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Hydrometry — Measurement of liquid flow in open channels — Velocity area methods using point velocity measurements

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Foreword

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This document was prepared by Technical Committee ISO/TC ..., *title*, Subcommittee SC ..., *title*.

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Hydrometry — Measurement of liquid flow in open channels — Velocity area methods using point velocity measurements

1 Scope

This International Standard specifies methods for determining the velocity and cross-sectional area of water flowing in open channels and for calculating the discharge employing point velocity measurement devices.

It covers methods using rotating element Current Meters, Acoustic Doppler Velocimeters (ADV), Acoustic Doppler Velocity Profiler (ADVP) – Stationary method, Surface Velocity measurement including floats and other surface velocity systems.

Although some general procedures are discussed, it does not describe in detail how to use or deploy these systems. For detailed procedures, reference should be made to guidelines from instrument manufacturers and appropriate public agencies.

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 772:2011, *Hydrometry — Vocabulary and symbols*

ISO 1088:2007, *Hydrometry — Velocity-area methods using current-meters — Collection and processing of data for determination of uncertainties in flow measurement*

ISO 2537:2007, *Hydrometry — Rotating-element current-meters*

ISO 3455:2007, *Hydrometry — Calibration of current-meters in straight open tanks*

ISO/TR 24578:2012, *Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels*

ISO 25377:2007, *Hydrometry — Hydrometric uncertainty guidance (HUG)*

ISO 5168:2005, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

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

The principle depends upon determining velocity and cross-sectional area.

This is characterized by

— A measuring site shall be chosen conforming to the specified requirements.

— Cross sectional area shall be measured by a method specified in this standard, appropriate to the dimensions.

— Velocity observations shall be made by a method specified in this standard.

— The discharge shall be calculated by a method specified in this standard.

$$Q=\bar{V}A \tag{1}$$

where

Q Flow

$\bar{V}$ Mean Velocity

A Cross sectional Area

5 Site selection

5.1 Selection of site

The site selected shall comply with the following requirements.

a) The channel at the measuring site shall be straight and of uniform cross-section and slope in order to minimize abnormal velocity distribution. The straight length upstream shall be as at least twice that downstream.

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

c) The bed and margins of the channels shall 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 shall be regular in the vertical and horizontal planes of measurement.

e) Conditions at the section and in its vicinity shall 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 shall be avoided.

g) The measurement section shall be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles.

h) When gauging from a bridge with divide piers, each section of the channel shall be measured separately. Particular care shall be taken in determining the velocity distribution when bridge apertures are surcharged or obstructed.

i) The depth of water at the section shall be sufficient at all stages to ensure whichever device is deployed, it conforms to the manufactures minimum criteria for use.

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

k) Measurements made directly from a bridge should usually be made on the downstream side, taking care to avoid turbulence and eddies produced by bridge piers and other structures.

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

m) Sites where there is converging or diverging flow shall be avoided.

n) If a suitable straight section includes a bridge, wading and boat measurements shall be made upstream of the bridge.

o) The measurement of flow under ice cover is dealt with in Annex E. For streams that are subject to formation of ice cover, the main part of this standard shall be used when the stream is free flowing.

p) It may, under certain conditions of river flow or level, prove necessary to carry out measurements on sections upstream or downstream of 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.

Note *Ideal measurement conditions will be found when all requirements are satisfied. If ideal conditions are not available, it may still be possible to make a measurement, but uncertainty will be increased.*

5.2 Demarcation of site

A permanent station or one likely to be used frequently for future measurement, shall 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 the start and end of the measurement period. If the water level changes rapidly, a level measurement is recommended to be taken every 30 min.

5.2.3 If there is a possibility of a difference in the level of the water surface between two banks then an auxiliary gauge shall be considered. 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. 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 and to minimize the uncertainty in the calculation of the cross sectional area.

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 vertical plane as the cross-section at the measuring site.

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 is to be measured shall be at least the same as the points at which velocity is measured.

The number of sampling points depends on the variability of the water depth in the cross section. This number is adequate when the number of points does not significantly change the value obtained.

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

7 Measurement of velocity

7.1 Determination of velocity using point velocity measurements

A range of instruments are available to measure point velocity. These are described in Annex A

7.1.1 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, such as at a pre surveyed station, 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 and 6.3

For all measurements, the best professional judgement of an experienced hydrographer should be used, and detailed notes regarding the measurement and assumptions made should be included in the record.

In judging the recommended minimum number 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.

— Channel width < 0,5 m $n \geq 15$

— Channel width > 0,5 m and < 5m $n \geq 20$

— Channel width > 5 m $n \geq 22$

— The closeness of adjacent verticals should not be less than the minimum recommendations of equipment providers for specific instrument.

NOTE 1 For very small channels, practical considerations may not allow the recommended minimum number of verticals.

NOTE 2 insofar as possible, verticals should be chosen so that the discharge of each segment is less than 5 % of the total.

In all instances, measurements of depth made at the water's edge are additional to the above. The first and last verticals shall 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 device used for point velocity measurement shall be held in position to ensure movement is minimised during the measurement period. It shall be held so that it is not affected by any disturbances of flow.

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.

For continuity with previous versions of this standard the following criteria can be used but the level of uncertainty of the overall measurement will be much greater.

— 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 $n \geq 22$

— See Annex D.4.4 Table D6 for a guide to percentage uncertainty in measurement of mean velocity due to limited number of verticals

7.1.2 Skew flow

If skew flow is unavoidable, either the velocity component perpendicular to the cross section should be measured directly or the velocity magnitude measured and corrected based upon the angle from perpendicular. 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, subjected to tides or 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:

$$^{V}\text{corrected} = {}^{V}\text{measured x } cos\theta \quad (2)$$

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.

7.1.3 Determination of the mean velocity in a vertical

7.1.3.1 Choice and classification

The choice of the method for determining mean velocity depends on certain factors. These are: safety, time available, width and depth of the channel, bed conditions in the measuring section and the upstream reach, rate of change of stage, degree of accuracy desired and equipment used.

These methods are classified as follows:

a) velocity distribution method (see 7.1.3.2);

b) reduced point methods (see 7.1.3.3);

c) integration method (see 7.1.3.4).

7.1.3.2 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 shall 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 shall be chosen, taking into account the specification under 7.1.1 and 7.1.2.

NOTE 1 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 Formula (3):

$$v_x = v_a \left(\frac{x}{a} \right)^{\frac{1}{m}} \tag{3}$$

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 Formula (4):

$$\bar{v} = \left(\frac{m}{m+1} \right) v_a \tag{4}$$

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:

$$m = \frac{C_{\text{ver}}}{\sqrt{g}} \left(\frac{2\sqrt{g}}{\sqrt{g} + C_{\text{ver}}} + 0{,}3 \right) \tag{5}$$

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.

7.1.3.2.1 ADCP Stationary method

In the ADCP stationary method the ADCP is held in a specific location for a specified time and then averaging the data at that vertical to obtain a mean velocity profile or a depth-integrated mean velocity at that location.

It should be noted that ADCP instrumentation cannot measure velocity near the ADCP transducers, above the transducers or near the bed. Current manufacturer software allows extrapolation in these areas based upon the measured velocities to compute a mean velocity for the vertical.

7.1.3.3 Reduced point methods

7.1.3.3.1 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 (7.1.3.2).

It is recommended that for a new gauging section the accuracy of the selected method be assessed by the velocity distribution method.

7.1.3.3.2 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.

7.1.3.3.3 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.

$$\bar{v} = 0,5(v_{0,2} + v_{0,8}) \quad (6)$$

An alternative method of determining the mean velocity of a vertical is the Kreps method which uses velocity observations at the surface and at 0,62 of the depth below the surface

When using the Kreps method, velocity observations shall be made as near as possible to the surface and 0.62 of the depth below the surface. See Formula (7)

$$\bar{v} = 0,31*v_0+0,634*v_{0,38} \quad (7)$$

NOTE The “Kreps method“, which was developed by the Austrian hydrologist Harald Kreps, is also a two point method, See Bibliography No. 15

7.1.3.3.4 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 Formula (8):

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

7.1.3.3.5 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 $\bar{v}$ obtained from Formula (9).

$$\bar{v} = 0,1\left(v_{\text{surface}} + 3v_{0,2} + 3v_{0,6} + 2v_{0,8} + v_{\text{bed}}\right) \quad (9)$$

7.1.3.3.6 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., The mean velocity $\bar{v}$ may be found from Formula (9).

$$\bar{v} = 0,1\left(v_{\text{surface}} + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 2v_{0,8} + v_{\text{bed}}\right) \quad (10)$$

7.1.3.3.7 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.

7.1.4 Integration method

In this method the velocity throughout each vertical is measured by raising and lowering a current-meter at a uniform rate.

7.1.4.1 Current-meter

In the current-meter 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.

The average number of revolutions is the total number of revolutions divided by the total time taken for the measurement in that vertical. The average velocity can then be read from the instrument calibration corresponding to the average number of revolutions. Uncertainties introduced by using meters with more than one calibration equation should be avoided.

The discharge in the near-bed layer can be estimated using the velocity measured at the lower end of the measured area, similar to the velocity distribution method, (7.1.3.2)

If the current-meter measures velocity directly, and the velocity displayed is the mean velocity, the final reading displayed at the end of the integration period is the mean velocity in the vertical.

7.1.5 Errors and limitations

Estimates of the possible errors that may occur when using the various methods detailed in 7.1 are given in section 9. It should be noted that these estimates are of possible random errors which may occur even when all the precautions noted earlier and below are observed. If the measurement is not made under these best conditions, additional uncertainty shall 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 skew flow occurs, and the appropriate correction factors are not known accurately;

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

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

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

g) if the device is not held steadily in the correct place during the measurement or when an oscillating movement occurs. In the latter case, the resultant of the flow velocity and the transverse velocities gives rise to serious positive errors.

7.2 Determination of mean velocity from surface velocity

7.2.1 General

Traditionally determination of mean velocity from surface velocity was not encouraged as uncertainties are high. As technologies have developed it is now accepted that there are a range of techniques and instruments that are able to measure mean velocity more accurately using measurements from the water surface.

Instruments that are designed to measure discharge by measuring surface velocity only, shall conform to the relevant parts of this standard.

Reference shall be made to ISO/TR 24577, Hydrometry — Use of non-contact methods for measuring water surface velocity and discharge.

7.2.2 Non-contact systems

Particular attention shall be paid to section 5 (site selection) of this standard. Measurement of the cross-sectional area shall be in accordance of section 6 of this standard.

The coefficient at a site shall be derived using a proven technique. If the site is to be used regularly, an index rating shall be calculated. This shall be applied to the surface velocity measured to ensure the mean velocity is used in the calculation of the discharge.

7.2.3 Surface one-point method by current-meter

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 described previously.

7.2.4 Measurement of velocity using floats

7.2.4.1 General

A full description of this method is described in Annex B

This method shall only be used when it is impossible to employ other point measurement devices, however it is a useful technique in cases of reconnaissance or because of access difficulties, excessive velocities and depths or the presence of material in suspension.

7.2.4.2 Exceptions

Where it is not possible to check the coefficient directly, it may be assumed for guidance that, in general, the coefficient of the surface velocity varies between 0.84 and 0.90 depending on the shape and velocity profile of the channel.

7.2.4.3 Main sources of error

Errors that may occur during the measurement of surface velocity are listed below. They shall be taken into consideration when estimating the overall error as given in Clause 9.