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Liquid flow measurement in open channels — Velocity-area methods

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up has the right to be represented on that Committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

Prior to 1972, the results of the work of the Technical Committees were published as ISO Recommendations; these documents are now in the process of being transformed into International Standards. As part of this process, International Standard ISO 748 replaces ISO Recommendation R 748-1968, drawn up by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

The Member Bodies of the following countries approved the Recommendation :

Argentina	Greece	New Zealand
Belgium	India	Romania
Brazil	Ireland	South Africa, Rep. of
Canada	Israel	Switzerland
Chile	Italy	Turkey
Czechoslovakia	Japan	United Kingdom
France	Korea, Rep. of	
Germany	Netherlands	

No Member Body expressed disapproval of the Recommendation.

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Liquid flow measurement in open channels — Velocity-area methods

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies methods for determining the velocity and cross-sectional area of water flowing in open channels, and of computing the discharge therefrom.

It covers methods of employing current-meters and floats to measure the velocities. Although, in most cases, these measurements are intended to determine the stage-discharge relationship by means of readings at several stages, this International Standard deals only with single measurements of the discharge; the continuous recording of discharges over a period of time will be covered in a separate International Standard.

NOTE — Measurements for the purpose of determining the discharge in efficiency tests of hydraulic turbines are specified in IEC Publication 41, *International code for the field acceptance tests of hydraulic turbines.*

2 TERMINOLOGY

For the purposes of this International Standard, the definitions given in ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols,* apply.

3 UNITS OF MEASUREMENT

The units of measurement used in this International Standard are seconds, metres (or feet), kilograms and degrees Celsius (or Fahrenheit).

4 PRINCIPLE OF THE METHODS OF MEASUREMENT

4.1 The principle of these methods consists in effectively measuring the flow velocity and cross-sectional area. A gauging-site is chosen conforming to the specified requirements; the width is measured either by means of a steel tape or by some other surveying method, depending on its magnitude, and the depth is measured at a number of verticals along the width, sufficient to determine the shape and area of cross-section.

Velocity observations are made at the same time as measurement of depth, especially in the case of unstable beds; they are made by any one of the standard methods by the use of current-meters, the principle of which is based on the proportionality between the local flow velocity and the speed of the rotor. Velocity observations are also made by the use of surface-floats and velocity-rods under certain circumstances. From the individual observations the mean velocity is generally computed; however, in certain methods such as the integration method, the mean velocity is directly obtained.

4.2 The discharge is computed by summing the products, either arithmetically or graphically, of the velocity and corresponding area for a series of observations in a cross-section.

5 SELECTION AND DEMARCATION OF SITE

5.1 Initial survey of site

It is desirable that approximate measurements of widths, depths and velocities should be made in a preliminary survey to decide on the suitability of a site conforming as far as possible with the conditions given in 5.2. It is only intended that these measurements should serve as a guide that both the longitudinal and transverse bed profiles and the velocity distribution are acceptable for the purpose of discharge measurement.

5.2 Selection of site

The accuracy of the determination of the discharge by the velocity-area method is increased if

a) the conditions of flow do not change within the period of measurement;

b) the velocities at all points are parallel to one another and at right angles to the measuring cross-section;

c) the curves of the distribution of the velocities are regular in the vertical and horizontal planes on which they are measured;

d) the geometrical dimensions of the cross-section of the open channel are clearly defined.

Hence, the most favourable conditions for accurate measurements are to be found where the cross-section is in a straight reach. On this basis, therefore, the site shall be selected such that, as far as possible, the requirements and points given in 5.2.1 and 5.2.2 are met.

5.2.1 The site selected shall comply, as far as possible, with the following requirements :

a) the open channel at the gauging-site shall be straight and of uniform cross-section and slope, as far as possible, in order to avoid an abnormal velocity distribution. When the length of the straight channel is restricted, it is recommended for current-meter measurements that the straight length upstream of the measuring cross-section should be twice that downstream;

b) the depth of water in the selected reach shall be sufficient to provide for the effective immersion of either the current-meters or floats, whichever are to be used;

c) the view of the gauging-site shall be clear and unobstructed by trees or other obstacles.

5.2.2 In addition to the requirements specified in 5.2.1, the following points shall be taken into consideration when selecting the gauging-site :

a) the bed of the reach shall not be subject to changes during the period of measurement;

b) irrespective of the flow, all discharges shall be contained within a defined channel or channels, or within an unobstructed floodway having substantially stable boundaries, with well-defined geometrical dimensions;

c) the site shall be remote from any bend or natural or artificial obstruction if disturbance of the flow is likely to be caused thereby;

d) the gauging-site shall be kept clear of aquatic growth during the period of measurement;

e) sites at which vortices, backward flow, or dead zones tend to develop shall be avoided;

f) measurement with converging, and more so with diverging, flow over an oblique measuring-section shall be avoided as it is difficult to allow for the systematic errors that can arise;

g) the orientation of the reach shall be such that the direction of flow is as closely as possible normal to that of the prevailing wind.

Where these requirements cannot be met (for instance, when in alluvial rivers the river-bed is changing during the period of measurement, or when, under flood conditions, the river is not confined to a single channel in embankments), a gauging-site shall be chosen such that the bed change and/or overflow is a minimum. Flood-plains — if they cannot be avoided — shall be of minimum width, as smooth as possible, without a distinct channel, and clear of bushes and trees.

In those instances where it is necessary to make measurements in the neighbourhood of a bridge, it is preferable that the gauging-site should be upstream of the bridge. However, in special cases and where accumulation of ice, logs or debris is liable to occur, it is preferable that the gauging-gite should be downstream of the bridge.

NOTE — If, after the site has been selected, unacceptable changes occur in the channel conditions, another site shall be selected for the measurements.

5.3 Demarcation of site

The site, after selection, shall be provided with means for demarcation of the cross-section and for determination of the stage.

5.3.1 The position of each cross-section, normal to the mean direction of flow, shall be defined on the two banks by clearly visible and readily identifiable markers.

5.3.2 The stage shall be read from a gauge at intervals throughout the period of measurement and the gauge datum shall be related by precise levelling to a standard system of levels.

5.3.3 An auxiliary gauge on the opposite bank shall be installed where there is likelihood of a difference in the level of water-surface between the two banks. This is particularly important in the case of very wide rivers. The mean of the meaurements taken from the two gauges shall be used as the mean level of the water-surface and as a base for the cross-sectional profile of the stream.

6 MEASUREMENT OF CROSS-SECTIONAL AREA

The cross-sectional profile of the open channel at the gauging-site shall be determined by measuring, at the cross-section, the depth relative to the water-surface at a sufficient number of points to establish the shape of the bed.

The location of these points shall be determined by measuring their horizontal distance to a fixed reference point in the cross-section. In practice, these measurements determine the cross-sectional area of the individual segments between successive verticals where velocities are measured.

6.1 Measurement of widths

The measurements of the width of the channel and the widths of the individual segments may be obtained by measuring the distances from or to a fixed reference point which shall be in the same plane as the cross-section at the gauging-site.

6.1.1 Where the width of the channel permits, or when the surface is covered by ice, these distances shall be measured by direct means, for example a steel tape or suitable marked wire, care being taken to apply the necessary corrections given in Annex A. The intervals between the verticals, i.e. the widths of the segments, shall be similarly measured.

6.1.2 Where the channel is too wide for the above methods of measurement, the distances shall be determined by optical or electrical distance-meters, or by one of the surveying methods given in Annex B.

6.2 Measurement of depth

6.2.1 Measurements of depth shall be made at intervals close enough to define the cross-sectional profile accurately. In general, the intervals shall not be greater than 1/15 of the width in the case of regular bed profiles, and shall not be greater than 1/20 of the width in the case of irregular bed profiles.

NOTE — For small channels with a regular bed profile, the number of intervals may be reduced. This may, however, affect the accuracy of the determination of the bed profile (see section 9).

6.2.2 The depth shall be measured employing either sounding-rods or sounding-lines, or other suitable devices. Where the channel is of sufficient depth, an echo-sounder may be used. If the velocity is high, it is preferable to use an echo-sounder or other device which will not require large corrections.

NOTE — When measuring the depth under an ice-cover on the water, it is necessary to determine the space, if any, between the water-surface and the underside of the ice by using special devices such as L-shaped scales. If there is a layer of frazil ice, its thickness shall also be determined.

6.2.3 When a sounding-rod or sounding-line is used, at least two readings shall be taken at each point and the mean value adopted for calculations, unless the difference between the two values is more than 5 %, in which case two further readings shall be taken. If these are within 5 %, they shall be accepted for the measurement and the two earlier readings discarded. If they are again different by more than 5 %, no further readings shall be taken, but the average of all four readings shall be adopted for the measurement, noting that the accuracy of this measurement is reduced.

When an echo-sounder is used, the average of several readings should preferably always be taken at each point, but regular calibrations of the instrument are required under the same conditions of salinity and temperature of the water.

Where it is impracticable to take more than one reading of the depth, the error in measurement may be increased (see section 9).

NOTES

1 Where measurements of the depths are made separately from the velocity measurements and the water-level is not steady, it shall be observed at the time of each measurement of depth. If this is not possible, the water-level shall be observed at intervals of 15 min and the value of the level at the time of each determination of depth shall be obtained by interpolation.

2 If the bed is composed of unstable material (shifting sand, silt), repeated measurements by a rod or line of the depth at one point are not recommended with a view to avoiding disturbance of the bed.

3 When, during the measurement of discharge, the bed profile changes appreciably, depth measurements shall be carried out by taking one reading at each point at the beginning and one at the end of each measurement of velocity verticals, and the mean value of these two measurements shall be taken as the effective depth.

4 Inaccuracies in soundings are most likely to occur

a) owing to the departure from the vertical of the sounding-rod or line, particularly in deep water, when the velocity is high;

b) owing to the penetration of the bed by the sounding-lead or rod;

c) owing to the nature of the bed when an echo-sounder is used.

Difficulties due to a) may be avoided by the use, where practicable, of an echo-sounder, or pressure-measuring device. The effects of drag on a sounding-line may be reduced by using a streamlined lead weight at the end of a fine wire. A correction shall be applied to the wetted length of wire if the wire is not normal to the water-surface. It is recommended that the angle should not be greater than 30° in view of the inaccuracies involved. Methods of applying the correction are given in Annex C.

Difficulties due to b) may be overcome by fitting a baseplate to the lower end of the sounding-rod, or by fastening a disk to the end of the sounding-line, when they will not cause scour of fine bed material due to high velocities.

5 In certain cases, for example floods, it may be impossible to determine an adequate profile of cross-section during the measurement. For those cases, the full profile shall be determined by surveying methods, either before or after the measurement; however, it should be recognized that this method is subject to errors due to possible erosions or deposits in the cross-section between the time the profile is determined and the time of measurement.

7 MEASUREMENT OF VELOCITY

7.1 Measurement of velocity using current-meter

7.1.1 *Calibration of current-meter*

The current-meters shall be individually rated to cover the range of velocities of the flow in the channel, taking care that the calibration is carried out under similar conditions of suspension to those used during the discharge measurement. If an individual calibration is not possible, a mean rating, determined from a number of current-meters of the same type, may be adopted, but particular regard shall then be paid to the question of the tolerance to be used in the estimation of errors.

NOTE — The rating of the current-meter can be effected by drawing it through still water and noting the angular velocity of the rotor of the current-meter for known speeds of the carriage. The rating of the meter shall be checked by repetition of the rating operation or by comparison with a standard current-meter at sufficiently frequent intervals to ensure that the rating has not changed.

7.1.1.1 The current-meter shall be kept in good condition by thorough cleaning after each use, and by timely replacement of all worn or damaged parts. Where important parts are replaced, recalibration of the current-meters is necessary.

7.1.1.2 Cup-type meters shall be tested by the "spin test" as specified by the manufacturer, before and after each use. The bucket-wheel shall come to rest slowly and evenly and shall revolve throughout in the same horizontal plane. Propeller-type current-meters shall be tested before and after each use, as specified by the manufacturer; it may be useful to check, with the help of moulds or metal calipers, that the propellers have not become deformed since their calibration.

7.1.2 *Measuring procedure*

Velocity observations are normally made at the same time as measurements of the depth. This method shall be used in the case of unstable beds. Where, however, the two measurements are made at different times, the velocity observations shall be taken at a sufficient number of places, ordinarily in fifteen to twenty verticals, and the intervals shall be measured as described in 6.1.1 and 6.1.2.

At least eight verticals shall be used, provided that this does not necessitate the distance between the verticals being less than one diameter of the current-meter rotor. A smaller number of verticals may be used if the width is less than eight diameters of the current meter rotor, or the depth and velocity profile are uniform.

The measuring verticals, as well as the number of observation points on these verticals, shall be chosen such that each measuring-point controls a fairly equal portion of the flow.

NOTE — If conditions arise in which water runs both over and under the ice, the measurement of discharge shall be carried out in the two parts separated by the ice.

7.1.2.1 The current-meter shall be held in the desired position in any vertical by means of a wading-rod in the case of shallow channels, or by suspending it from a cable or rod from a bridge, trolley or boat in the case of deeper channels. When a boat is used, the current-meter shall be held so that it is not affected by disturbances of flow caused by the boat. After the current-meter has been placed at the selected point in the vertical, it shall be permitted to become adjusted to the flow before the readings are started.

NOTES

1 Care shall be taken to ensure that the current-meter observations are not affected by random surface-waves and wind.

2 When a number of segments having sensibly the same flow of water are to be explored, a battery of current-meters fixed to the same rod can be used to measure corresponding velocities simultaneously, ensuring that there is no mutual interference.

3 If there is any appreciable deflection of the cable on which the meter is suspended, a correction shall be applied for the depth of the measuring-point. No generally applicable correction factor can be given, but it shall be determined by the user for his particular instrument and conditions of measurement.

7.1.2.2 The current-meter shall be exposed at each selected point for a minimum of 40 s. If the water velocity is known to be subject to periodic pulsations, it is advisable that the current-meter should be exposed at each selected point for at least three consecutive periods of 1 min, or for periods of sufficient duration to cover at least two periods of the pulsation. The velocity at the point shall then be taken to be the average of all the separate readings, unless it is apparent that the difference is due to some cause other than pulsation of the flow.

7.1.2.3 The current-meter shall be removed from the water at intervals for examination, usually when passing from one vertical to another.

7.1.2.4 More than one current-meter may be used in determining velocities in the individual verticals, different current-meters being used for consecutive verticals. The averaging effect will tend to reduce the systematic error of measurement.

7.1.2.5 In channels where the flow is unsteady, it is useful to correct for the variations in the total discharge during the period of the measurement not only by observing the change in stage, but also by continuously measuring the velocity at some conveniently chosen point. Experience has shown that, provided the variations in the discharge are small, the velocity distribution is not modified significantly. A reference current-meter can be positioned in the main current and the velocity at this point measured, if possible, at the same time as each local point velocity measurement in the cross-section is made. All the individual measurements during the test can then be referred to the corresponding reference reading. The *mean reference velocity,* defined as the average of all the readings of the reference current-meter, can be calculated precisely. Each reading of the local point velocity can then be corrected by multiplying by the ratio of the mean reference velocity to the reference velocity reading at the instant being considered. If the reference current-meter measurements are not made at the same time as the individual measurements, they shall be taken at regular intervals as frequently as possible throughout the measurement and the reference reading appropriate to a local point velocity measurement obtained by interpolation.

7.1.3 *Oblique flow*

If oblique flow is unavoidable, the angle of the direction of the flow to the perpendicular to the cross-section must be measured and the measured velocity corrected. Special instruments have been developed for measuring the angle and velocity at a point simultaneously. Where, however, these are not available and there is insignificant wind, the angle of flow throughout the vertical may be taken to be the same as that observed on the surface. If the channel is very deep, or if the local bed profile is changing rapidly, this assumption shall not be accepted without checking.

If the measured angle to the perpendicular is γ, then

$$v_{\text{corrected}} = v_{\text{measured}} \cos \gamma$$

7.1.4 *Method for mean velocity measurement in each vertical*

The mean velocity of the water in each vertical can be determined by any of the following methods, depending on the time available and having regard to the width and depth of the water, to the bed conditions, and to changing stage and whether there is ice-cover, as well as to the accuracy which is to be obtained.

a) Velocity-distribution method (see 7.1.4.1).

b) Reduced-point methods (see 7.1.4.2).

c) Intergration method (see 7.1.4.3).

d) Other methods (see 7.1.4.4).

In the neighbourhood of the minimum velocity of use, the error in determining the velocity increases appreciably. With normal current-meters, the minimum velocity for reliable measurements is 0,15 m/s. Special current-meters giving reliable measurements below this velocity may be used if they have been tested in this range of velocities for repeatability and accuracy, prior to the measurement.

The horizontal axis of the current-meter shall not be situated at a distance less than one and a half times the rotor height from the water-surface, nor shall it be at a distance less than three times the rotor height from the bottom of the channel. Furthermore, no part of the meter shall break the surface of the water.

When the current-meter is used close to the bed or surface, particularly when there are ripples or waves, additional calibrations shall be made under immersed conditions similar to those encountered during the measurement.

7.1.4.1 VELOCITY-DISTRIBUTION METHOD

The measurement of the mean velocity by this method is obtained from velocity observations made at a number of points along each vertical between the surface of the water and the bed of the channel. The spacing of the points shall be so chosen that the difference of velocity between two adjacent points is not more than 20 % with respect to the higher value of the two. The top and bottom points shall be located respectively near to the water-surface and bed of the channel taking into account the specification of 7.1.4. The velocity observations at each position shall be plotted in graphical form and the mean velocity determined with the aid of a planimeter.

NOTES

1 This method may not be suitable for routine discharge measurements because the apparent gain in precision may be more than offset by errors resulting from change of stage during the long period of time needed for making the measurement.

2 The velocity curve can be extrapolated from the last measuring point to the bed or wall by calculating v_x from the equation

$$v_x = v_a \left(\frac{x}{a}\right)^{\frac{1}{m}}$$

where

v_x is the point velocity in the extrapolated zone at a distance x from the bed;

v_a is the velocity at the last measuring point at a distance a from the bed.

The mean velocity $\bar{v}_x$ between the bottom (or a vertical side) of the channel and the nearest point of measurement (where the measured velocity is v_a) can be calculated directly from the equation

$$\bar{v}_x = \frac{m}{m+1} v_a$$

Generally, m varies between 5 (for coarse sides) and 7 (for smooth sides).

3 An alternative method of obtaining the velocity in the region beyond the last measuring-point is based on the assumption that the velocity for some distance up from the bed of the channel is proportional to the logarithm of the distance x from that boundary. If the observed velocities at points approaching the bed are plotted against log x, then the best-fitting straight line through these points can be extended to the boundary. The velocities close to the boundary can then be read from the graph.

7.1.4.2 REDUCED-POINT METHODS

a) Two-point method

Velocity observations shall be made at each vertical by exposing the current-meter at 0,2 and 0,8 of the depth below the surface. The average of the two values shall be taken as the mean velocity in the vertical.

NOTE — This method is applicable without correction for depths greater than 1 m (3 ft) where measurements are made under ice-cover.

b) One-point method

Velocity observations shall be made at each vertical by exposing the current-meter at 0,6 of the depth below the surface. The value observed shall be taken as the mean velocity in the vertical.

NOTE — This method is applicable with correction for depths shallower than 1 m (3 ft) where measurements are made under ice-cover, the correction factor being taken as 0,92.

7.1.4.3 INTEGRATION METHOD

In this method, the current-meter is lowered and raised through the entire depth at each vertical at a uniform rate. The speed at which the meter is lowered or raised shall not be more than 5 % of the mean velocity of flow in the cross-section, and in any case it shall not be greater than 0,04 m/s (approximately 0,1 ft/s). Two complete cycles are made in each vertical and, if the results differ by more than 10 %, the measurement is repeated.

For calculating the mean velocity in the vertical, the average number of revolutions per second is determined and this is incorporated in the formula for the current-meter calibration coefficient. The error introduced by using the normal meter calibration coefficient for measurement near the bed of the channel is not significant, provided that the current-meter is not allowed to remain in its lowest position for any appreciable length of time. This method is only used in water having a depth greater than 1 m (3 ft).

7.1.4.4 OTHER METHODS

a) Six-point method

This method may be used in difficult conditions, for instance where there is aquatic growth or where there is a covering of ice. Velocity observations are made by exposing the current-meter on each vertical at 0,2 – 0,4 – 0,6 and 0,8 of the depth below the surface and as near as possible to the surface and the bottom according to the requirements of 7.1.4. The velocity observations at each position are plotted in graphical form and the mean velocity determined with the aid of a planimeter.

Alternatively, the mean velocity may be found algebraically from the equation

$$\bar{v} = 0{,}1\,(v_{surface} + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 2v_{0,8} + v_{bed})$$

b) Five-point method

When the channel is free from ice and aquatic growth, a reduced-point method is to measure on each vertical at 0,2 – 0,6 and 0,8 of the depth below the surface and as near as possible to the surface and the bottom. The mean velocity may be determined from a graphical plot of the velocity profile with a planimeter, or from the equation

$$\bar{v} = 0{,}1\,(v_{surface} + 3v_{0,2} + 3v_{0,6} + 2v_{0,8} + v_{bed})$$

c) Three-point method

Velocity observations are made by exposing the current-meter at each vertical at 0,2 – 0,6 and 0,8 of the depth below the surface. The average of the three values may be taken as the mean velocity in the vertical.

Alternatively, the 0,6 measurement may be weighted and the mean velocity obtained from the equation

$$\bar{v} = 0{,}25\,(v_{0,2} + 2v_{0,6} + v_{0,8})$$

When there is a covering of ice, measurements may be made at 0,15 – 0,5 and 0,85 of the depth below the surface, and the mean velocity obtained as the average of these measurements.

d) Alternative one-point method

Velocity observations shall be made at each vertical by exposing the current-meter at 0,5 of the depth below the surface. The values observed, multiplied by a coefficient, shall be taken as the mean velocity in the vertical. This coefficient shall be verified by analysis using the velocity-distribution method, but is approximately 0,95.

NOTE — This method is applicable with correction for depths shallower than 1 m (3 ft) where measurements are made under ice-cover, the correction factor being taken as 0,88.

e) Surface one-point method

In flashy or other conditions where the above methods are not feasible, velocity shall be measured at one point just below the surface. The depth of submergence of the current-meter shall be uniform over all the verticals, and care shall be taken to ensure that the current-meter observations are not affected by random surface-waves and wind. This "surface" velocity may be converted to the mean velocity in the vertical by multiplying it by a predetermined coefficient.

The coefficient shall be computed for all stages by correlating the "surface" velocity with the velocity at 0,6 depth or, where greater accuracy is desired, with the mean velocity obtained by the integration method.

Where it is not possible to check the coefficient directly, it may be noted for guidance that, in general, the coefficient varies between 0,84 and 0,90 depending upon the shape of the velocity profile, The higher values between 0,88 and 0,90 are usually obtained when the bed is smooth but values outside this range may occur under special conditions.

7.1.5 *Errors and limitations*

Estimates of the possible errors that may occur when using the various methods detailed in 7.1.4 are given in section 9. It should be noted that these estimates are of possible random errors which may occur even when all the precautions noted earlier and below are observed. If the measurement is not made under these best conditions, an additional tolerance must be included when estimating the overall accuracy of the measurement.

Errors may arise

a) if the flow is unsteady and if material in suspension interferes with the rotation of the current-meter;

b) if the direction of flow is not parallel to the axis of the propeller-type current-meter, or is oblique to the plane of the cup-type meter, and if the appropriate correction factors are not known accurately;

c) if the current-meter is used for measurement of velocity outside the range established by the calibration;

d) if the set-up for measurement (such as rods or cable suspending the current-meter, the boat, etc.) is different from that used during the calibration of the current-meter, in which case a systematic error may be introduced;

e) if there is a significant disturbance of the water-surface by wind;

f) if the current-meter is not held steadily in the correct place during the measurement, which is the case when the boat is drifting (see Annex D), or when an oscillating transverse movement occurs. In the latter case, the resultant of the flow velocity and the transverse velocity is measured, which at high transverse velocities gives rise to serious positive errors.

7.2 Measurement of velocity using floats

This method shall only be used when it is impossible to employ a current-meter because of excessive velocities and depths, or because of the presence of material in suspension, or where velocities are too low for current-meter measurement.

7.2.1 *Selection of site*

Three cross-sections shall be selected along the reach of the channel as described in section 5, at the beginning, midway and at the end of the reach. The cross-sections shall be far enough apart for the time which the floats take to pass from one cross-section to the next to be measured accurately. The midway cross-section shall be used only for the purposes of checking the velocity measurement between the cross-sections at the beginning and the end of the reach. A minimum duration of float movement of 20 s is recommended.

7.2.2 *Measuring procedure*

The float shall be released far enough above the upper cross-section to attain a constant velocity before reaching the first cross-section. The time at which the float passes each of the three cross-sections is then noted. This procedure shall be repeated with the floats at various distances from the bank of the river. The distances of the float from the bank as it passes each cross-section may be determined by suitable optical means, for example, a theodolite.

Increasing the number of floats used to determine the velocity in each segment will improve the accuracy of the measurement.

The width of the channel shall be divided into a certain number of segments of equal width. If, however, the channel is very irregular, each segment shall have approximately the same discharge. The number of segments shall not be less than three, but where possible a minimum of five shall be used, the actual number of segments depending on the time available for these observations at the particular stage of the river.

7.2.3 *Types of float*

The velocity of the water in each segment can be determined by

a) surface-floats;

b) double floats;

c) other types of float.

NOTE – Separately flowing blocks of ice, provided they are small, can be used as surface-floats during ice drifting.

The coefficients for obtaining the mean velocity from the measurements from the various types of floats are given in 7.2.4.

7.2.3.1 Surface-floats

These may be used during floods when velocity measurements are to be made quickly. They shall not be used when their movement is likely to be affected by winds.

7.2.3.2 Double floats

These may be used for measurement of velocities in deep rivers. The sub-surface body may be positioned at 0,6 of the depth below the surface, or at other depths to obtain direct velocity measurements at these depths (for example those given in 7.1.4).

7.2.3.3 Other types of float

Other methods of obtaining the mean velocity in each segment may be used if the bed profile is regular over the measuring reach :

a) Sub-surface floats

These may be used for measurement of velocities in very deep rivers. The length of the sub-surface float, sometimes called the "multiple float", which consists of separate elements suitably attached together to permit flexibility and supported by a surface-float, shall be approximately equal to the water depth, but shall in no case touch the bottom.

b) Velocity-rods

These may be used for measurement of velocities in the case of artificial or other regular channels where the cross-section is uniform, the bed is free from weeds, and the depth of the water is constant. The velocity-rod (sometimes called a float-rod) shall be at leat 0,95 of the depth of the channel but shall not touch the bottom.

7.2.4 *Evaluation of velocity*

The float velocity shall be determined by dividing the distance between the cross-sections by the time taken by the float to travel this distance. Several readings of the float velocities shall be taken and the mean of these readings shall be multiplied by the appropriate coefficient to obtain the mean velocity in the segment. The coefficient derived from current-meter measurements at the site at a stage as near as possible to that during the float measurement may be used for converting the float velocity to mean velocity.

It is evident that this method necessarily gives an approximation to the flow rate.

7.2.4.1 Surface-floats

Where it is not possible to check the coefficient directly, it may be noted for guidance that in general the coefficient of the surface-float varies between 0,84 and 0,90 depending upon the shape of the velocity profile. The higher values are usually obtained when the bed is smooth, but values outside this range may occur under special conditions.

7.2.4.2 Double floats

Where it is not possible to check the coefficient directly, it may be noted for guidance that when the sub-surface body is situated at 0,6 of the depth, the coefficient is approximately equal to 1,0 and at 0,5 of the depth, the coefficient is approximately equal to 0,96.

7.2.4.3 Other types of float

Where a direct check on the coefficient is not possible, it may be noted that the coefficient of sub-surface floats and velocity-rods varies in general over the range 0,8 to 1,0.

7.2.5 *Main sources of error*

Errors may occur during the measurement of discharge by floats and the main sources are listed below. They shall be taken into consideration when estimating the overall error as given in section 9.

Errors may arise

a) if the coefficient from which the mean velocity is obtained from the float velocity is not known accurately;

b) if a limited number of segments is used for the velocity distribution;

c) if a sub-surface float or velocity-rod is used and the depth of the channel is not uniform throughout the measuring-reach;

d) if the float does not travel in the centre of the panel due to oblique currents;

e) if there is wind, but it should be noted that this error is generally negligible in comparison with others listed above.

8 COMPUTATION OF DISCHARGE

8.1 General

The determination of the mean velocity in each vertical has been dealt with in 7.1 and 7.2. In 8.2 and 8.3 the determination of the discharge from current-meter measurements and float measurements is given. The methods of determination by current-meters given in 8.2.1 and 8.2.2 are those most generally used, that given in 8.2.2 being particularly useful for rapid estimations carried out in the field. The methods given in 8.2.3 and 8.2.4 are applicable for special conditions, for example the method given in 8.2.4 is suitable when the channel is of rectangular cross-section.

8.2 Determination of discharge from current-meter measurements

8.2.1 *Graphical method (depth-velocity integration or mid-section method)*

The value of the product of the mean velocity $\bar{v}$ at each vertical and the corresponding depth, i.e. $\bar{v}d$, shall be plotted over the water-surface line and a curve drawn through the $\bar{v}d$ points as shown in Figure 1.

When velocity measurements are not carried out on the same verticals on which the depth measurements are made, the $\bar{v}$ curve shall be plotted across the width of the stream and the value of $\bar{v}$ corresponding to the verticals where depth measurements are made shall be taken for plotting the $\bar{v}d$ curve.

The area enclosed between this $\bar{v}d$ curve and the water-surface line represents the discharge of the cross-section.

8.2.2 *Arithmetical methods*

8.2.2.1 Mean-section method

The cross-section is regarded as being made up of a number of segments, each bounded by two adjacent verticals.

If $\bar{v}_1$ and $\bar{v}_2$ are the mean velocities at the first and second verticals respectively, if d_1 and d_2 are the total depths measured at verticals 1 and 2 respectively, and if b is the horizontal interval between the said verticals, the discharge of segment is taken to be :

$$q = \left(\frac{\bar{v}_1 + \bar{v}_2}{2}\right) \left(\frac{d_1 + d_2}{2}\right) b$$

This is repeated for each segment and the total discharge is obtained by adding the discharge from each segment.

NOTE — The additional discharge in the segments between the bank and vertical 1, and between vertical m and the other bank, can be estimated from the above equation and on the assumption that the velocity and depth at the banks are zero. If, however, this discharge is a significant proportion of the total flow, then the equation given in Note 2 of 7.1.4.1 can be used to obtain the mean velocity in the region of the bank.

8.2.2.2 Mid-section method

Assuming a straight-line variation of $\bar{v}d$, the discharge in each segment shall be computed by multiplying $\bar{v}d$ by the corresponding width measured along the water-surface line. This width shall be taken to be the sum of half the width from the adjacent vertical to the vertical for which $\bar{v}d$ has been calculated plus half the width from this vertical to the corresponding adjacent vertical on the other side. The value for $\bar{v}d$ in the two half-widths next to the banks shall be taken as zero.

8.2.3 *Area-velocity integration method (velocity-contour method)*

Based on the velocity-distribution curves of the verticals, a velocity-distribution diagram for the cross-section (see Figure 2) shall be prepared showing curves of equal velocity. Starting from the maximum, the areas enclosed by the successive equal-velocity curves shall be measured by a planimeter and shall be plotted in another diagram (as shown in Figure 2) with the ordinate indicating the velocity and the abscissa indicating the corresponding area enclosed by the respective velocity curve. The summation of the area enclosed by the velocity-area curves represents the discharge of the cross-section.

8.2.4 *Mean-section method : horizontal planes*

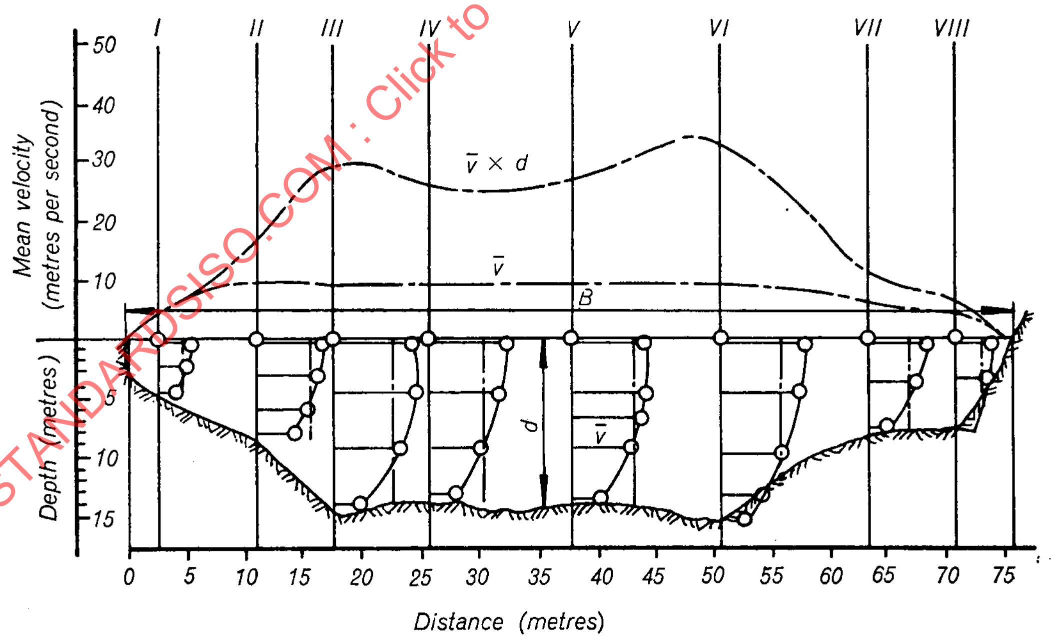
Instead of determining the mean velocity in each vertical, the mean velocities for a number of horizontal planes can be determined by a corresponding procedure to that given in 7.1.4.1. A similar method to that given in 8.2.2.1 can then be used to determine the discharge. The use of horizontal- and vertical-plane computation is particularly suited to measurements in regular-shaped channels as it enables a check to be made on the accuracy of the computations.

8.3 Determination of discharge from surface-float velocity measurements

If the upper and lower cross-sections are plotted as shown in Figure 3, and then divided into a suitable number of equal segments, the cross-sectional area of each of these segements can be determined. Halfway between the two cross-sectional lines, another line (MN in Figure 3) shall be drawn parallel to the cross-sectional lines. The starting and ending points of each float can then be plotted and joined by firm lines, while the surface-points separating the various panels of the two cross-sections can be joined by dotted lines. Where the firm lines cross the line MN, the corresponding mean velocity (float velocity multiplied by the appropriate coefficient) shall be plotted normal to MN and the end points of these velocity vectors joined to form a velocity-distribution curve.

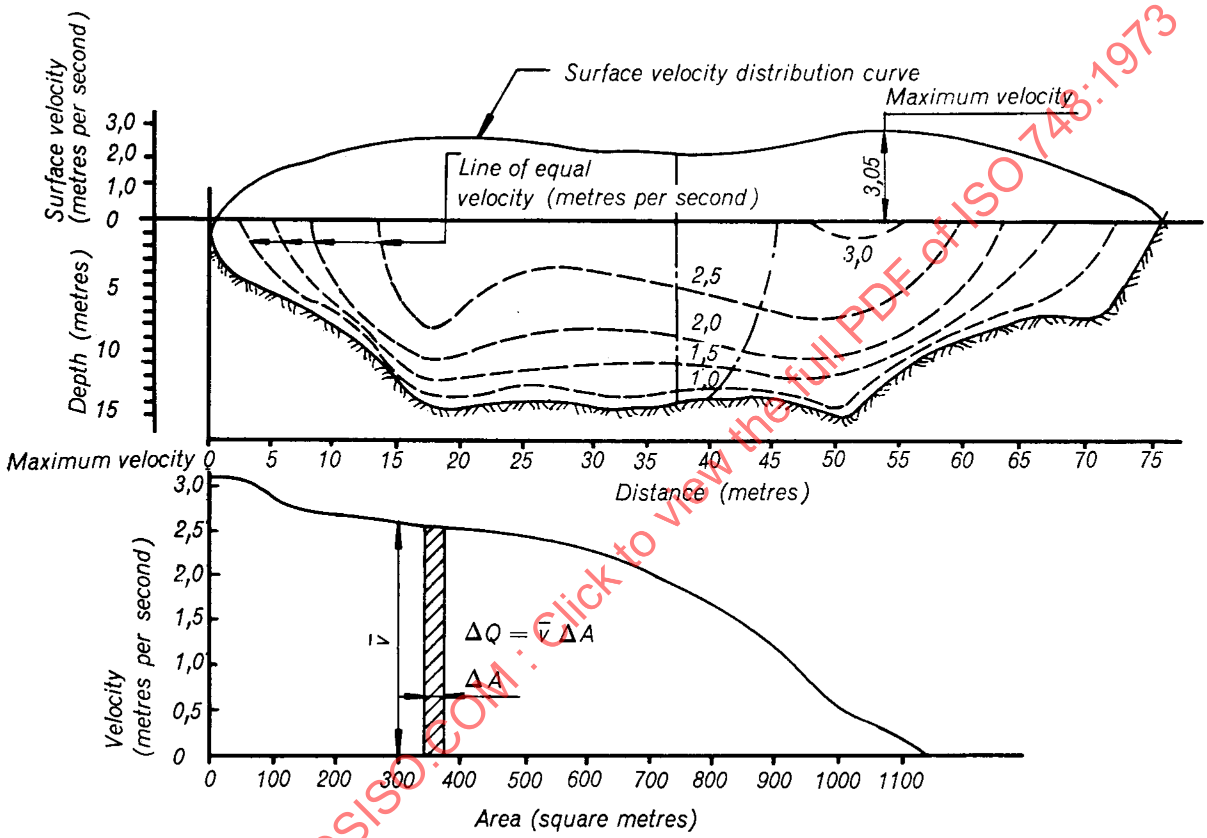
The mean area of corresponding segments of the upper and lower cross-sections, when multiplied by the mean velocity for this panel as shown by the velocity-distribution curve, represents the discharge through that segment. The summation of the discharges for all the segments is equal to the total discharge. The mean velocity in a panel may be determined by measuring by means of a planimeter the area under the velocity-distribution curve for the corresponding segment or, alternatively, an approximate value may be adopted equal to the reading of the velocity halfway across the panel.

NOTE — When it is impossible to obtain satisfactory movement of the floats across the whole width of the river, for instance if the floats move towards the centre line of the flow, a fictitious discharge may be determined by measuring the mean of the surface-velocities. This discharge has then to be multiplied by a coefficient, determined from the results of current-meter measurements carried out at the level which approximates to that of the float measurements.



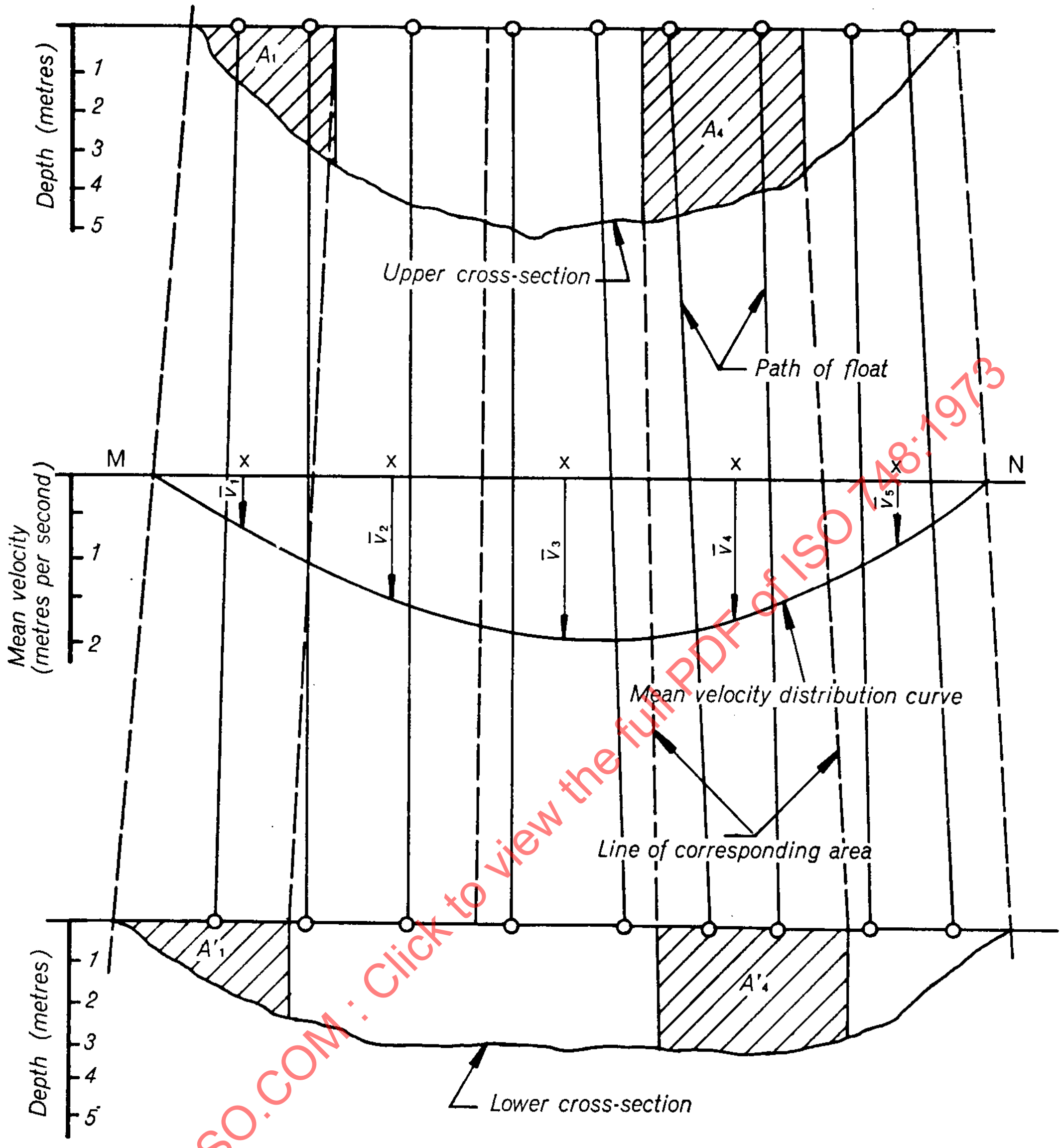
$$Q = \sum_{0}^{B} \bar{v}d \, \Delta B$$

FIGURE 1 — **Computation of discharge from current-meter measurement — Depth-velocity integration method**



$$Q = \sum_{0}^{A} \bar{v} \Delta A$$

FIGURE 2 – **Computation of discharge from current-meter measurements – Area-velocity integration method**



$$Q = \sum_{1}^{m} q = \sum_{1}^{m} \bar{v} \frac{(A + A')}{2}$$

NOTES

1 x indicates the mid-points of the panels in the mid-section.

2 $\bar{v}_1, \bar{v}_2 \ldots \bar{v}_5$ are the mean velocities in each of the five panels.

FIGURE 3 – **Computation of discharge from float measurement**

8.4 Determination of discharge for variations of water-level

If the fluctuation of water-level during the period of velocity measurement is less than 0,05 m (0.15 ft), the mean value shall be adopted for the computation of the discharge. If the fluctuation is more than this amount, then the discharge shall be computed as shown in 8.4.1 and the mean water-level corresponding to this discharge computed as shown in 8.4.2.

8.4.1 *Computation of discharge*

The water-level shall be plotted in steps for each segment as shown in Figure 4, or by a smooth curve, and a curve of mean velocity multiplied by actual depth plotted over the stepped or curved water-surface line. The area enclosed between this curve and the stepped water-surface represents the total discharge.

8.4.2 *Computation of mean water-level*

The mean water-level representative of the discharge measurement shall be computed from the equations

$$\bar{z} = \frac{\Sigma q_i \bar{z}_i}{Q} \quad \text{and} \quad q_i = b_i d_i \bar{v}_i$$

$\bar{z}$ is the mean water-level above the gauge datum;

q_i is the partial discharge in the ith segment;

$\bar{z}_i$ is the mean water-level corresponding to the partial discharge q_i;

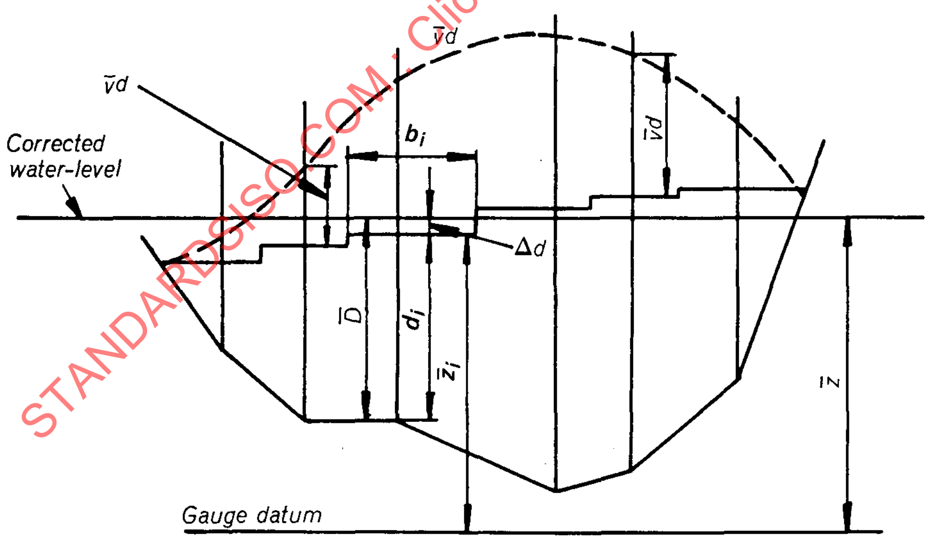
Q is the total discharge and equal to the sum of the partial discharges Σq_i;

b_i is the width of the ith segment;

d_i is the depth of the ith segment;

$\bar{v}_i$ is the mean velocity in the ith segment.

The method is indicated in Figure 4.



$$\bar{z} = \frac{\Sigma q_i \bar{z}_i}{Q}$$

$$q_i = b_i d_i \bar{v}_i$$

FIGURE 4 — **Computation of discharge and mean water-level for variations of water-level**

9 ERRORS OF FLOW MEASUREMENT

In 9.1 below, a general outline of the method of estimating the accuracy of a measurement of the flow is given. The subject is not dealt with in great detail but a simplified approach is presented which makes it possible to calculate the approximate order of the error for any given set of data. In Annex E, the individual components of the overall error are examined and examples of these given. It should not be assumed, however, that these are generally applicable and it should be stressed that the observations on which they are based did not include all kinds and sizes of rivers.

9.1 Method of calculation

9.1.1 *Definition of error*

No measurement of a physical quantity can be free from uncertainties which may be associated with either systematic bias caused by errors in the standardizing equipment of a random scatter caused by a lack of sensitivity of the measuring equipment. The former is unaffected by repeated measurements and can be reduced only if more accurate equipment is used for the measurements. Repetiation does, however, reduce the error caused by random scatter. The precision of the average of m repeated measurement is $\sqrt{m}$ times better than that of any of the points by themselves.

In this section, the estimated errors of the individual components are expressed as, or derived from, standard deviations of the measurements and are combined to obtain the standard error of these components on the whole flow measurement.

When considering the possible uncertainty of any measurement of the discharge in an open channel, it is not possible to predict this uncertainty exactly, but an analysis of the individual measurements which are required to obtain the discharge can be made and a statistical estimate made of the likely "tolerance". A 95 % tolerance on a measurement may be defined statistically as the bandwidth around the calculated value which, on an average of 19 times out of 20, can be expected to include the true value. In case the distribution of the errors is approximately normal, the tolerance can be taken to equal twice the overall standard error of the measurement of flow.

9.1.2 *Sources of error*

The sources of error may be identified by considering a generalized form of the working equation used for gauging by the velocity-area method :

$$Q = \sum_{i=1}^{m} b_i \, d_i \, \bar{v}_i$$

where

Q is the total discharge;

b_i, d_i and $\bar{v}_i$ are the width, depth and mean velocity of the water in the ith of the m verticals or segments into which the cross-section is divided.

The overall error in the discharge is then composed of

a) errors in widths;

b) errors in depths, both of individual soundings and readings of water-level. These shall be determined having regard to 6.2.3;

c) errors in determination of local point velocities. These will depend on the accuracy of the apparatus and the technique employed (see 7.1.1, 7.1.5 and 7.2.5) and on the irregularity of the velocity distribution in time and space;

d) errors in the use of the velocity-area method, particularly those concerned with the number of verticals and the number of points in each vertical. These errors will also depend on the width of the channel, the ratio of width to depth, and the method of computation used.

9.1.3 *Determination of individual components of error*

9.1.3.1 ERRORS IN WIDTH (X_{b_i})

The measurement of the width between verticals is normally based on distance measurements from a reference point on the bank. If the determination is based on the use of a tag-line or measurement of the movement of the wire in the case of a trolley suspension, then the error in the distance measurement is usually negligible. Where optical means are used to determine the distances, the error will depend on the distance measured.

9.1.3.2 ERRORS IN DEPTH (X_{d_i})

The error in depth shall be determined by the user, based on the particular method which has been adopted, with due regard to variations in water-level during the measurement, according to 6.2.3.

9.1.3.3 ERRORS IN DETERMINATION OF LOCAL POINT VELOCITIES (X_v)

The velocity at any point in the cross-section is continuously and randomly fluctuating with time. Hence, a single measurement over a period of any 40 s is one sample which may differ from that found over a very long period. By analysis of a large number of observations at individual points where the time of measurement is varied, the standard deviation X_f can be determined. In practice, it is found that the error is increased when measurements are taken approaching the bed of the channel. As an approximation, if, during the actual measurement of the discharge, the average number of point measurements in the vertical is $\bar{p}$, then the contribution to the standard error $X_{\bar{v}}$ of the mean velocity in the vertical from this source may be calculated from the equation

$$X_{\bar{v}} = \pm\sqrt{\frac{X_f^2}{\bar{p}}}$$

9.1.3.4 ERRORS IN DETERMINATION OF THE MEAN VELOCITY

It is not possible to predict accurately the errors which may arise, but there are two main sources; the first arising from the use of a limited number of points in a vertical, and the second arising from the use of a limited number of verticals. The method of combining errors in the first category with those from 9.1.3.3, where they apply, is given in b) below.

a) Number of points (X_o)

As a general rule, the error decreases as the number of points per vertical increases. It should be noted that, in the case of the integration method, the measurement is continuous and the two sources of error, i.e. for the number of points and the determination of local point velocities (see 9.1.3.3), cannot be separated. The integration method is subject therefore to a single source of error only on this account.

b) Mean velocity in a vertical ($X_{\bar{v}_i}$)

The standard error in the mean velocity determined for each vertical is found by combining the local point velocity error with that for the number of points at which velocity measurements are made. The resulting standard error $X_{\bar{v}_i}$ is given by the equation

$$X_{\bar{v}_i} = \pm \sqrt{X_{\bar{v}}^2 + X_o^2}$$

c) Number of verticals (X_m)

The value of the standard error depends not only on the number of verticals but also on the size and shape of the channel, the variations in the bed profile and the horizontal distribution of the velocity profile. It follows that the value in any particular channel will be peculiar to that channel alone. It can only be determined if the discharge can be measured separately by some more accurate method or if an extensive investigation of the flow at the cross-section of the channel has already been made.

The error from this cause decreases with an increase in the number of verticals.

9.1.4 *Overall error in measurement of discharge*

The total error in the measurement of discharge is the resultant of a number of contributory errors which may themselves be composite errors (for example, the error in the determination of mean velocity in a vertical), and will therefore tend to be normally distributed.

a) Overall random standard error (X'_Q)

If X'_{b_i}, X'_{d_i} and $X'_{\bar{v}_i}$ are the percentage random standard errors in b_i, d_i and $\bar{v}_i$ for each of the m verticals,

X'_Q is the percentage random standard error in the discharge Q,

then

$$X'_Q = \pm \sqrt{X_m^2 + \frac{\sum_1^m (b_i d_i \bar{v}_i)^2 (X'^2_{b_i} + X'^2_{d_i} + X'^2_{\bar{v}_i})}{\left(\sum_1^m b_i d_i \bar{v}_i\right)^2}}$$

where X_m is as defined in 9.1.3.4.

$X'^2_{b_i}$ in this equation is normally negligible in comparison to $X'^2_{d_i}$ and $X'^2_{\bar{v}_i}$.

This equation can be simplified if it is assumed that average values of X'_b, X'_d and $X'_{\bar{v}}$ are taken for all verticals and X'_{b_i} is negligible if the number of verticals is more than ten and particularly if the partial discharges are nearly equal.

With these assumptions, the equation becomes

$$X'_Q = \pm \sqrt{X_m^2 + \frac{1}{m}(X'^2_d + X'^2_{\bar{v}})}$$

b) Overall systematic standard error (X''_Q)

The above equations are satisfactory for estimating the precision of the measurement but do not take account of the possibility of systematic errors. Systematic errors which behave as random errors shall be estimated separately and may be combined as follows :

$$X''_Q = \pm \sqrt{X''^2_b + X''^2_d + X''^2_{\bar{v}}}$$

where X''_b, X''_d and $X''_{\bar{v}}$ are the percentage systematic standard errors in b, d and $\bar{v}$.

The major source of systematic error will arise from errors in the calibration of the current-meter. As a guide, it may be noted that the error in calibration is of the order of ± 0,5 to ± 1 % for an individually rated current-meter. The systematic error in the instruments used for width and depth measurements is usually negligible.

NOTE — $X''_{\bar{v}}$ is the systematic error of an instrument which varies randomly from instrument to instrument and not the systematic error inherent in the type of instrument or measurement which can be eliminated or determined only if a superior instrument of improved method is available.

c) Combined standard error (X_Q)

The overall estimate of the standard error of the discharge will then be

$$X_Q = \pm \sqrt{X'^2_Q + X''^2_Q}$$

This value must be doubled to give the statistical tolerance on the measurement of the discharge as stated in 9.1.1.

Hence, the estimated relative tolerance equals

$$\pm 2 X_Q = \pm 2 \sqrt{X'^2_Q + X''^2_Q}$$

ANNEX A[1)]

METHODS OF CORRECTING FOR SAG, PULL, SLOPE AND TEMPERATURE IN MEASURING THE WIDTH OF THE CROSS-SECTION BY TAPE OR WIRE

A.1 CORRECTION FOR SAG

A.1.1 The correction due to sag of the measuring tape or wire to be applied to the measured length is given by the following formula :

$$k_s = \frac{W^2 l^3}{24 F_T{}^2}$$

where

k_s is the sag correction for length (shortening);

W is the weight of tape or wire per unit length;

l is the actual length of tape or wire which has been previously standardized;

F_T is the total pull applied.

A.1.2 When the tape or wire has been calibrated on the flat, the horizontal distance between the end marks when it is used in catenary are obtained by subtracting the sag correction from the calibrated length on the flat. Similarly, if the tape or wire was calibrated in catenary, the true length on the flat is obtained by adding the catenary correction.

A.1.3 For odd lengths, or lengths differing from that in which the tape or wire was calibrated, the correction for the particular span involved is subtracted from that span to give the corrected horizontal distance if the tape or wire was calibrated on the flat; if it was calibrated in catenary, the correction to be applied is given by the equation

$$k = \left(\frac{x}{l} k_s\right) - k_x$$

where

k is the correction;

x is the length of span involved;

k_s is the sag correction for length l;

k_x is the sag correction for length x.

NOTE — The above correction is positive if x is less than l; it is negative if x is greater than l.

A.2 CORRECTION FOR PULL

A.2.1 If the pull applied to the tape or wire is not the same as that used during calibration, the following correction for pull shall be applied :

$$k_F = \frac{l(F_t - F_l)}{AE}$$

where

k_F is the correction for pull;

l is the actual length of tape or wire;

F_t is the pull at the time of measurement;

F_l is the pull corresponding to l;

A is the area of cross-section of tape or wire;

E is the Young's modulus of the material of the tape or wire.

NOTE — As far as possible, a tape or wire shall be used under the same pull as that at which it was calibrated, so that this correction becomes unnecessary.

A.3 CORRECTION FOR SLOPE

A.3.1 The correction for slope, if measured as angle, is given by the equation

$$k_i = l(1 - \cos\beta)$$

where

k_i is the correction for slope;

β is the angle of slope.

1) See 6.1.1.

A.3.2 The correction for slope, if measured as difference in height, is given by the equation

$$k_i = \frac{y^2}{2l} - \frac{y^4}{8l^3}$$

where y is the difference in height.

NOTES

1 The term $\frac{y^4}{8l^3}$ is negligible for a slope of about 8°.

2 This correction is always negative.

A.4 CORRECTION FOR TEMPERATURE

The correction due to temperature variation is negative or positive according to whether the temperature at measurement time is less or more than the temperature at calibration of the tape or wire, and is given by the equation

$$k_t = l \lambda \theta$$

where

k_t is the correction for temperature;

λ is the coefficient of thermal expansion;

θ is the increase or decrease in temperature from the temperature at calibration.

ANNEX B[1)]

METHODS OF MEASUREMENT ACROSS THE CROSS-SECTION

B.1 ANGULAR METHOD

A theodolite is set up on one of the banks and angular measurements taken to the boat used for taking soundings and its position fixed (see Figure 5). Alternatively, a sextant may be used from the boat to note the readings to two flags, one fixed on the cross-section and the other at right angles to it.

B.2 LINEAR MEASUREMENT

Four flags, A, B, C, D, are fixed, two on each bank along the cross-section line (see Figure 6). One more flag, E, is fixed on one of the banks along a line at right angles to the cross-section line and passing through the flag point B, nearer to the water's edge and at a known distance from it. An observer, with a flag in his hand, then moves on the opposite bank from C, towards a position N, along a line perpendicular to the cross-sectional line, until the corresponding flag E on the opposite bank, the flag on the boat M, and the flag in his hand N are all in one line. The perpendicular distance from the flag in his hand to the cross-section line is determined, and the distance of the boat is computed as follows :

$$MC = \frac{CN \times BC}{BE + CN}$$

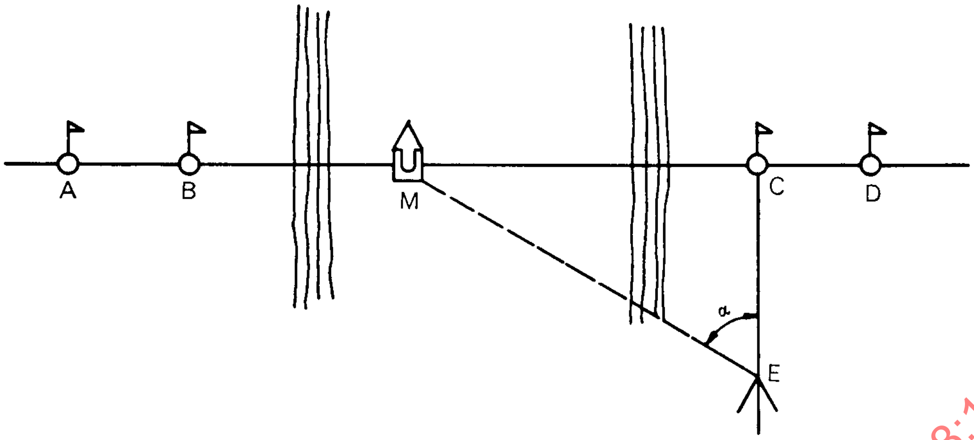
If the channel is very wide so that objects on the opposite bank are not clearly visible, the position of the boat is fixed from measurements made on one bank only (see Figure 7). Two flags on lines perpendicular to the cross-sectional line, and on the same side, are marked on one bank of the river such that the distance of the boat is computed as follows :

$$MD = \frac{DE \times CD}{DE - CN}$$

B.3 PIVOT-POINT METHOD

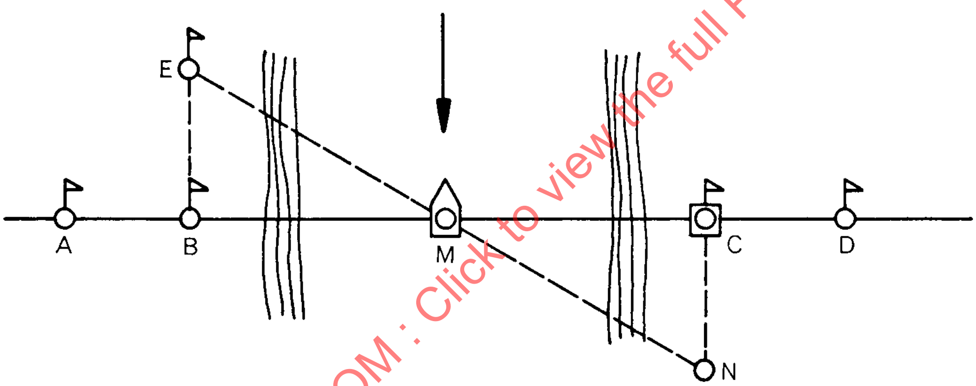
When the river is wide and flat land is available, the pivot-point method may be used. In Figure 8, the distance AP is approximately half the width of the river and PD is about one-fifth of AP. On a line DD′, points are marked at fixed intervals depending on the width between the selected verticals. The boat moving on the line AA′ can be fixed in the selected vertical by lining up with points P and E_1, E_2, etc. A second set of pivot-points on the other bank can be used if required.

1) See 6.1.2.



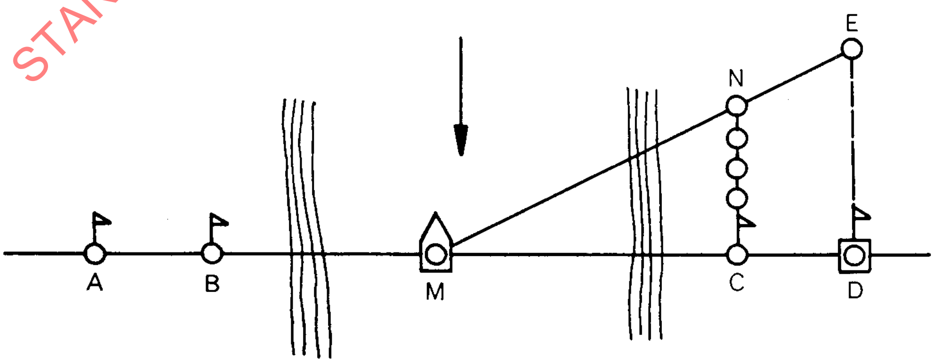
$$MC = CE \tan \alpha$$

FIGURE 5 – **Measurement of cross-section – Angular method**



$$MC = \frac{CN \times BC}{BE + CN}$$

FIGURE 6 – **Measurement of cross-section – Projection from opposite bank**



$$MD = \frac{DE \times CD}{DE - CN}$$

FIGURE 7 – **Measurement of cross-section – Projection from one bank**