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Hydrometry — Measurement of liquid flow in open channels using current-meters or floats

Hydrométrie — Mesurage du débit des liquides dans les canaux découverts au moyen de débitmètres ou de flotteurs

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Foreword

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The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 748 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This fourth edition cancels and replaces the third edition (ISO 748:1997), which has been technically revised.

Hydrometry — Measurement of liquid flow in open channels using current-meters or floats

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 or floats to measure the velocities. It should be noted that although, in some 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.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometric determinations — Vocabulary and symbols*

ISO 1088, *Hydrometry — Velocity-area methods using current-meters — Collection and processing of data for determination of uncertainties in flow measurement*

ISO 2537, *Hydrometry — Rotating-element current-meters*

ISO 3455, *Hydrometry — Calibration of current-meters in straight open tanks*

ISO/TS 15768, *Measurement of liquid velocity in open channels — Design, selection and use of electromagnetic current meters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 apply.

4 Principle of the methods of measurements

4.1 The principle of these methods consists of determining velocity and cross-sectional area. A measuring site is chosen conforming to the specified requirements (see Clause 5); 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 (known as verticals) across the width, sufficient to determine the shape and area of the cross-section (see Clause 6).

Velocity observations using current-meters are made at each vertical preferably at the same time as measurement of depth, especially in the case of unstable beds (see 7.1.5).

Velocity observations can also be made using surface floats or velocity-rods (see 7.2).

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. If unit width discharge is required, it is generally computed from the individual observations at each measurement vertical.

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. When the length of the channel is restricted, it is recommended for current-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.

h) Measurement of flow from bridges can be a convenient and sometimes safer way of sampling width, depth and velocity. When gauging from a bridge with divide piers, each section of the channel should be measured separately. Particular care should be taken in determining the velocity distribution when bridge apertures are surcharged or obstructed.

i) 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.

j) If the site is to be established as a permanent station, it should be easily accessible at all times with all necessary measurement equipment.

k) The section should be sited away from pumps, sluices and outfalls, if their operation during a measurement is likely to create unsteady flow conditions.

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

m) 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 certain 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.

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

o) It may, under certain conditions of river flow or level, prove necessary to carry out current-meter measurements on sections other than the original chosen location. This is quite acceptable if there are no substantial unmeasured losses or gains to the river in the intervening reach and so long as all flow measurements can be related to any stage value recorded at the principal reference section.

5.2 Demarcation of site

5.2.1 If the site is to be established as a permanent station or likely to be used frequently for future measurement, it should be provided with means for demarcation of the cross-section and for determination of stage. Where the site is used only once, or infrequently, and there are no means of determining stage values on site, care should be taken to ensure that the water level and/or flow do not change significantly during the measurement period.

5.2.2 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.

5.2.3 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.

5.2.4 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.

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 separated by successive verticals where velocities are measured.

6.2 Measurement of width

6.2.1 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.

6.2.2 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.

6.2.3 Where the channel is too wide for the above methods of measurement, and a boat is used, the horizontal distance may be determined by optical or electronic distance-meters, by the use of a differential Global Positioning System, 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. The number of points at which depth shall be measured should be the same as the number of points at which velocity is measured (see 7.1.3).

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. Difficulty may be experienced when attempting to measure depth at times of high velocity. Annex C of this document offers alternative methods.

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 as those of the water to be measured.

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 sufficient intervals for the value of the level at the time of each determination of depth to be obtained by interpolation.

6.3.5 When, during the determination 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.

6.3.6 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 30° in view of the inaccuracies involved. Two alternative methods of applying the correction are given in Annex C.

Errors due to b) may be reduced by fitting a base plate 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.

6.3.7 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 shall be manufactured, 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.

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 where the depth at the point of measurement is less than four 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. An exception to this is the case where the cross-section is very shallow at one side but is the best available.

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 uncertainty due to 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 may be capable of operation in shallower depths than rotating element current-meters and of detecting and measuring flow reversal.

No electromagnetic current-meter should be selected for use where the depth at the point of measurement is less than three times the vertical dimension of the probe (see ISO/TS 15768). An exception to this is the case where the cross-section is very shallow at one side but is the best available.

7.1.3 Measurement procedure

Velocity observations are normally made at the same time as measurements of the depth. This method shall be particularly 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 6.2.2 and 6.2.3.

In judging the specific number n of verticals in small channels (< 5 m) that are to be defined for the purpose of determining flow at a particular location, the following criteria shall be applied. These criteria shall be the minimum requirement and only practical constraints of time, costs, or on site conditions should result in a reduction of these numbers.

— Channel width $< 0{,}5$ m $n = 5$ to 6

— Channel width $> 0{,}5$ m and < 1 m $n = 6$ to 7

— Channel width > 1 m and < 3 m $n = 7$ to 12

— Channel width > 3 m and < 5 m $n = 13$ to 16

— Channel width > 5 m $n \geqslant 22$

For channel widths > 5 m, the number of verticals shall 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 exceed 10 %.

In all instances, measurements of depth made at the water's edge are additional to the above. The first and last verticals should be as close as practically possible to the water's edge.

It is further recommended that the location of the verticals be selected after a previous cross-section survey.

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. The current-meter shall be held so that it is not affected by any disturbances of flow.

Current-meter counters or velocity indicators with a digital display of low resolution should not be used at low velocities, e.g. less than 0,15 m/s.

When the orientation of the current-meter can be controlled, e.g. when wading gauging with rods, the meter should be held at right angles to the measuring cross-section. Where oblique flow occurs, or the cross-section is not at right angles to the direction of flow (see 7.1.4) and the meter is suspended, it will align itself with the direction of flow. In such cases, the meter shall be allowed to adjust to the flow before readings are started.

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

When a number of points in a vertical are to be measured, a number of current-meters fixed to the same rod or cable 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 (see Annex C).

NOTE 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 the current-meter for a minimum of 30 s.

Where the velocity is subject to periodic pulsations in excess of 30 s, the exposure time should be increased accordingly (see ISO 1088).

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

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

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 assumed 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 between the flow direction and the perpendicular to the cross-section is θ the velocity used for the computation of flow discharge shall be:

$$v_{\text{corrected}} = v_{\text{measured}} \cos\theta \quad (1)$$

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

7.1.5 Determination of the mean velocity in a vertical

7.1.5.1 Choice and classification

The choice of the method for determining velocity 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 desired 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).

7.1.5.2 Velocity distribution method

Using this method, the values of the velocity are obtained from observations at a number of points in 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 in 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 and 7.1.2 (see also ISO 1088).

The velocity observations at each position are then plotted graphically and the unit width discharge or mean velocity determined by planimeter, digitizer or equivalent method. The mean velocity in the vertical may also be obtained by dividing the unit width discharge by the total depth.

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 Although this clause deals primarily with the determination of mean velocity in the vertical, it may be necessary to apply the same principle to the determination of mean velocity close to the vertical side or wall of a channel. The velocity curve can be extrapolated from the last measuring point to the bed or vertical side of the channel by calculating v_x from Equation (2):

$$v_x = v_a \left(\frac{x}{a}\right)^{1/m} \quad (2)$$

where

v_x is the open point velocity in the extrapolated zone at a distance x from the bed or vertical side;

v_a is the velocity at the last measuring point at a distance a from the bed or vertical side;

m is an exponent.

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 Equation (3):

$$\bar{v} = \left(\frac{m}{m+1}\right) v_a \tag{3}$$

Generally, m lies between 5 and 7 but it may vary over a wider range depending on the hydraulic resistance. The value $m = 4$ applies to coarse beds or vertical sides while $m = 10$ is characteristic of smooth beds or vertical sides.

m is obtained as follows:

$$m = \frac{C_{\text{ver}}}{\sqrt{g}}\left(\frac{2\sqrt{g}}{\sqrt{g}+C_{\text{ver}}}+0{,}3\right) \tag{4}$$

where

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

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

NOTE 3 An alternative method of obtaining the velocity in the region below 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

7.1.5.3.1 General

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 theoretical 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.

7.1.5.3.2 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.

7.1.5.3.3 Two-point method

Velocity observations shall be made on 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.

7.1.5.3.4 Three-point method

Velocity observations shall be made on each vertical by exposing the current-meter at 0,2, 0,6 and 0,8 of the depth below the surface. The 0,6 measurement may be weighted and the mean velocity $\bar{v}$ obtained from Equation (5):

$$\bar{v} = 0{,}25\left(v_{0,2} + 2v_{0,6} + v_{0,8}\right) \tag{5}$$

7.1.5.3.5 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 v may be determined from a graphical plot of the velocity profile with a planimeter, or from Equation (6).

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

7.1.5.3.6 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 7.1.5.3.7.2). 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 $\bar{v}$ may be found algebraically from Equation (7).

$$\bar{v} = 0{,}1\left(v_{\text{surface}} + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 2v_{0,8} + v_{\text{bed}}\right) \tag{7}$$

7.1.5.3.7 Surface one-point method

7.1.5.3.7.1 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; 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 velocity at the surface with the velocity at 0,6 of the 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.

7.1.5.3.7.2 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 and 7.1.2).

7.1.5.3.8 Alternate sampling methods

Alternative sampling methods for determining the mean velocity in the vertical may be utilized under exceptional circumstances, e.g. high velocity, rapidly changing stage or floating debris provided the method applied can be demonstrated by experiment to give results of similar accuracy to those listed above.

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.

The integration method gives good results if the time of measurement allowed is sufficiently long (60 s to 100 s). The technique can be, but 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 equation should be avoided.