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Measurement of liquid flow in open channels — Velocity-area methods

Mesure de débit des liquides dans les canaux découverts — Méthodes d'exploration du champ des vitesses

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established 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. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 748 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 1, *Velocity area methods*.

This third edition cancels and replaces the second edition (ISO 748:1979), which has been technically revised.

Annexes A to G of this International Standard are for information only.

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Measurement of liquid flow in open channels — Velocity-area methods

1 Scope

This International Standard specifies methods for determining the velocity and cross-sectional area of water flowing in open channels without ice cover, and for 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 relation of a gauging station, this International Standard deals only with single measurements of the discharge; the continuous recording of discharges over a period of time is covered in ISO 1100-1 and ISO 1100-2.

NOTE The methods for determining the velocity and cross-sectional area of water flowing in open channels with ice cover are specified in ISO 9196.

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2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772:1996, *Hydrometric determinations — Vocabulary and symbols.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 772 and the following definition apply.

3.1 unit-width discharge
discharge through a unit width of a section at a given vertical

4 Principle of the methods of measurements

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

Velocity observations are made at each vertical preferably 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 using current-meters. If unit width discharge is required, it is generally computed from the individual observations.

In the integration method, the mean velocity is obtained directly.

Under certain circumstances, velocity observations can also be made using surface floats or velocity-rods. Other methods consist of measuring the velocity along one or several horizontal lines of the section (e.g. moving-boat and ultrasonic methods.)

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

5 Selection and demarcation of site

5.1 Selection of site

The site selected should comply as far as possible with the following requirements:

a) The channel at the measuring site should be straight and of uniform cross-section and slope in order to minimize abnormal velocity distribution.

NOTE When the length of the channel is restricted, it is recommended for current-meter measurements, or other velocity-meter measurements, that the straight length upstream should be at least twice that downstream.

b) Flow directions for all points on any vertical across the width should be parallel to one another and at right angles to the measurement section.

c) The bed and margins of the channels should be stable and well defined at all stages of flow in order to facilitate accurate measurement of the cross section and ensure uniformity of conditions during and between discharge measurements.

d) The curves of the distribution of velocities should be regular in the vertical and horizontal planes of measurement.

e) Conditions at the section and in its vicinity should also be such as to preclude changes taking place in the velocity distribution during the period of measurement.

f) Sites displaying vortices, reverse flow or dead water should be avoided.

g) The measurement section should be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles. When gauging from a bridge with divide piers, each section of the channel should be treated accordingly.

h) The depth of water at the section should be sufficient at all stages to provide for the effective immersion of the current-meter or float, whichever is to be used.

i) The site should be easily accessible at all times with all necessary measurement equipment.

j) The section should be sited away from pumps, sluices and outfalls, if their operation during a measurement is likely to create flow conditions inconsistent with the natural stage-discharge relationship for the station.

k) Sites where there is converging or diverging flow should be avoided.

l) In those instances where it is necessary to make measurements in the vicinity of a bridge, it is preferable that the measuring site be upstream of the bridge. However in special cases and where accumulation of ice, logs or debris is liable to occur, it is acceptable that the measuring site be downstream of the bridge. Particular care should be taken in determining the velocity distribution when bridge apertures are surcharged.

m) The measurement of flow under ice cover is dealt with in ISO 9196 but for streams subject to formation of ice cover, requirements of measurement specified in this International Standard can be used during the free water season.

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n) It may, at certain states of river flow or level, prove necessary to carry out current-meter measurements on sections other than that selected for the station. This is quite acceptable if there are no substantial ungauged losses or gains to the river in the intervening reach and so long as all flow measurements are related to levels recorded at the principal reference section.

5.2 Demarcation of site

NOTE If the site is to be established as a permanent station or likely to be used for future measurement, it should be provided with means for demarcation of the cross-section and for determination of stage.

5.2.1 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. Where a site is subject to considerable snow cover, the section line-markers may be referenced to other objects such as rock cairns.

5.2.2 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 datum.

5.2.3 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 measurements 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.

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6 Measurement of cross-sectional area

6.1 General

The cross-sectional profile of the open channel at the gauging-site shall be determined at a sufficient number of points to establish the shape of the bed.

The location of each point is determined by measuring its horizontal distance to a fixed reference point on one bank of the channel, in line with the cross-section. This in turn allows calculation of the area of individual segments separating successive verticals where velocities are measured.

6.2 Measurement of width

Measurement of the width of the channel and the width of the individual segments may be obtained by measuring the horizontal distance from or to a fixed reference point which shall be in the same plane as the cross-section at the measuring site.

6.2.1 Where the width of the channel permits, these horizontal distances shall be measured by direct means, for example a graduated 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.

6.2.2 Where the channel is too wide for the above methods of measurement, the horizontal distance shall be determined by optical or electronic distance-meters, or by one of the surveying methods given in annex B.

6.3 Measurement of depth

6.3.1 Measurement 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 1/20 of the width.

NOTE 1 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 7.1.3 and clause 9).

NOTE 2 Accuracy of measurement of discharge is increased by decreasing the spacing between verticals.

6.3.2 The depth shall be measured by 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 and the channel is sufficiently deep, it is preferable to use an echo-sounder or other device which will not require large corrections.

6.3.3 When a sounding-rod or sounding-line is used, it is desirable that at least two readings 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 shall always be taken at each point. Regular calibrations of the instrument shall be carried out under the same conditions of salinity and temperature of the water to be measured.

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

6.3.4 Where measurements of the depths are made separately from the velocity measurements and the water level is not steady, the water level shall be observed at the time of each measurement of the depth. When 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.

NOTE 1 When, during the measurement of discharge, the bed profile changes appreciably, depth measurements should be carried out by taking one depth reading at each point at the beginning and one at the end of the velocity measurement at each vertical, and the mean value of these two measurements shall be taken as the effective depth. Care should be exercised when taking repeated soundings to avoid disturbance of the bed.

NOTE 2 Inaccuracies in soundings are most likely to occur owing to:

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

b) the penetration of the bed by the sounding-weight or -rod;

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

Errors due to a) may be minimized by the use, where practicable, of an echo-sounder, or pressure-measuring device. The effect 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 of departure from the vertical of the sounding line should not be greater than 300 in view of the inaccuracies involved. Methods of applying the correction are given in annex C.

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

Errors due to c) may be reduced by selecting an echo-sounder frequency that most adequately depicts the bed-water interface.

NOTE 3 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 erosion or deposition in the cross-section between the time the profile is determined and the time of discharge measurement.

7 Measurement of velocity

7.1 Measurement of velocity using current-meters

7.1.1 Rotating-element current-meters

Rotating-element current-meters should be constructed, calibrated and maintained according to ISO 2537 and ISO 3455.They should be used only within their calibrated range and fitted on suspension equipment similar to that used during calibration.

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In the vicinity of the minimum speed of response, the uncertainty in determining the velocity is high. Care should be exercised when measuring velocities near the minimum speed of response.

For high velocities, the propeller, in the case of propeller-type current-meters, or the reduction ratio where available, shall be chosen in order that the maximum speed of rotation can be correctly measured by the revolution counter.

No rotating-element current-meter shall be selected for use in water where the mean depth is less than 4 times the diameter of the impeller that is to be used, or of the body of the meter itself, whichever is the greater. No part of the meter shall break the surface of the water.

7.1.2 Electromagnetic current-meters

Electromagnetic current-meters are acceptable for making measurements of point velocity. These current-meters have the advantage that they have no moving parts and thereby eliminate all friction and resistance. They should be calibrated throughout the range of velocity for which they are to be used, and should meet accuracy requirements similar to rotating-element current-meters. They should not be used outside the range of calibration. Electromagnetic current-meters are capable of operation in shallow depths and of detecting and measuring flow reversal. No electromagnetic current-meter shall be selected for use in water whose mean depth is less than 3 times the vertical dimension of the probe.

The control box of the electromagnetic meter should be splashproof and provide a digital readout of velocity instantaneously or averaged over preset time periods.

The sensor of the electromagnetic meter should have a moulded epoxy resin pod with no protrusions, containing an electromagnetic sensor and solid-state encapsulated circuitry. It shall be relatively immune to fouling or damage, simple to clean and maintain and be readily interchangeable.

7.1.3 Measurement 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, and the horizontal distance between observations shall be measured as described in 6.2.1 and 6.2.2.

In judging the specific number n of verticals that are to be defined for the purpose of gauging flow at a particular location, the following criteria shall be applied.

Channel width > 0 and < 0,5 m	$n = 3$ to 4
Channel width > 0,5 m and < 1 m	$n = 4$ to 5
Channel width > 1 m and < 3 m	$n = 5$ to 8
Channel width > 3 m and < 5 m	$n = 8$ to 10
Channel width > 5 m and < 10 m	$n = 10$ to 20
Channel width >10 m	$n \geqslant 20$

In all instances, measurements of depth or velocity made at the water's edge are additional to the above.

It is further recommended that the location of the verticals be selected after a previous cross-section survey. When the channel is sufficiently uniform it may be possible to reduce the number of verticals and to allocate equal distance spacing between the verticals without conflicting with the above requirement.

The verticals should be chosen so that the discharge in each segment is less than 5 % of the total, insofar as possible, and that in no case should it exceed 10 %.

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The current-meter shall be held in the desired position in each vertical by means of a wading-rod in the case of shallow channels, or by suspending it from a cable or rod 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.

The current-meter shall be placed at the selected point in the vertical so that the horizontal axis of the meter is parallel to the direction of flow at that point. The meter shall be allowed to adjust to the flow before the readings are started.

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

NOTE 2 When a number of points in a vertical are to be measured, a battery of current~meters fixed to the same rod can be used to measure corresponding velocities simultaneously whilst ensuring that there is no mutual interference.

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 the particular instrument and conditions of measurement. However, the values given in annex C may serve as a guide.

NOTE 3 The selection and use of appropriate suspension equipment is described in ISO 3454 and ISO 4375.

The velocity at each selected point shall be observed by exposing

a) a rotating-element current-meter for a minimum of 30 s, or

b) an electromagnetic current-meter for a minimum of 10 s.

Where the velocity is subject to periodic pulsations, the exposure time should be increased accordingly. (See ISO/TR 7178.)

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

A spin test, where appropriate, should be performed after each discharge measurement to ensure that the mechanism operates freely (see ISO 2537).

More than one current-meter may be used in determining velocities in the individual verticals, different current-meters being used for consecutive verticals.

In channels where the flow is unsteady, it is possible 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 in the main current.

7.1.4 Oblique flow

If oblique flow is unavoidable, the angle of the direction of the flow to the perpendicular to the cross-section shall be measured and the measured velocity adjusted. 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 can be taken to be the same as that observed on the surface. This angle can be measured with appropriate equipment provided that the operator is located above the measurement vertical. If the channel is very deep or if the local bed profile is changing rapidly, this assumption shall not be accepted without confirmation.

If the measured angle to the perpendicular to the cross section is g ,the velocity used for computation of flow discharge shall be:

$$v_{corrected} = v_{measured} \cos \Upsilon$$

NOTE Some current-meters are equipped to measure the normal component of velocity directly when held perpendicular to the measurement cross-section. This correction should not be applied in such cases.

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7.1.5 Method for mean velocity measurement in a vertical

7.1.5.1 Choice and classification

The choice of the method for velocity measurement depends on certain factors. These are: time available, width and depth of the channel, bed conditions in the measuring section and the upstream reach, rate of variation of level, degree of accuracy wanted and equipment used.

These methods are classified as follows:

a) Velocity distribution method (see 7.1.5.2).

b) Reduced point methods (see 7.1.5.3).

c) Integration method (see 7.1.5.4).

d) Other methods (see 7.1.5.5).

7.1.5.2 Velocity distribution method

Using this method, the values of the velocity are obtained from observations at a number of points on each vertical between the surface of the water and the bed of the channel. The number and spacing of the points should be so chosen as to define accurately the velocity distribution on each vertical with a difference in readings between two adjacent points of not more than 20 % with respect to the higher value. The location of the top and the bottom readings should be chosen, taking into account the specification under 7.1.1 (see ISO 1088).

The velocity observations at each position are then plotted and the unit width discharge or mean velocity determined by planimeter, digitizer or equivalent method.

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

NOTE 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 open point velocity in the extrapolated zone at a distance X from the bed or wall.

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

The mean velocity $\bar{v}$ 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

$$\bar{v} = \frac{m}{m+1} \left(\frac{d}{a} \right)^{\frac{1}{m}} v_a$$

where

m is an exponent

d is the total depth of flow

Generally m lies between 5 and 7 but it may vary over a wider range depending on the hydraulic resistance. The value $m = 2$ applies to coarse beds or walls while $m = 10$ is characteristic of smooth beds or walls.

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m is obtained as follows:

$$m = \frac{C_{ver}}{\sqrt{g}}\left(\frac{2\sqrt{g}}{\sqrt{g} + C_{ver}} + 0{,}3\right)$$

where

g = acceleration due to gravity (m/s^2);

C_{vert} = Chezy's coefficient on a vertical (m^{0,5}/s).

NOTE 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.

7.1.5.3 Reduced point methods

These methods, less strict than methods exploring the entire field of velocity, are used frequently because they require less time than the velocity-distribution method (7.1.5.2). They are based, however, on assumed velocity profiles.

It is recommended that for a new gauging section the accuracy of the selected method be assessed by comparing the results of preliminary gaugings with those obtained from the velocity distribution method.

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.

b) One-point method

   Velocity observations shall be made on 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.

7.1.5.4 Integration method

In this method, the current-meter is lowered and raised through the entire depth on each vertical at a uniform rate. The speed at which the meter is lowered or raised should not be more than 5 % of the mean water velocity and should not in any event exceed 0,04 m/s. Two complete cycles should be made on each vertical and if the results differ by more than 10 %, the operation (two complete cycles) should be repeated until results within this limit are obtained. This method is suitable for propeller-type current-meters and cup-type meters provided the vertical movement is less than 5 % of the mean velocity and for electromagnetic current-meters.

The integration method gives good results if the time of measurement allowed is sufficiently long (60 s to 100 s). The technique is not normally used in depths of less than 1 m.

With a propeller-type current-meter, the average velocity can then be read from the instrument calibration as equivalent to the average number of revolutions (being derived as the total number of revolutions divided by the total time taken for the measurement in that vertical). Uncertainties introduced by using meters with more than one calibration coefficient should be avoided.

By using a current-meter which measures velocity directly, such as the electromagnetic current-meter, the mean velocity on the vertical can be obtained by direct reading of the instrument.

When a sounding-rod or -weight is used, it will not be possible to measure the velocity throughout the entire vertical; a relatively large zone may, for example, remain unmeasured near the channel bed. An estimate of the unit width discharge of this zone can be obtained from:

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$$q_u = 2\frac{V_m \; x \; h_f}{3}$$

where

q_u = the unit width discharge below the measured zone;

v_m = mean velocity for the measured part of the vertical;

h_f = the depth of the unmeasured zone.

Similarly, the unit width discharge for any unmeasured zone near the surface is obtained from:

$$q_s = \frac{V_m \; x \; h_s}{0,9}$$

where

q_s = the unit width discharge above the measured zone;

h_s = the depth of the unmeasured zone.

As far as possible, the type of measuring equipment should be selected to minimize the depth of the unmeasured zones.

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7.1.5.5 Other methods

a) Six-point method

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 bed [see Note in d)]. The velocity observations at each point are plotted in graphical form and the mean velocity or unit width discharge determined with the aid of a planimeter.

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

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

b) Five-point method

Velocity measurements are made by exposing the current-meter 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 bed. The mean velocity may be determined from a graphical plot of the velocity profile with a planimeter, or from the equation.

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

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

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

d) 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 specific to the section and to the discharge.

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 one of the other methods previously described.

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.

NOTE The use of current-meters near to the surface, or to the bed of the channel, shall be in accordance with the manufacturer's instructions (see also 7.1.1).

7.1.6 Errors and limitations

Estimates of the possible errors that may occur when using the various methods detailed in 7.1.5 are given in 9.3.3. 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, additional uncertainty should be included when estimating the overall uncertainty of the measurement.

Errors may arise

a) if the flow is unsteady;

b) if material in suspension interferes with the performance of the current-meter;

c) 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;

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

e) 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;

f) if there is significant disturbance of the water surface by wind;

g) 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 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, because of the presence of material in suspension, where velocities are too low for current-meter measurement or in cases of reconnaissance.

7.2.1 Selection of site

Three cross-sections shall be selected along the reach of the channel as described in clause 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-sections shall be used only for the purposes of checking the velocity measurement between the cross-sections at the beginning and at 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

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float from the bank as it passes each cross-section may be determined by suitable optical means, for example, a theodolite.

It is also possible to use the double stopwatch method described in annex F. This allows the determination of the velocity of the float and the position of its path in the section in a single operation and without the need for special or surveying equipment.

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

7.2.3.1 General

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 for the various types of floats are given in 7.2.4.

7.2.3.2 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.

7.2.3.3 Double floats

These may be used for measurements 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.

7.2.3.4 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 the float 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 least 0,95 of the depth of the channel but shall not touch the bottom.

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7.2.4 Evaluation of velocity

7.2.4.1 Method

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 measurements of the float velocities shall be taken and the mean of these measurements 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. This method gives an approximate value of the flowrate.

NOTE The distance travelled by a float may be, in some cases, significantly longer than the distance between cross-sections. In such cases it is the distance travelled which is used to estimate the velocity.

7.2.4.2 Surface floats

Where it is not possible to check the coefficient directly, it may be assumed 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 circumstances.

7.2.4.3 Double floats

Where it is not possible to check the coefficient directly, it may be accepted 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.

7.2.4.4 Other types of float

Where a direct check on the coefficient is not possible, it may be assumed that the coefficient of the 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 clause 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 too few segments are 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, unless a surface float is used.

8 Computation of discharge

8.1 General

The method of determination of the mean velocity or unit width discharge in each vertical has been dealt with in 7.1 and 7.2. In these subclauses the method of determination of discharge from current-meter measurements and float measurements is presented. These methods have been classed as the graphical method (8.2) and the arithmetic

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method (8.3), the latter being particularly useful for computations carried out in the field. The methods given in 8.4 to 8.7 are applicable for special circumstances.

8.2 Graphical method

8.2.1 Depth-velocity-integration

The velocity readings recorded for each vertical are plotted against depth as shown in figure 1. The area contained by the velocity curve produced for each vertical gives the discharge for unit width of the corresponding section. Where necessary, velocity curves can be extrapolated to the surface and bed using the methods described in notes at the end of 7.1.5.2. The values of unit-width discharges $(\bar{v} \cdot d)$ are then plotted on the upper part of the diagram and joined to form a continuous curve. The area enclosed between this curve and the line representing the water surface gives the total discharge through the section.

In the case of velocity measurements by the integration or reduced point methods, the unit-width discharge at each vertical is obtained directly as the product of the mean velocity $\bar{v}$ and the corresponding depth d.

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 $\bar{v} \cdot d$ curve.

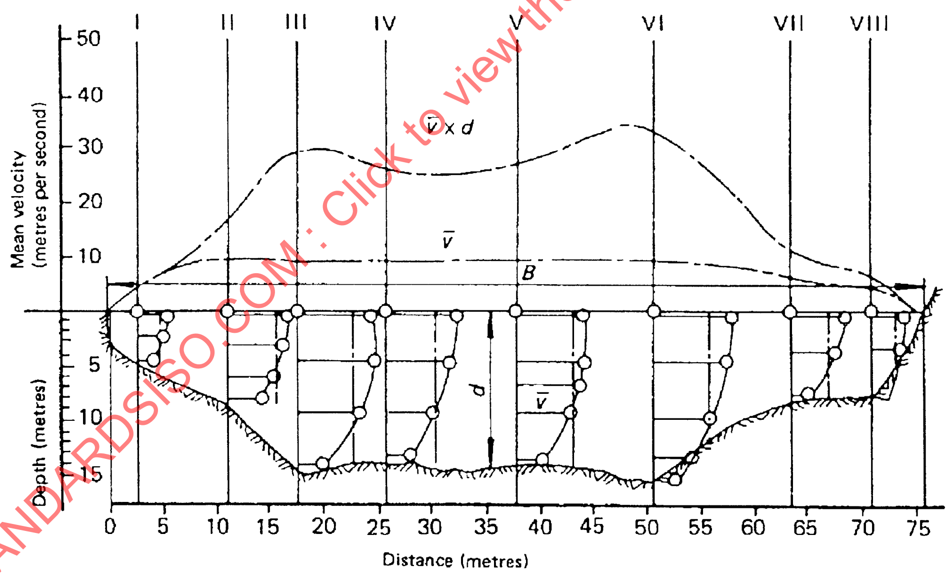

Figure 1 — Computation of discharge from current-meter measurements — Depth-velocity integration method

$$Q = \int q_i db \ \ or \ \ Q = \sum \bar{v}_i d_i \Delta B$$

where

Q = total discharge;

$\bar{v}_i$ = average velocity in segment;

d_i = depth of segment;

ΔB = incremental width;

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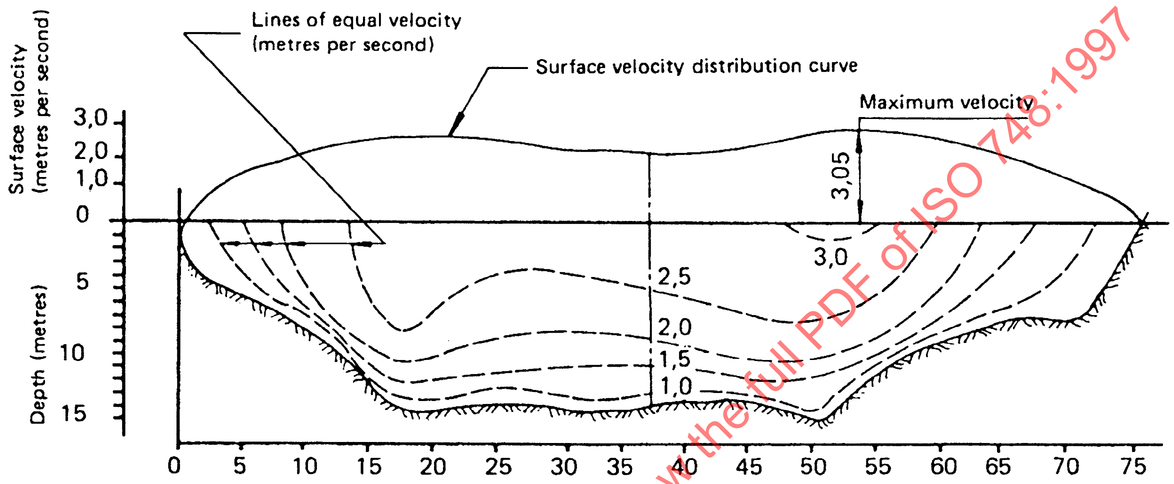
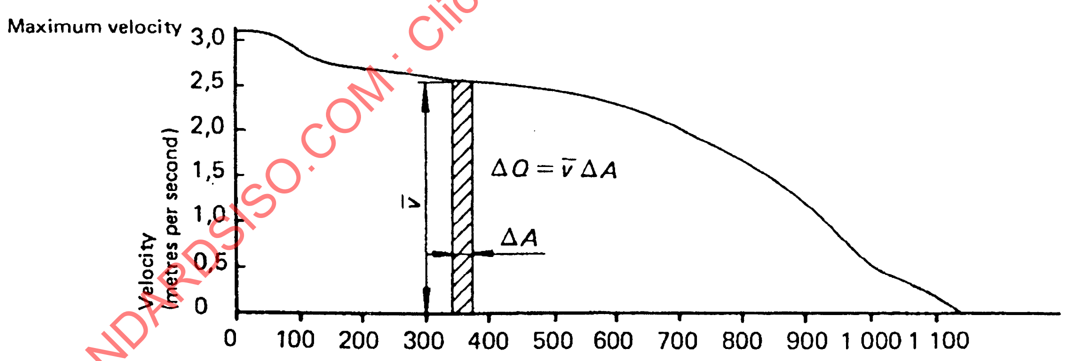
8.2.2 Velocity-area integration method (velocity-contour method)

Based on the velocity-distribution curves of the verticals, a velocity-distribution diagram for the cross-section [see figure 2 a)] shall be prepared showing lines 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 b)] 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.



a) Velocity contours in a section



b) Total flow

$$Q = \sum \bar{v} \Delta A$$

Figure 2 — Computation of discharge from current-meter measurement — Velocity-area integration method

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8.3 Arithmetic methods

8.3.1 Mean-section method

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

If v_1 and 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 width between the said verticals, the discharge of a segment is taken to be:

$$Q = \left(\frac{\overline{v_1} + \overline{v_2}}{2}\right)\left(\frac{d_1 + d_2}{2}\right) b$$

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, 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 7.1.5.2 can be used to obtain the mean velocity in the region of the bank.

8.3.2 Mid-section method

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

For this reason, the first and last verticals of a measurement should be as close to the banks as possible if the mid-section method of calculation is used.

The computation is carried out at each vertical and the total discharge through the section is obtained by summing these partial discharges as follows:

$$Q = \sum q_i \frac{b_i + b_{i+1}}{2} \quad or \quad Q = \sum \overline{v}_i d_i \frac{b_i + b_{i+1}}{2}$$

NOTE It has been found in practice that the mid-section method offers some advantage over the mean-section method in that it yields slightly more accurate results and affords a saving of time in computation.

8.4 Independent vertical method

The method is useful for measuring streams with rapidly changing discharge. Several verticals are chosen and their distances measured from a fixed reference point [figure 3 a)]. On each gauging, measurements of velocity and depth at all the chosen verticals are made, using one of the methods described above. The water level is measured at the beginning and end of the series of measurements on each vertical. For each segment a separate stage discharge relation is prepared. Subsequently, the discharge of the river at a given stage can be determined by combining the discharges for each segment.

By employing this gauging technique over a period of time and if a sufficiently large range in flow has been covered, it will be possible to derive a relationship between stage and unit-width discharge for each vertical. A family of curves can then be constructed, each curve representing an independent stage/discharge relationship for the corresponding segment of channel width [figure 3 b)]. This assumes that the channel geometry remains constant and that no change occurs in the position of a vertical relative to the reference point.

Then, for a given value of stage, total flow in the cross-section is obtained by using a mathematical method by summation of all segment discharges [figure 3 c)]; or with a graphical method [figure 3 d)] by plotting the unit-width discharge for all verticals and determining the area under this curve.

Total flow in the cross-section for any given value of stage can be obtained by either of these methods.

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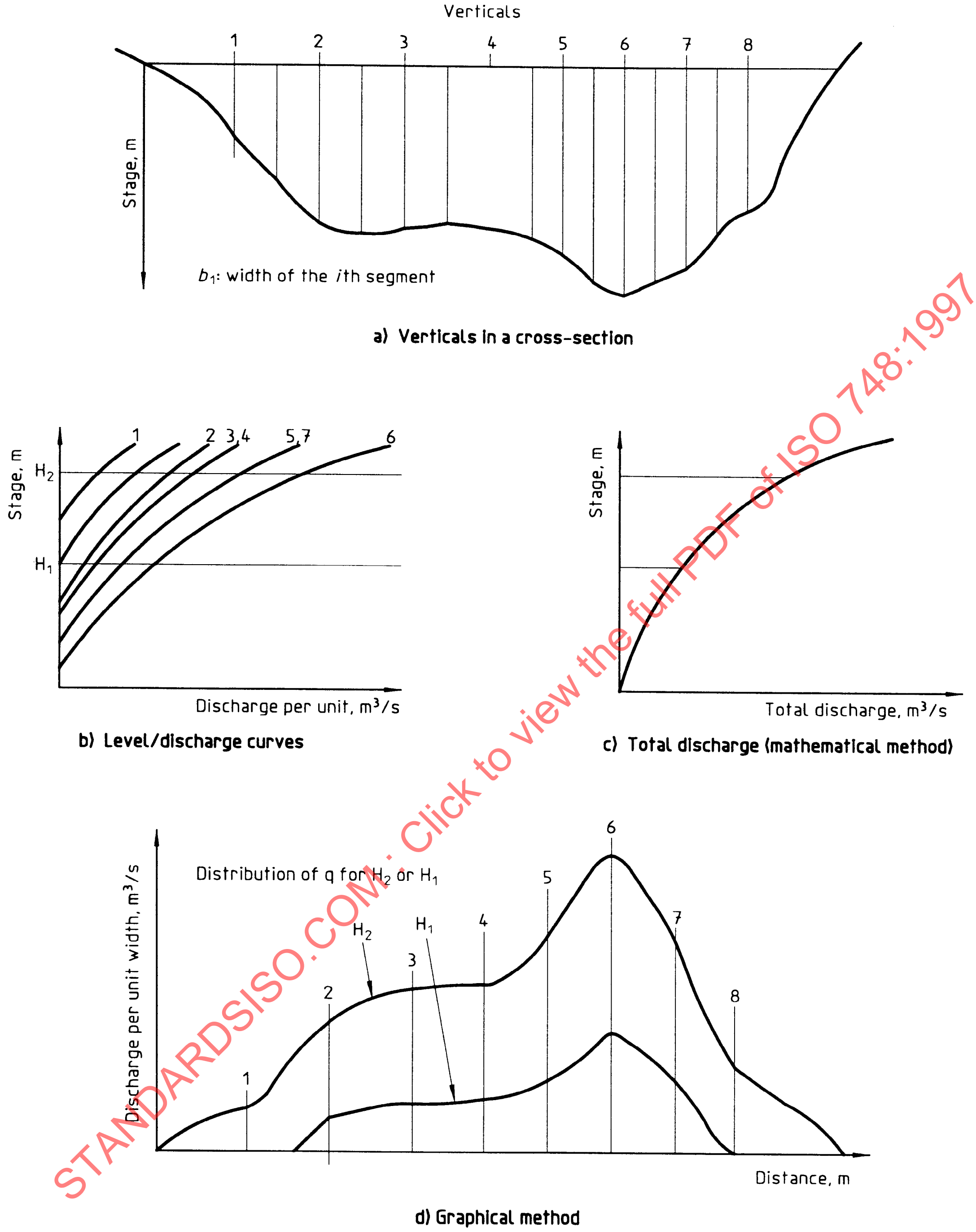

Figure 3 — Computation of discharge from current-meter measurement — Independent vertical method

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8.5 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 7.1.5.2. A similar method to that given in 8.3.1 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 computation.

8.6 Determination of discharge from surface-float velocity measurements

If the upstream and downstream cross-sections are plotted as shown in figure 4 a) and then divided into a suitable number of segments of equal width, the cross-sectional area of each of these segments can be determined. Halfway between the two cross-section lines, another line MN shall be drawn parallel to the cross-sectional lines. The starting and ending points of each float may then be plotted and joined by firm lines, while the surface-points separating the various panels of the two cross-sections may be joined by dotted lines. Where the firm lines cross the line MN, the corresponding mean velocity (float velocity multiplied by the appropriate coefficient- see note 1 below) shall be plotted normal to MN and the end points of these velocity vectors joined to form a velocity-distribution curve [figure 4 b)].

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 1 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 centreline of the flow, an unadjusted 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 simultaneously with float measurements at the level which approximates to that of the float measurements.

NOTE 2 Annex F presents a method for determining the discharge from a float measurement using two stop watches (see 7.2.2).

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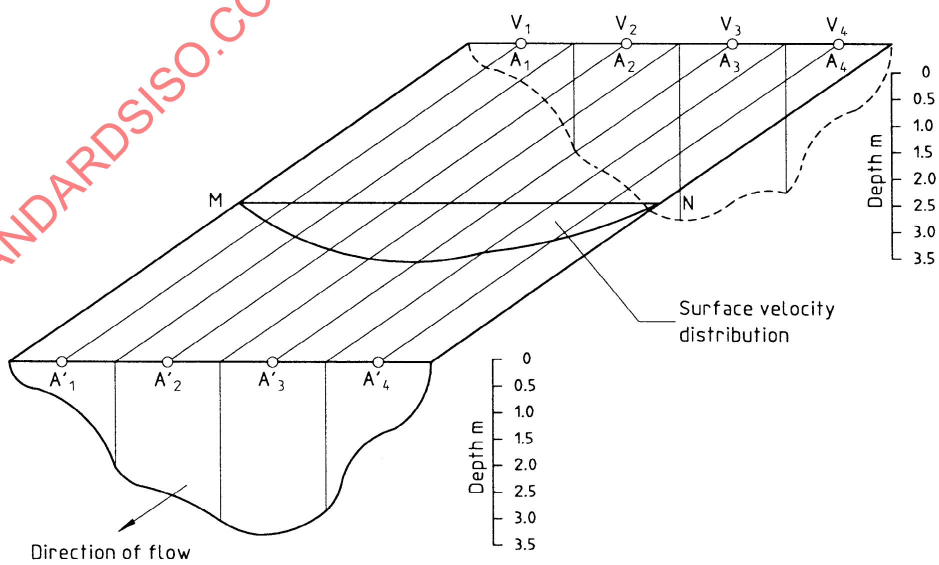


a) Measurement sections and float paths

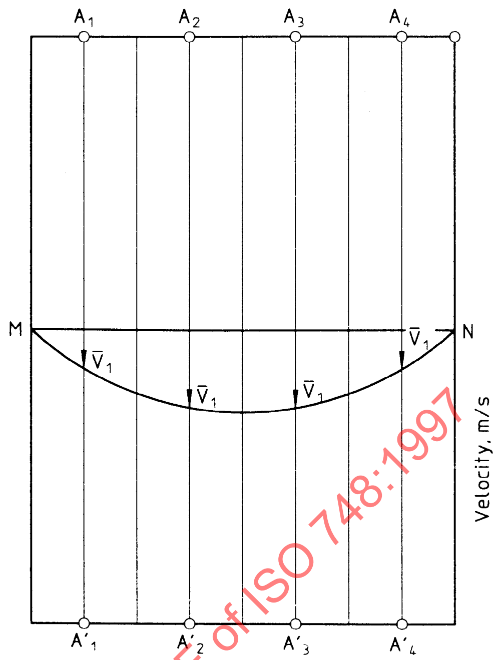
$$Q = \sum_{1}^{m} \bar{v}_i \frac{A_i + A_i'}{2}$$

where

$\bar{v}_i$ = mean surface velocity in the segment;

A_i = area of upstream segment;

A_i' = area of downstream segment.



b) Mean surface velocity-distribution curve from float measurements

Figure 4 — Computation of discharge from float measurements

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8.7 Determination of discharge for variations of water level

8.7.1 General

If the fluctuation of water level during the period of velocity measurement is less than 5 % of the mean depth or 0,05 m, whichever is the lesser dimension, 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 8.7.2 and the mean water level corresponding to this discharge computed as shown in 8.7.3.

8.7.2 Computation of discharge

The water level is plotted separately for each segment to form a series of steps as shown in figure 5. Alternatively, the level can be joined by a smooth curve. A curve of mean velocity multiplied by depth is then plotted above the water-surface line, the area enclosed representing the total discharge.

8.7.3 Computation of mean water level

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

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

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

where

$\bar{z}$ 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 required measurements are illustrated in figure 5.

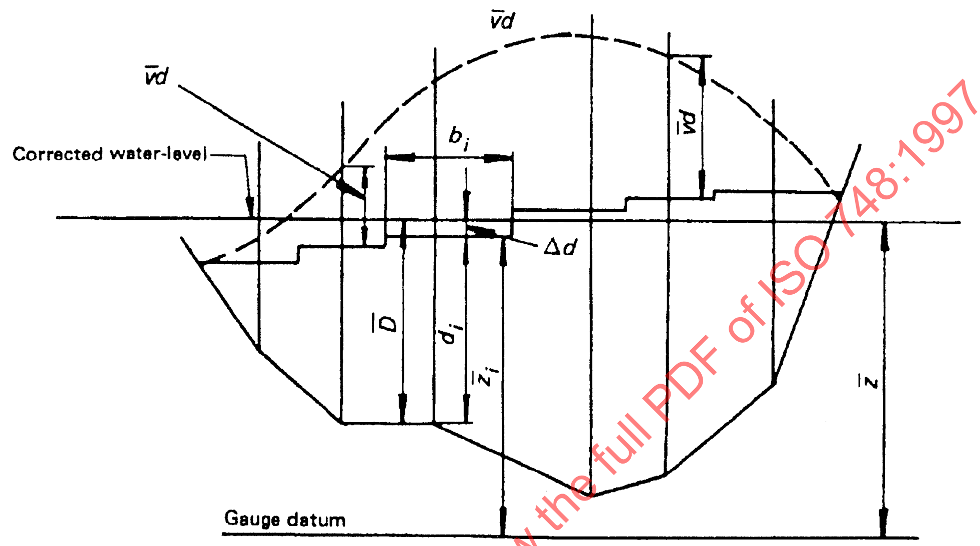

Figure 5 — Computation of discharge and mean water level for variations of water level

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9 Uncertainties in flow measurement

9.1 General

The uncertainty in a single measurement of discharge is dealt with in ISO/TR 5168, to which reference should be made. In this clause a general outline of the method of estimating this uncertainty under conditions of steady flow is given. In annex E, the individual components of the overall uncertainty 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 (see ISO/TR 7178).

9.2 Definition of uncertainty

No measurement of a physical quantity can be free from errors which may be associated with either systematic bias caused by errors in the standardizing equipment or random scatter caused by 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. With random errors, the average of m repeated measurements is $\sqrt{m}$ times better than that of any of the measurements by themselves.

In this clause, the estimated uncertainties of the individual components are considered as twice the standard deviations of the normal distributions and are combined by the root-sum-square method to obtain the total uncertainty in a single determination of discharge.

When considering the possible *error* of any measurement of discharge in an open channel, it is not possible to predict this *error* exactly, but analysis of the individual measurements that are required to obtain the discharge can be made and a statistical estimate made of the likely *magnitude of error*. The statistical estimate of error magnitude is called the uncertainty of the measurement; the associated measure of likelihood is called the level of confidence. The measurement uncertainty at the 95 % level of confidence is a value which, when added to and subtracted from the measured value, defines a band around the measured value that in an average of 19 measurements out of 20 is expected to contain the true value. The measurement uncertainty at the 68 % level of confidence is called the standard uncertainty, and may be thought of as the standard deviation of the population of all possible measured values of the quantity being measured, considering all sources of measurement error. Uncertainties at levels of confidence other than 68 % are called expanded uncertainties and are obtained by multiplying the standard uncertainty by a factor called the coverage factor. The coverage factor for 95 % confidence can be taken as 2. In this clause, uncertainties are given as expanded uncertainties with a coverage factor of 2 (approximate level of confidence of 95 %) and are expressed as percentages of the measured values (relative or percentage uncertainties).

9.3 Sources of uncertainties

The sources of uncertainties 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 uncertainty in the discharge is then composed of:

a) uncertainties in width. These shall be determined having regard to 6.2;

b) uncertainties in depth. These shall be determined having regard to 6.3;

c) uncertainties in determination of local point velocities. These will depend on the accuracy of the apparatus and the technique employed and on the irregularity of the velocity distribution in time and space;

d) uncertainties in the estimation of mean velocity (see clause 7) and the computation of discharge (see clause 8).

9.4 Determination of individual components of uncertainty

9.4.1 Uncertainties in width (X_{bi})

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, as in the case of a trolley suspension, then the uncertainty in the distance measurement is usually negligible. Where optical or electronic means are used to determine the distances, the uncertainty will depend on the distance measured and the device used.

9.4.2 Uncertainties in depth (X_{di})

The uncertainty 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.

9.4.3 Uncertainties in determination of the mean velocity with current-meters

It is not possible to predict accurately the uncertainties which may arise, but there are four main sources, the first arising from the limited time of exposure of the current-meter, the second arising from the use of a limited number of points in a vertical, the third arising from the uncertainty in the current-meter rating, and the fourth arising from the use of a limited number of verticals:

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a) Time of exposure

The velocity at any point in the cross-section is continuously and randomly fluctuating with time. Hence, a single measurement over a period of, for example 60 s, is one sample which may differ from that found over a much longer period. By analysis of a large number of observations at individual points where the time of measurement is varied, the standard deviation can be determined.

In practice, it is found that the uncertainty X_e decreases with an increase in velocity.

b) Number of points in a vertical

As a general rule, the uncertainty X_p 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 uncertainty, i.e. for the number of points and the determination of local point velocities, cannot be separated. The integration method is subject therefore to a combined source of uncertainty only on this account.

c) Current-meter calibration

An uncertainty X_c will arise from the calibration of the current-meter. This will have both a random component and a systematic component, the former arising from the determination of the calibration from the calibration points, and the latter from any systematic shift of that line or systematic error in the rating tank.

d) Number of verticals

The value of the uncertainty X_m depends not only on the number of verticals but also on the size and shape of the channel and the variations in the bed profile.

The uncertainty from this source decreases with an increase in the number of verticals.

9.5 Method of calculating the uncertainty in discharge using current-meter measurements of velocity

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

a) Overall random uncertainty (X'_Q)

If X'_{bi}, X'_{di}, X'_{ei}, X'_{pi} and X'_{ci} are the percentage random uncertainties in b_i, d_i, e_i, p_i and c_i for each of the m verticals, and X'_Q is the percentage random uncertainty in the discharge Q at the 95 % confidence level, then

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

where X_m is as defined in 9.4.3.

This equation can be simplified as follows if it is assumed that average values of X'_b, X'_d, X'_e, X'_p and X'_c are taken for all verticals, if the number of verticals is more than ten, and particularly if the partial discharges are nearly equal.

$$X'_Q = \pm \sqrt{\left[X_m^2 + \frac{1}{m} \left(X'^2_b + X'^2_d + X'^2_e + X'^2_p + X'^2_c \right) \right]}$$

NOTE For special studies, however, the basic equation should be used.

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b) Overall systematic uncertainty (X''_Q)

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

$$X''_Q = \pm\sqrt{X''^2_b + X''^2_d + X''^2_c}$$

where X''_b, X''_d and X''_c are the percentage systematic standard uncertainties in *b*, *d* and *c*, respectively.

X''_c is the systematic uncertainty of the current-meter which varies randomly from instrument to instrument and not the systematic uncertainty inherent in the type of instrument or measurement which can be eliminated or determined only if a superior instrument or improved method is available.

c) Combined uncertainty (X_Q)

The overall estimate of the uncertainty of the discharge at the 95 % confidence level will then be

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

The final presentation of the result should be made by one of the following methods (see ISO/TR 5168).

1) Discharge = $Q \pm X_Q$

random uncertainty = $\pm X'_Q$

2) Discharge = Q

random uncertainty = $\pm X'_Q$

systematic uncertainty = $\pm X''_Q$

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9.6 Method of calculating the uncertainty in discharge by float measurements of velocity

9.6.1 Sources of uncertainties

The sources of uncertainties may be identified by considering the following equation:

$$Q = K_f \sum_{i=1}^{m} \bar{v}_i \frac{(A'_i + A_i)}{2}$$

or

$$Q = K_f \sum_{i=1}^{m} \frac{\left(\frac{L}{T}\right)[b_i\,(d_{i-1} + d_i) + b'_i\,(d'_{i-1}{}^4 + d'_i)]}{4}$$

where

Q is the total discharge;

m is the number of segments;

v_i is the mean float velocity in the ith segment;

A_i and A_i' are the ith segment area of upstream and downstream cross-section respectively;

b_i and b_i' are the widths in the ith segment of upstream and downstream cross-section respectively;

d_i and d_i' are the depths in the ith vertical of upstream and downstream cross-section respectively;

L is the distance between the upstream and downstream cross-sections;

T is the mean time taken for the floats to traverse the distance between upstream and downstream cross-sections;

K_f is the coefficient of velocity for the float.

The overall uncertainty in the discharge is composed of:

a) uncertainties in width;

b) uncertainties in depth;

c) uncertainties in determination of surface float velocities;

d) uncertainty in the coefficient of velocity for the float;

e) uncertainty due to the limited number of segments;

f) uncertainties due to using the cross-section measured either before or after the float measurements.

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9.6.2 Determination of individual components of uncertainty

9.6.2.1 Uncertainties in width (X_{bi}) and depth (X_{di})

These shall be determined as in 9.4.1 and 9.4.2.

9.6.2.2 Uncertainties in surface float velocities (X_{vi})

There are two components:

a) uncertainties of the travel path between the upstream and downstream cross-section (X_{Li});

b) uncertainties of the time taken for the float to transverse between the upstream and downstream cross-sections (X_{ti}).

9.6.2.3 Uncertainty of coefficient of velocity of a float (X_{kf})

If the coefficient is determined by current-meter measurements carried out simultaneously with float measurements, X_{kf} may be considered as 4,5% for the case of 20 verticals, 5,3 % for 15 verticals, 6,1 % for 10 verticals.

9.6.2.4 Uncertainty due to tbe limited number of verticals (X_m)

It shall be determined as in 9.4.3 d).

9.6.2.5 Uncertainties due to using the cross-section measured either before or after the float measurement (X_{af}).

For a gauging station with a stable, steady river bed, these uncertainties vary in general over the range 2 % to 3 % for each cross-section.

9.6.3 Overall uncertainty in the float measurement of discharge

The method of calculation is similar to that given in 9.5.

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a) Overall random uncertainty (X'_Q)

The simplified equation is

$$X'_Q = \pm\sqrt{X'^2_m + X'^2_{kf} + \left(\frac{1}{m}\right)\frac{\left(X'^2_b + X'^2_d\right) + X'^2_L + X'^2_t}{2}}$$

where

X'_{kf}, X'_b are percentage random uncertainties;

m is the number of segments.

If the cross-sections cannot be measured during the flood period, the uncertainty X_{af} should be considered.

The equation is then

$$X'_Q = \pm\sqrt{X'^2_m + X'^2_{kf} + \left(\frac{1}{m}\right)\frac{\left(X'^2_b + X'^2_d\right) + X'^2_L + X'^2_t + \frac{X'^2_{af}}{2}}{2}}$$

b) Overall systematic uncertainty (X''_Q)

$$X''_Q = \pm\sqrt{\frac{(X''^2_b + X''^2_d)}{2}}$$

where

X''_b, X''_d are percentage systematic uncertainties.

c) Combined uncertainty (X_Q)

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

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Annex A
(informative)

Correction for sag, pull, slope and temperature in measurement of cross-section width 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:

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

where

k_s is the sag correction for length (shortening);

m is the mass of tape or wire per unit length;

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

F_T is the cable tension.

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

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

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.

The above correction is positive if X is less than l; it is negative if X is greater than l

1) See 6.2.1

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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 length 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 during calibration;

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.

A.3 Correction for slope

A.3.1 The correction for slope, if measured as an 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.

A.3.2 The correction for slope, if measured as a 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.

NOTE 1 The term $y^4/8l^3$ is negligible for a slope of about 8° or less

NOTE 2 This correction is always negative.

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A.4 Correction for temperature

The correction due to temperature 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

$$k_t = l \cdot \lambda \cdot \Delta\theta$$

where

k_t is the correction for temperature;

λ is the coefficient of thermal expansion;

$\Delta\theta$ is the increase or decrease in temperature from the temperature at calibration.

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Annex B
(informative)

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 B.1). 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.

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B.2 Linear measurement

Four flags, A, B, C and D, are fixed, two on each bank along the cross-section line (see figure B.2). One more flag, E, is fixed on one of the banks along 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 along the 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 B.3). 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 B.4, 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 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 may be used if required.

B.4 Other methods

Other methods using high technology are available.

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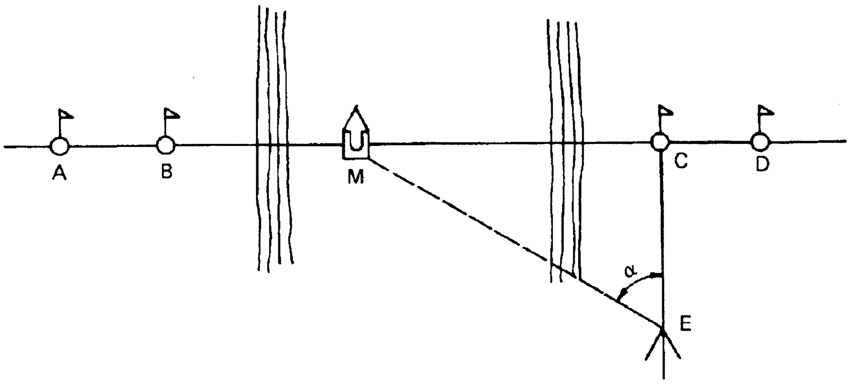
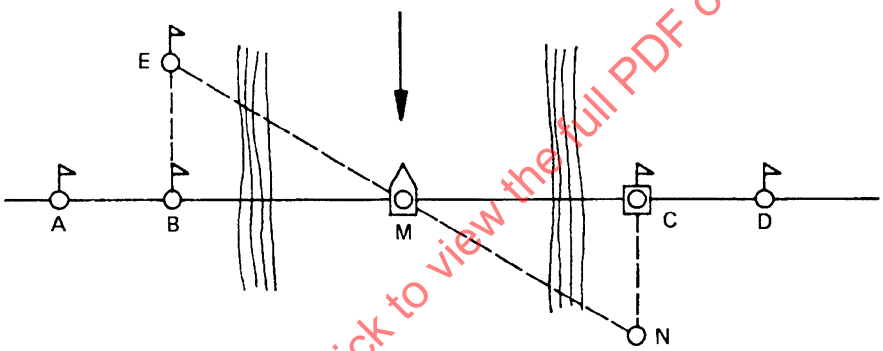
1) See 6.2.2



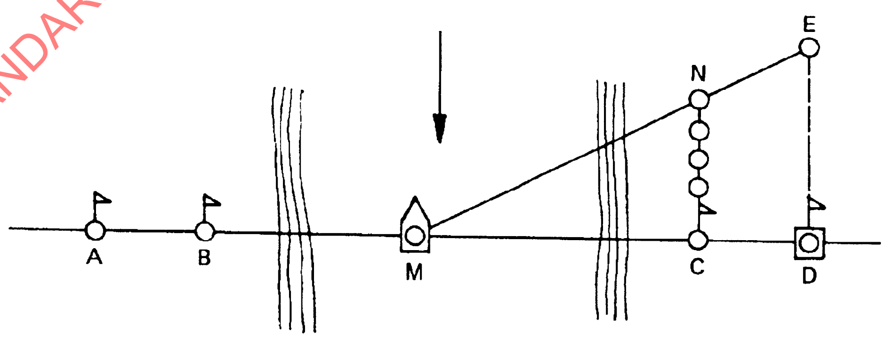
$$MC = CE \tan \alpha$$

Figure B.1 — Measurement of cross-section — Angular method



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

Figure B.2 — Measurement of cross-section — Projection from opposite bank



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

Figure B.3 — Measurement of cross-section — Projection from one bank

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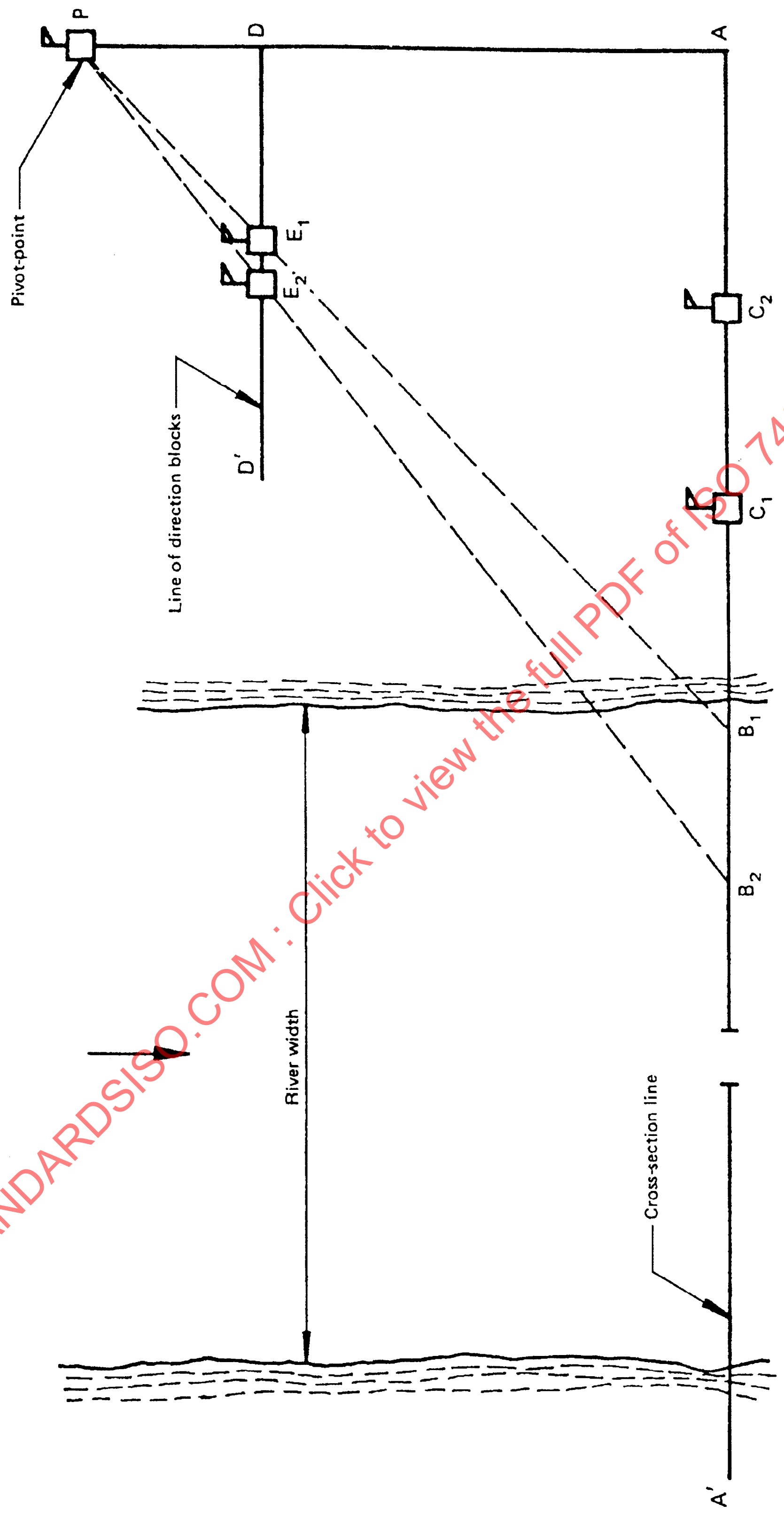

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Figure B.4 — Measurement of cross section — Pivot-point method

Annex C
(informative)

Corrections for wetted length of wire when measuring depths with wire not normal to surface

The following tables are based on *Measurement and computation of streamflow*, Vol 1, *Measurement of stage and discharge*, the United States Geological Survey, Water Supply, Paper No. 2175, 1982. It should be noted that a correction must also be made for the change between the vertical length and the slant length of the line above the water surface. If the point of suspension of the sounding line is at a vertical distance X above the surface and the angle between the sounding line and vertical is a, then the air line correction k_{1a} to be applied is given by the formula

$$k_{1a} = (\sec a - 1) \cdot X$$

The percentage correction (k_{1a}/X) to be deducted from the measured length of the sounding line, for angles up to 30°, is given in table C.1.

Table C.1 — Air line correction

Vertical angle	Correction %	Vertical angle	Correction %
4°	0,24	18°	5,15
6°	0,55	20°	6,42
8°	0,98	22°	7,85
10°	1,54	24°	9,46
12°	2,23	26°	11,26
14°	3,06	28°	13,26
16°	4,03	30°	15,47

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The wet-line correction k_{1w} (see table C.2), also expressed as a percentage to be deducted from the measured length of the sounding line is estimated on the assumptions that the horizontal drag pressure on the weight in the comparatively still water near the bottom can be neglected, that the velocity distribution in the vertical is normal, and that the sounding wire and the weight are designed to offer little resistance to the water current.

The uncertainties in this estimation are such that significant errors may be introduced if the vertical angle is more than 30°.

1) See 6.3.4, note 2.

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Table C.2 — Wet-line correction

Vertical angle	Correction %	Vertical angle	Correction %
4°	0,06	18°	1,64
6°	0,16	20°	2,04
8°	0,32	22°	2,48
10°	0,50	24°	2,96
12°	0,72	26°	3,50
14°	0,98	28°	4,08
16°	1,28	30°	4,72

The corrections given in this table are percentages of the wet-line depth.

(See also ISO/TR 9209.)

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Annex D
(informative)

Correction for drift

Where motor launches are used, they shall be of sufficient power to avoid drift under normal circumstances. In great depths and high velocities, it is sometimes impossible to keep the measuring launch exactly at the desired point. The upstream or downstream and lateral movements of the launch during velocity observation shall be measured by appropriate surveying techniques or electronic distance-measuring equipment, and a vector analysis made to determine the true velocity corrected for movement of the measuring launch.

For downstream drift in high velocities, the drift can be measured and due allowance made in the velocity measurement. For example, based on 388 observations carried out on the River Indus at Kotri (range of velocities between 1,146 and 2,911 m/s), the correction for drift was obtained statistically using the following formula:

$$\bar{v}_p = 0{,}064 + 0{,}98\overline{v_b} + 0{,}98\overline{v_d}$$

where

v_p is the true velocity, in metres per second;

v_b is the velocity, in metres per second, observed at the point with the boat drifting;

v_d is the drift velocity, in metres per second;

v_d = drift (in metres)/120 s (period of observation).

In the above set of observations, the velocity without drift was observed by means of a sufficiently powered motor launch, while that with drift was observed by means of a flat-bottomed boat. A two-pronged anchor weighing 28,123 kg (62 lb) was used for partially anchoring the boat, the length of the rope paid out generally varying between 20 m and 25 m. After the boat was towed sufficiently upstream, the anchor was dropped, and the velocity was measured while the boat drifted.

The drift velocity was measured from drift flags fixed at known distances apart on both the banks.

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1) See 7.1.6

Annex E
(informative)

Uncertainty of a velocity-area measurement

E.1 General

See also clause 9.

It should be noted that the values given in this annex are the result of investigations carried out since the publication of the first edition of this International Standard in 1968. In particular, reference should be made to ISO/TR 7178. Nevertheless, it is recommended that each user should determine independently the values of the uncertainties which will apply to a particular case. The values in table E.1 are percentages at the 95 % confidence level (twice the standard deviation of normal distributions).

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E.2 Uncertainties in width (X'_b)

The uncertainty in the measurement of width should be not greater than 1 %.

As an example, the error introduced for a particular range finder having a base distance of 800 mm varies approximately as given in table E.1.

Table E.1 — Example of errors for a range finder

Range of width m	Absolute error m	Relative error %
0 to 100	0 to 0,3	± 0,3
101 to 150	0.3 to 0,5	± 0,4
151 to 250	0.5 to 1,2	± 0,5

E.3 Uncertainties in depth (X'_d)

For depths up to 0,300 m the uncertainty should not exceed ±3 %, and for depths over 0,300 m the uncertainty should not exceed ±1 %.

As an example, the error in depth in an alluvial river whose depth varied from 2 m to 7 m and where the velocity varied up to 1,5 m/s was, for these conditions, of the order of 0,05 m measured using a suspension cable.

As another example, measurements of depth were taken with a sounding-rod up to a depth of 6 m, and beyond that value by a log line with standard air-line and wet-line corrections. These observations were made within the range of 0,087 m/s to 1,3 m/s, the results being as given in table E.2.