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

Hydrométrie — Mesurage du débit des écoulements à surface libre — Méthodes d'exploration du champ des vitesses utilisant le mesurage de la vitesse par point

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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This document was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 318, *Hydrometry,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fifth edition cancels and replaces the fourth edition (ISO 748:2007), which has been technically revised. The main changes compared with the previous edition are as follows:

— the document has been updated to take account of technological developments;

— Clause 7 has been revised to reduce uncertainties in measurements;

— ISO 9196 regarding measurement under ice conditions has been incorporated.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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

1 Scope

This document 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 is applicable to methods using rotating-element current meters, acoustic doppler velocimeters (ADVs), acoustic doppler current profiler (ADCP) stationary method, surface velocity measurement including floats and other surface velocity systems.

Although some general procedures are discussed, this document does not describe in detail how to use or deploy these systems.

NOTE For detailed procedures, refer to guidelines from instrument manufacturers and the appropriate public agencies.

2 Normative references

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The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *Hydrometry — Vocabulary and symbols*

ISO 25377:2020, *Hydrometric uncertainty guidance (HUG)*

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3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Principle of the methods of measurements

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

This is characterized as shown by Formula (1):

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

where

Q is the flow (m^3/s);

$\bar{V}$ is the mean velocity (m/s) (averaged over the cross-section);

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A is the cross-sectional area (m^2).

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

The cross-sectional area shall be measured by a method specified in this document, appropriate to the dimensions.

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

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

5 Site selection

5.1 Selection of site

The site selected should conform to 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 should be at least six times the width of the channel upstream, and at least three times the downstream width.

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.

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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.

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

g) The measurement section (including approach and exit) 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) The section shall 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 shall be avoided.

m) If a suitable straight section includes a bridge, wading and boat measurements shall be made away from the effects of the bridge.

n) 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 document shall be used when the stream is free flowing.

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o) 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 can be found when all requirements are satisfied. If ideal conditions are not available, it is still possible to make a measurement, but uncertainty will be increased.

5.2 Demarcation of site

5.2.1 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.

5.2.2 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 natural objects and, if possible, the position noted using a global navigation satellite system (GNSS).

5.2.3 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 at least every 30 min.

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. 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

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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

Measurement of the width of the channel and the width of the individual segments shall 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

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 each vertical where velocity is measured.

The number of sampling verticals 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 of the cross-section obtained.

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

When measuring depths with a wire not normal to the surface, see Annex F.

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7 Measurement of mean velocity

7.1 Determination of mean velocity using point velocity measurements

7.1.1 General

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

7.1.2 Measurement procedure

Velocity observations are normally made at the same time as measurements of the depth. 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 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 $n \geq 22$

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As far as possible, verticals should be chosen so that the discharge of each segment is less than 5 % of the total and shall not exceed 10 % of the total.

For very small channels, practical considerations do not always allow the recommended minimum number of verticals.

The distance between two verticals shall be greater than the width of the sensor and should not be less than the minimum recommendations of the specific instrument used.

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.

The device used for point velocity measurement shall be held in position for a minimum of 30 s to obtain a good representation of mean velocity. It shall be held so movement of the instrument is minimized during the measurement period.

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 document, 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 $n \geq 22$

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See Table D.6 for guidance on percentage uncertainty in measurement of mean velocity due to a limited number of verticals.

7.1.3 Oblique flow

If oblique 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 as shown by Formula (2):

$$v_c = v_m \times \cos\theta \qquad (2)$$

where

v_c is the velocity corrected;

v_m is the velocity measured.

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 is not applied in such cases.

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7.1.4 Determination of the mean velocity in a vertical

7.1.4.1 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 7.1.4.2);

b) reduced point methods (see 7.1.4.3);

c) integration method (see 7.1.5).

7.1.4.2 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 7.1.2 and 7.1.3.

This subclause deals primarily with the determination of mean velocity in the vertical. It can be necessary to apply the same principle to the determination of mean velocity close to the vertical side

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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 can vary over a wider range depending on the hydraulic resistance. The value m = 4 applies to coarse beds or coarse vertical sides while m = 10 is characteristic of smooth beds or smooth vertical sides.

m is obtained as shown by Formula (5):

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

where

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

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

NOTE 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.

7.1.4.2.1 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.

7.1.4.3 Reduced point methods

7.1.4.3.1 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 (see 7.1.4.2).

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

7.1.4.3.2 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.

7.1.4.3.3 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. See Formula (6):

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

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):

$$\bar{v} = 0{,}31 \times v_0 + 0{,}634 \times v_{0{,}62} \qquad (7)$$

NOTE The Kreps method, which was developed by the Austrian hydrologist Harald Kreps, is also a two-point method[21].

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7.1.4.3.4 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):

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

7.1.4.3.5 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 $\bar{v}$ is obtained from Formula (9):

$$\bar{v} = 0{,}1\left(v_0 + 3v_{0{,}2} + 3v_{0{,}6} + 2v_{0{,}8} + v_{\mathrm{bed}}\right) \qquad (9)$$

7.1.4.3.6 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 $\bar{v}$ can be found from Formula (10):

$$\bar{v} = 0{,}1\left(v_0 + 2v_{0{,}2}\, 2v_{0{,}4} + 2v_{0{,}6} + 2v_{0{,}8} + v_{\mathrm{bed}}\right) \qquad (10)$$

7.1.4.3.7 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

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method applied can be demonstrated by experiment to give results of a similar accuracy to those listed above.

7.1.5 Integration method

In the integration method, the velocity throughout each vertical is measured by raising and lowering a current meter 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.

7.1.6 Errors and limitations

Estimates of the possible errors that can occur when using the various methods detailed in 7.2 are given in Clause 9. It should be noted that these estimates are of possible random errors which can 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.

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Errors can arise:

a) if the flow is unsteady;

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

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c) if oblique 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 it is possible that a systematic error is 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, there are a greater range of techniques and instruments that are able to calculate 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 document.

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