text{ but } X_m = 3.06$$

$$\therefore \hat{X}_m = 3.36 + 3.06 = 6.42 \text{ percent}$$

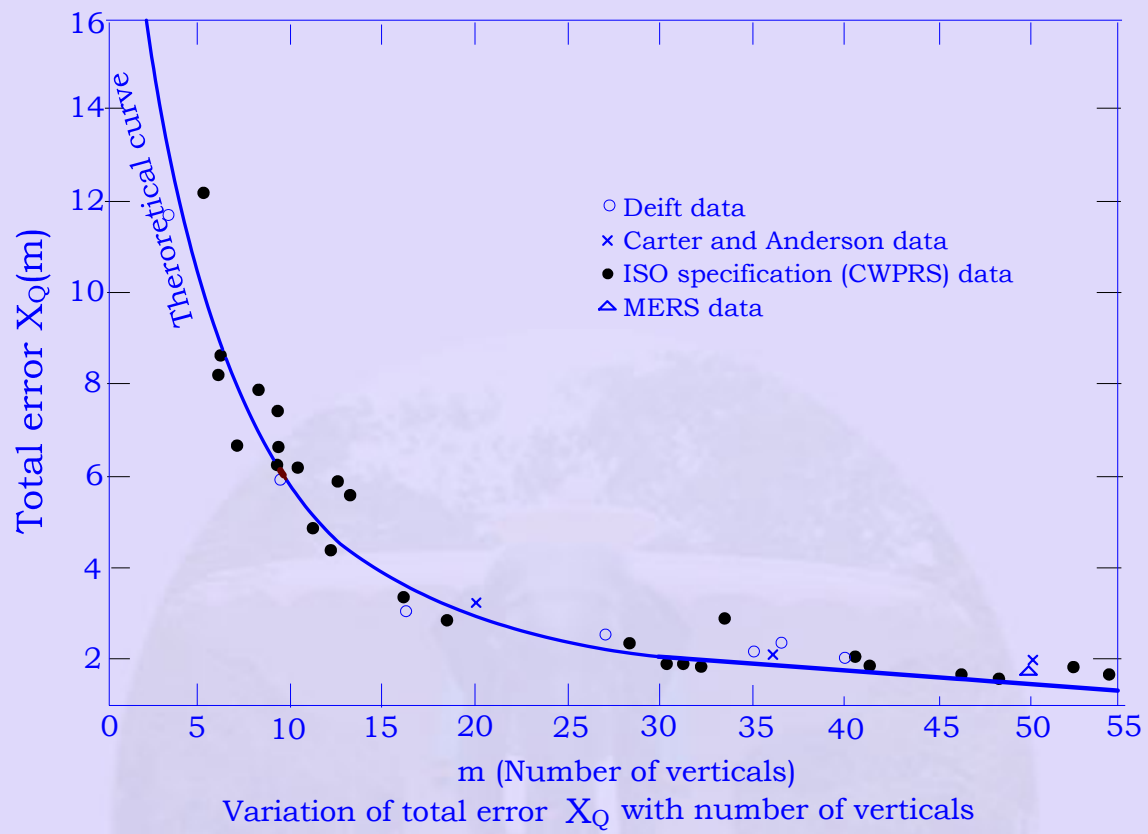
in which, $(\hat{X}_m - \bar{X}_m)$ is the estimate of the error due to reduced number of verticals, relative to the standard discharge.

4.4.11 Total Error X_Q

Total error could be worked out using Equations (9) and (10) for X_v^2 and X_y^2 and the

theoretical value X_m of for respective cases. Experimental data on total error obtained independently by Delft, Carter and Anderson and worked out at CWPRS, Pune using data of Maharashtra with equidistant verticals, are compared. The experimental data conformed closely to the semi-theoretical equation on total error obtained at CWPRS. Area velocity method results in biased estimation of the discharge which is in agreement with the findings of Delft and Dickinson. Theoretical mean bias, i.e., systematic error could be estimated as a function of the number of verticals or mean

width of the equidistant segments. Theoretical mean bias has been found to be close to independently observed data of Delft, Carter and Anderson and CWPRS.



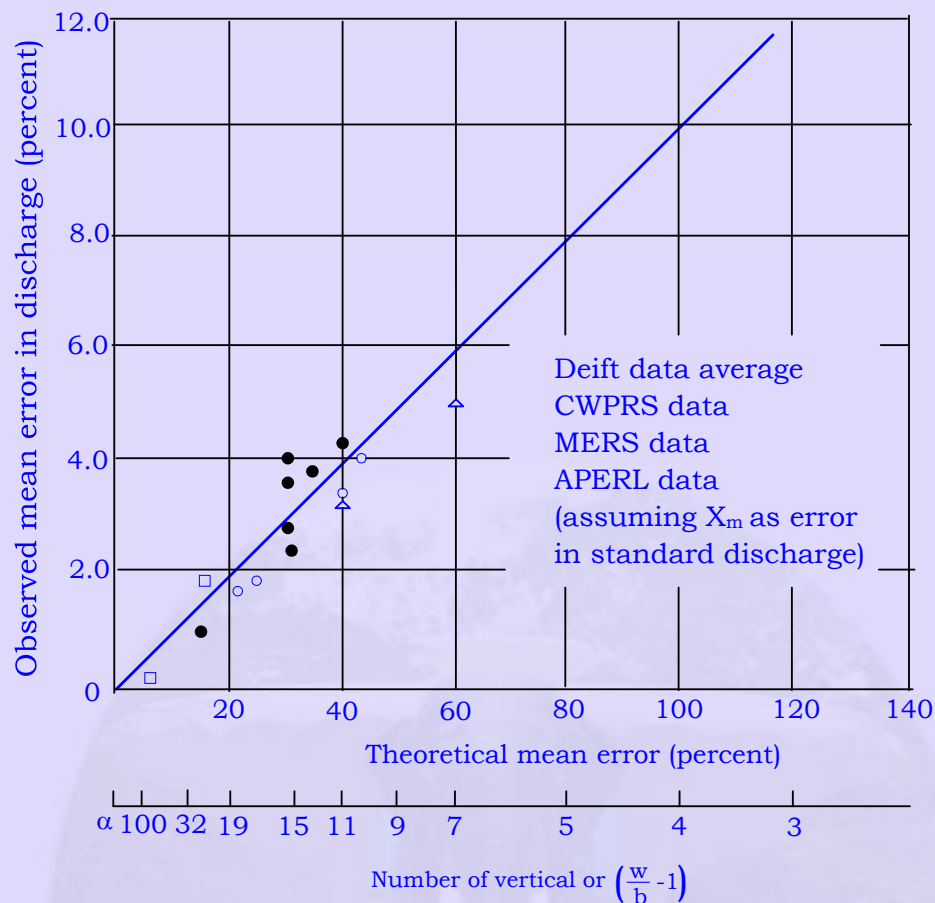


Figure showing the variation of mean observed error against theoretical error

The above method is applicable subject to following limitations:

- Above method is applicable subject to the data are free from systematic errors in observations. If data are expected to contain errors which are systematic in nature, while estimating the total error, the amount of systematic error entering into observations as per standard formula of root mean error is to be accounted.
- For computation of random error due to sources, velocity and depth, attempt should be made to compute them by using ISO/BIS formulae. When repetitive observations are not available then only the error may be worked out for actual deployment.
- When no observational data are available the empirical formulae (9) and (10) may be used for determining the approximate total error in discharge measured with finite number of verticals spaced nearly equidistant. This assumes that channel is straight and has got characteristics similar to canals whose data have been used in evolving the above formulae.

(d) The value of X_m could be obtained from [figure](#) for a given number of verticals with equal spacing. The formula $\frac{50b}{W}$ could be used only when end segment spacings are nearly equal. For completely unsymmetrical deployment this formula cannot be used.

4.4.12 Error in Area Measurements

As often contemplated, the error in estimation of area contributes the major source of error in this discharge estimation by area velocity method.

The total error in area can be obtained using

$$X_A = \sqrt{\left(\frac{50b}{W}\right)^2 + \frac{1}{m}\left(X_{\frac{2}{y}}\right)}$$

Since the systematic error ($50b/W$) is dominant one in X_A appreciable error reduction is possible if number of sounding verticals are more than the velocity verticals. But the gain in accuracy is not possible if area velocity method is used, since this method uses the information on the same number of depth verticals which are having velocity measurements to obtain q_i 's. Moreover, in view of systematic error due to discrete number of verticals being estimated precisely, there is no need for increasing the sound verticals, since with the same number of 'm' verticals the correction in discharge could be made to gain the accuracy equivalent to very large number of sounding verticals, made use for minimizing X_A .

4.4.13 Optimum Deployment

The Bureau of Indian Standard has laid down that the segmentation for measurement of depth in channels having different widths would be as given in Table.

Sl.No	Description	No. of verticals in a cross-section	Maximum space of verticals in m
1	Width of channel not exceeding 15 m where the river bed changes abruptly	15	1.5
2	Width of channel from 15 to 90 m	15	6.0
3	Width of channel from 90 to 180 m	15	15
4	Width of channels greater than 180 m	25	-

The spacing of verticals required a variation in discharge between adjacent segments not to exceed by 4 to 10 percent, preferably the smaller. It further stipulated discharge through any segment not to exceed 10 percent of the total discharge. For making velocity observations the maximum spacing of verticals has been so specified that the mean velocities on the adjacent vertical would not differ by 20 percent with respect to higher values of the two. In no case there could be less than five verticals. These specifications are for natural streams like rivers, drainage channels, etc.

Closer the interval of verticals, the more accurate will be the calculated discharge. Moreover, allowing a variation of ± 2 percent in discharge and adopting 15 verticals as standard of comparison a lesser number of verticals than 15 was recommended for adopting so as to enable a discharge observation to be completed in a working day of 6 to 8 hours. The criterion recommended for the number of depth and velocity verticals of

Channels of various capacities has been indicated in Table.

Sl.No	Channel capacity m^3s^{-1}	Approximate surface width (m)	No. of verticals for depth and velocity
1	Above 85	Above 35	11
2	Between 15 - 85	Between 15 - 35	9
3	Between 0 - 15	Between 0 - 15	5

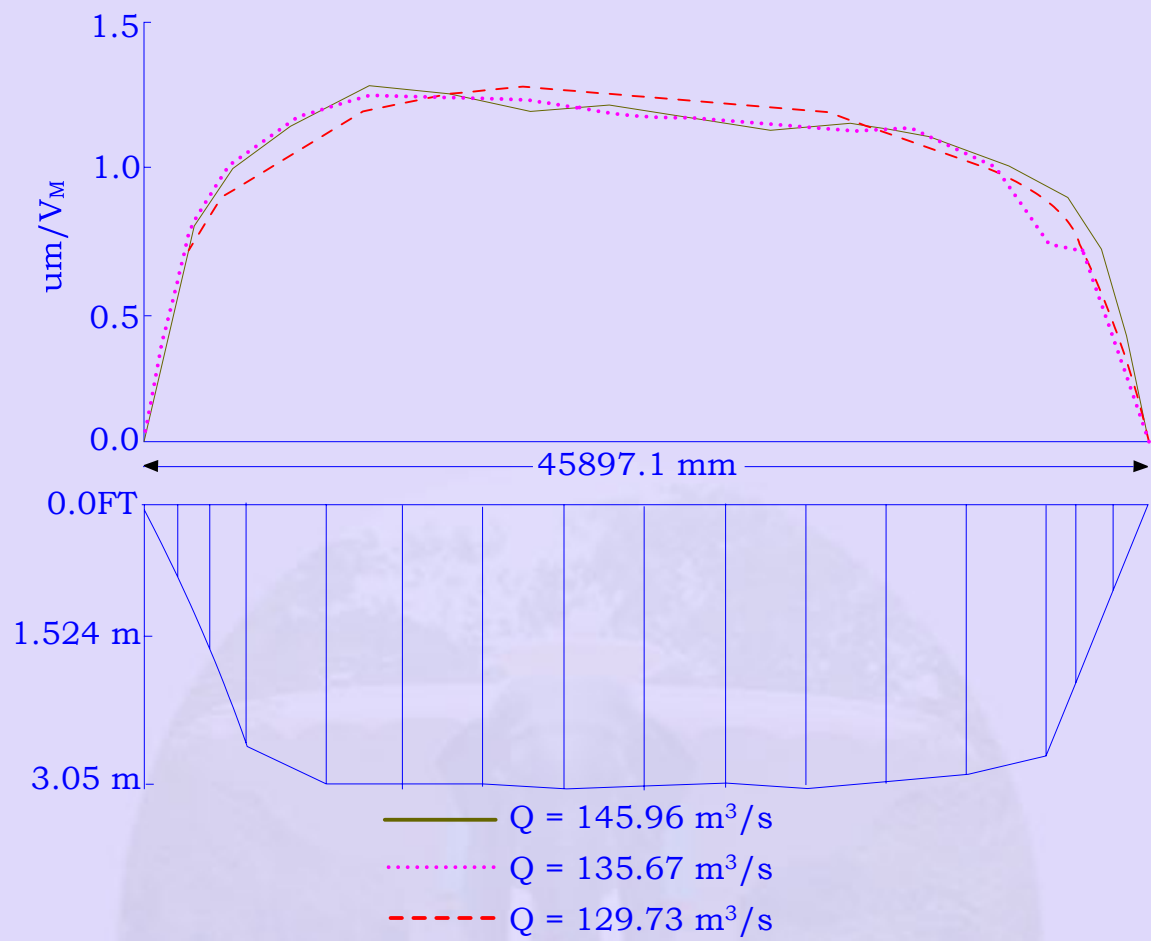
It was also recommended to increase the number of depth verticals to have a better appraisal of the cross sections of the channel in regard to its trend of silting or scouring.

If it is desired to determine the errors in discharge with 15 verticals, and also to determine the minimum number of verticals for measurement of canal discharge in order to restrict this error to ± 2 percent, more number of depth and velocity verticals should be observed.

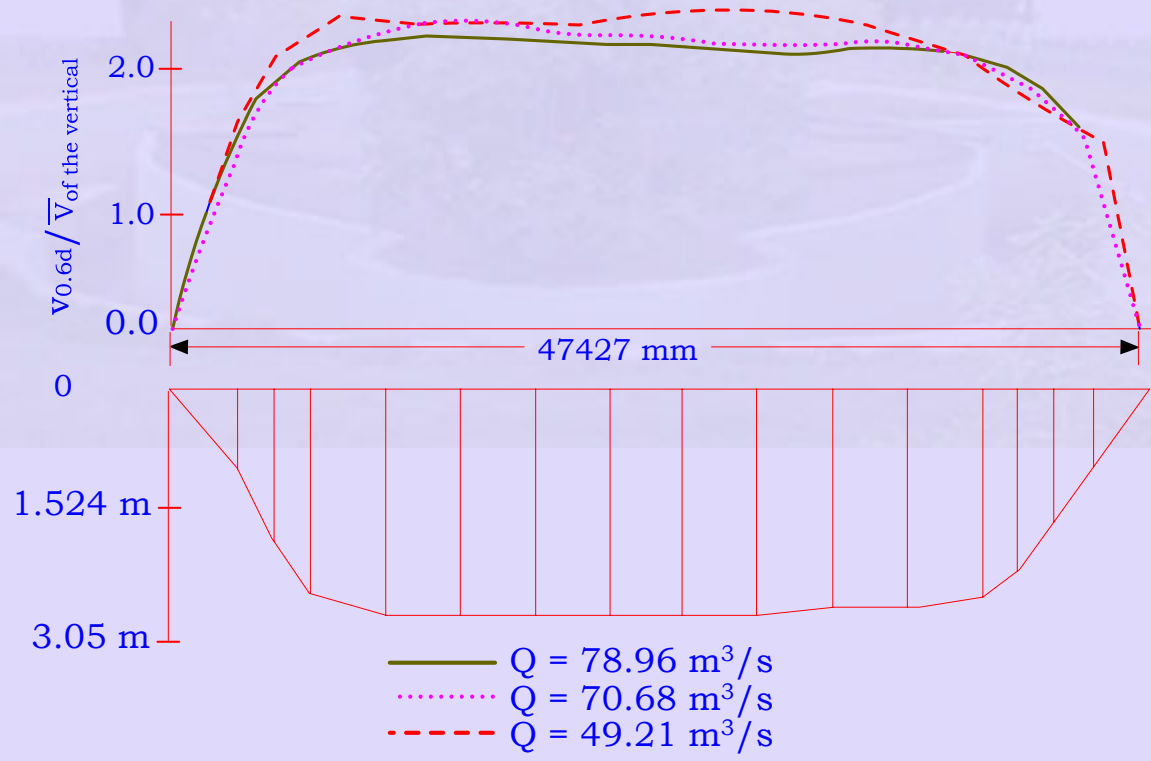
Total errors in CBI&P deployment for different ranges of discharge varies from ± 3.9 percent for 11 verticals to ± 8.10 percent for 5 verticals.

If discharge with 50 verticals is taken as standard the error in discharge for CBI&P deployment would be of the order of ± 2.75 percent, ± 3.5 percent and 6.7 percent for the number of verticals 11, 9 and 5 respectively. Since intrinsic error in discharge due to number of verticals, measured with 15 vertical works out to be of the order of +3 percent, the CBI&P deployments for different ranges of discharge with less than ± 2 percent error, investigated earlier in fact leads to total intrinsic error, systematic in nature of the order of +5 percent. With the knowledge of the systematic error in CBI&P deployment, the necessary correction could be made to get unbiased estimate of true discharge.

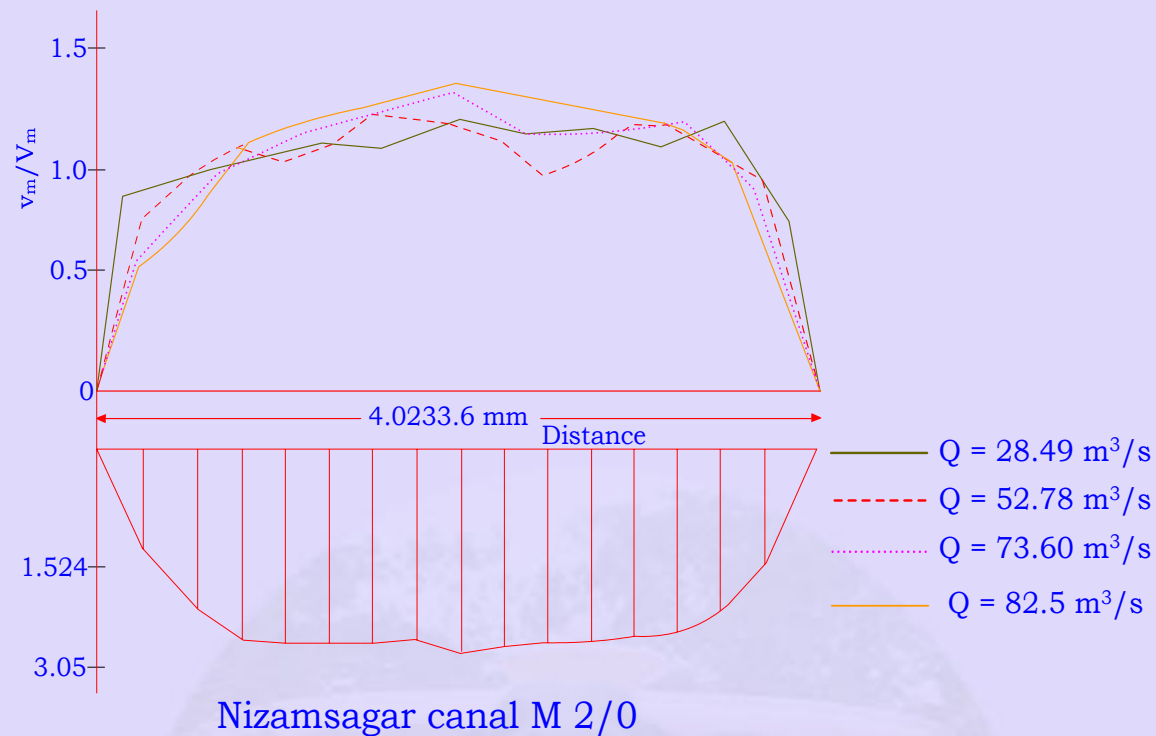
The data obtained from the Godavari Canals and the K.C. Canal were analyzed and it was found that for the range of discharges between $14 \text{ m}^3/\text{s}$ to $85 \text{ m}^3/\text{s}$, 5 or 7 verticals gave discharge values within a range of $\pm 5\%$ error, as compared to 15 verticals. For $85 \text{ m}^3/\text{s}$ to $225 \text{ m}^3/\text{s}$ range, with 9 verticals, the deployment being four verticals at either ends upto quarter length and a central vertical, discharges which were within and error of $\pm 4\%$ were obtained.



Godavari Western Main Canal - Mile 5/2



Godavari Western Main Canal - Mile 5/2



4.4.14 A note on the Optimum number of verticals to ensure required accuracy in current meter gauging

Instructions regarding the choice of number of verticals for current meter gauging have been drawn up by i) the I.S.I. ii) the C.B.I.P and iii) the C.W.P.R.S. The objective of these instructions is to ensure that the order of accuracy attainable by following these instructions is 2%.

The first point that attracts attention as for as the recommendations of the various authorities is the relative importance of a vertical and its spacing according as it is used for measurement of velocity or depth, the latter being intended to enable the measurement of area.

While the C.B.I.P. appears to imply that the number of verticals and their deployment recommended applies to the measurement of both depth and velocity, the C.W.P.R.S. is categorical that depth measurement is essential on verticals spaced at 60 cm intervals irrespective of the requirement of the verticals for velocity observations. The I.S.I. on the other hand bases its recommendation for the number of verticals for depth measurement on the criterion of variation of area from segment to segment and for velocity measurement on the criterion of variation of mean velocity on a vertical to the

mean velocity on an adjacent vertical. In all these cases the requirement implied appears to be a determination of such spacing wherein the variation is gradual and unidirectional. In an artificial channel where essentially uniform and stable conditions of flow may be expected, the elaborate requirement of the I.S.I. which included primarily stream gauging in its scope may be neither be necessary nor desirable.

Figures indicate the velocity measurement details for Nizamsagar canal, Godavari central main canal and Godavari western main canal for a wide range of discharge ($28.49 \text{ m}^3/\text{s}$ to $145.96 \text{ m}^3/\text{s}$). The velocity in plan is normalized with respect to mean value obtained at 0.6 times at the depth to the mean value at the vertical.

Reference:

Central Board of Irrigation and Power- Problem No. 4 APERI design of channels 1978.

