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Hydrometry — Measurement of liquid flow in open channels under tidal conditions

Hydrométrie — Mesurage du débit des liquides dans les canaux découverts dans des conditions de marée

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 2425 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This third edition cancels and replaces the second edition (ISO 2425:1999), which has been technically revised. It also incorporates the Amendment ISO 2425:1999/Amd.1:2003. Annex D on measurement of tidal flow using an acoustic Doppler velocity meter has been added.

Hydrometry — Measurement of liquid flow in open channels under tidal conditions

1 Scope

This International Standard provides a summary of recommended methods for the determination of liquid flow in tidal channels, special consideration being given to those techniques that are either unique to or particularly appropriate for application under tidal conditions, including treatment of uncertainties.

Reference is also made, where appropriate, to methods for the determination of flow in non-tidal channels, but attention is drawn to their limitations with respect to practicality and/or uncertainty.

This International Standard does not describe alternative methods, such as the use of weirs, flumes, dilution gauging, salt velocity and floats, although they might be suitable under certain conditions, especially where the effect of tides only impedes and does not stop or reverse the passage of stream flow. These methods are described in detail in other International Standards.

This International Standard specifies two types of technique:

a) techniques for single measurements of tidal flow;

b) techniques for continuous measurement of tidal flow.

Annex A specifies the cubature method of measurement. Annex B specifies methods for the determination of flow under tidal conditions, and Annex C gives an example of the computation for a single vertical. Similar computations are possible for other verticals. Annex D describes the determination of tidal flow using an acoustic Doppler velocity meter.

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 748:2007, *Hydrometry — Measurement of liquid flow in open channels using current-meters or floats*

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 1100-1, *Measurement of liquid flow in open channels — Part 1: Establishment and operation of a gauging station*

ISO 6416, *Hydrometry — Measurement of discharge by the ultrasonic (acoustic) method*

3 Terms and definitions

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

4 Abbreviated terms

ADCP acoustic Doppler current profiler

ADP acoustic Doppler profiler

ADV acoustic Doppler velocimeter

ADVM acoustic Doppler velocity meter

5 Principles of methods of measurement

5.1 General

Tidal flow measurement can be an instantaneous rate of flow or a total volume of flow during a flood or ebb tide. The unsteady nature and change in direction of flow under tidal conditions create problems of measurement additional to those associated with the measurement of the discharge of unidirectional streams. The methods specified in ISO 748, ISO 1100-1, ISO 4369, ISO 9123, ISO/TR 9823 and ISO 9825 cannot therefore always be applied to tidal channels. Any change in water quality brought about by tidal conditions can affect the methods specified in ISO 6416 and ISO 9213.

For various reasons, direct measurements of velocity in tidal channels are more liable to greater uncertainty than those made under conditions of unidirectional flow.

The methods of measurement in this International Standard can be grouped into either single or continuous measurements.

5.2 Single measurement methods

5.2.1 Velocity area method

At a chosen gauging site, the velocity of flow and the area of cross-section of the channel are measured. The product of these measurements at any instant is the rate of flow or discharge past the gauging site at that instant. It is referred to as the velocity area method and includes the following techniques.

a) current meter from a fixed station;

b) acoustic Doppler profiler or acoustic Doppler velocity meter from a fixed station;

c) current meter from a moving station (moving boat);

d) acoustic Doppler current profiler from a moving station (moving boat).

5.2.2 Cubature method

In an area that includes a stretch of river channel and its flood plain, surface areas and rise in water level of stored water are measured at known time intervals. Volumes of stored water are computed, and the flow into the upstream stretch of river is estimated, from which the average rate of flow is determined (see Annex A).

5.3 Continuous measurement methods

5.3.1 Ultrasonic method (ISO 6416)

Transducers are positioned on each bank of the river channel, such that the acoustic path is at an oblique angle to the direction of flow. The time taken for a pulse of sound to travel in both directions is measured and compared. From these two times, the velocity of the water can be computed. Knowledge of the cross-sectional area allows computation of discharge.

5.3.2 Electromagnetic method (ISO 9213)

A horizontal coil is constructed above or below a river channel. A magnetic field is generated by an alternating current and voltages are induced in the flowing water, which acts as an electrical conductor. After calibration, measurements of electrical parameters and water depth provide a means of determining the discharge.

5.3.3 Acoustic Doppler velocity method from a fixed station

Acoustic Doppler velocity meters (ADVMs) may be horizontally or vertically oriented and shall be fixed to a bridge pier or abutment, or other stable mountable structure for horizontal mountings, or to the channel bed for vertical mountings. The ADVMs measure an index velocity that is related to the measured average velocity of the channel (mean velocity) determined from current meter measurements and channel cross-sectional area. A separate water level-to-area relation is developed from regularly measured cross-sectional geometry at or near the location of the ADVM. Discharge is computed as a product of the mean velocity and cross-sectional area. The acoustic Doppler velocity method can be implemented using the following techniques:

a) horizontal measurement from a fixed station or stations;

b) vertical measurement from a fixed station or stations;

c) a combination of the horizontal and vertical methods at a fixed station.

5.3.4 Unsteady flow models

Unsteady flow models may be used for computing continuous records of discharge in open channels in both tidal and non-tidal conditions. These models, however, are not applicable where a longitudinal density gradient, such as a salt-water wedge, is present.

Unsteady flow models are based on the numerical solution of non-linear partial differential equations that describe gradually varied unsteady flow in open channels. The available models employ one or more of several numerical computation techniques. Data requirements, which can be substantial, depend on the numerical techniques employed by the model selected. It is necessary that techniques for the application of unsteady flow models and the data requirements be clearly defined and understood for successfully computing discharges.

6 Special considerations and choice of method

6.1 Special considerations

Changes in water level at the mouth of a river due to tidal action cause backwater effects in the channel. These changes can alter water level and flow magnitude only, or water level, flow magnitude, and direction of flow. The entire flow might be reversed in direction, or only some of the flow might be reversed due to variations in the density gradient.

Most flow-gauging techniques are generally best suited to conditions closely approximating to steady flow, but unsteady flow causes additional difficulties, as follows.

a) At any section, water levels continuously change.

b) At any point in a vertical, velocities continuously change either with or without change in direction.

c) In any vertical, the continuously changing velocities could create greater velocity gradients than in channels with steady uniform flow.

d) During the period of transition in flow direction (flood to ebb or ebb to flood), zero velocity can occur at a succession of points over the changing velocity profile.

e) High water and low water might not take place at the same time as the reversal in flow direction.

f) The change in direction of flow might not take place at the same time throughout the wetted cross-section and the flood and ebb channels might be positioned differently in a wide cross-section.

g) When the direction of flow changes, the characteristics of the approach conditions from the upstream and the downstream can be different and can result in divergence (when the angle between the flood and the ebb flow is other than 180°) between the flood and ebb flow.

h) Flow can be stratified, with liquids of different densities in each layer. While the liquid in the upper stratum may flow in one direction, the denser liquid in the lower stratum may flow at a different speed in the same or opposite direction. When a density difference due to a salt-water wedge occurs, the maximum velocity in each layer can occur at different times.

i) At any section in a channel, variations in water level can cause changes in width and cross-section of flow.

j) An increase in the number of measurements is required to make an estimate of discharge.

k) During a tidal cycle there can be variations in salinity, leading to changes in the speed of sound and conductivity of the water, and these can adversely affect ultrasonic, acoustic Doppler velocity meter, and electromagnetic methods.

l) During a tidal cycle there can be water column variations in temperature and/or conductivity that can cause acoustic beam direction changes that can adversely affect ultrasonic and acoustic Doppler velocity meter methods.

m) Spatial flow patterns during ebb flow can sometimes be significantly different from the flow conditions during flood tide (e.g. separate ebb and flood gullies in a tidal estuary).

6.2 Choice of method

6.2.1 General

In channels with steady flow, one of the main factors affecting the choice of gauging method is the frequency of measurements of discharge in the channel. Observations may be repeated over months or years (continual or repeated measurements), or as little as once only (occasional measurements). Under variable or unsteady conditions, the frequency of measurement, although affecting the cost of each gauging and important economically, shall not be compromised. The physical conditions of flow and waterway dominate the choice.

6.2.2 Physical conditions

The physical conditions that affect the choice of gauging method are:

a) tidal range including level, flow and velocity;

b) width of channel;

c) variation in width along a channel and with time;

d) depth of channel;

e) shape of channel;

f) change in flow direction during a tidal cycle including flow reversal or backwater effects;

g) density of river traffic;

h) the number of experienced staff available;

i) the number of boats and gauging equipment available;

j) environmental considerations;

k) the intrusion of a salt-water wedge;

l) a temperature gradient in the water;

m) the incidence of seiches and wind-induced waves;

n) health and safety of personnel (including the availability of lighting during hours of darkness);

o) the number of observations to be made, e.g. current meter gauging requires a considerable number of observations at one cross-section;

Guidance on the selection of the gauging method is summarized in Table B.1.

6.2.3 Selection and demarcation of site

6.2.3.1 General

The site should contain all stages of flow that occur or that need to be measured. Ideally, sites should conform to the following requirements.

a) Sites where aquatic vegetation grows should be avoided or kept free from aquatic vegetation to ensure there is no obstruction to the gauging operation, unless the method is tolerant to the presence of aquatic vegetation, e.g. electromagnetic method.

b) There should be no vortices, dead water, or strong cross-currents.

c) Sites where ice accumulates should be avoided.

d) The site should be accessible for personnel and equipment at all stages of flow.

6.2.3.2 Preliminary reconnaissance surveys

A preliminary reconnaissance survey of all potential sites should be made to eliminate those that are unsuitable and to ensure that the hydraulic and topographic features of the remainder conform to the requirements of the International Standards pertaining to the method of measurement to be used.

Inspections under different flow conditions might be necessary to ensure that conditions unsuitable for the method of measurement do not occur when observations are being made.

6.2.3.3 Survey of chosen site

A permanent benchmark should be established and related to a standard datum in general use in the area. All subsequent levelling surveys should be reduced to the standard datum.

A topographical survey of the channel at the proposed gauging site should be made. This should include a plan of the site indicating the width of the water surface at a stated stage, date and time, the edges of the natural banks of the channel or channels, the line of any definite discontinuity of the slope of these banks, and the toe and crest of any artificial flood bank.

The survey of the stretch of channel should be extended through the floodway to an elevation above the highest anticipated flood level. The spacing of levels or soundings should be close enough to reveal any abrupt change of the contour of the channel. The bed of the channel should be examined for the presence of rocks or boulders, particularly near positions where measurements will be made.

6.2.3.4 Additional site selection criteria for ADVMs

The ADVM is a device for measuring an index velocity from a fixed location. For tidal measurement, the site requirements such as minimum depth and velocities are largely dependent on the transducer frequency, sensor orientation (horizontal or vertical), and the mode of operation (how the instrument processes the acoustic signals and what setup parameters are used). Further guidance should be available from the manufacturer's instruction manual.

The ideal ADVM site satisfies the following criteria.

a) The general course of the stream is straight for sufficient distance upstream and downstream from the ADVM site to be outside the hydraulic effects of any flow control associated with the station.

b) If possible, the total flow is confined to one channel at all stages, and no flow bypasses the site during all normal tidal phases or storm tides. At the mouth/delta of a river system entering an ocean tidal environment this will be in the vicinity of a flow control structure such as a bridge.

c) The streambed is not subject to scour or accretion and is free of excessive aeration, turbulence or aquatic vegetation.

d) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site.

Rarely will an ideal site be found, and judgment shall be exercised in choosing between adequate sites, each of which has some shortcomings. Often, adverse conditions exist at all possible sites, and it is necessary to accept such a site.

7 Measurement of tidal flow

7.1 Techniques for single measurements of tidal flow

7.1.1 Measurement of tidal flow by velocity area methods

7.1.1.1 Site requirements

Details of the methods are provided in ISO 748, ISO 1100-1, ISO 3454, ISO 4366, ISO 4369, ISO 4375, ISO/TR 7178, ISO/TR 8363 and ISO/TR 9209.

The conditions in ISO 748 for selection of site might be difficult to achieve for tidal rivers, since the flow is unsteady and can reverse. Reversal of flow implies different approach conditions for flood and ebb at the measuring cross-section, making it difficult to obtain the idealized flow conditions specified in ISO 748. However, the site for measurement of tidal flow should be chosen to have as far as possible the following features.

a) The direction of velocities at all points, particularly during the period of maximum flow, should be at right angles to the measuring section.

b) The channel upstream and downstream of the gauging site should be straight and of uniform cross-section.

c) The depth of water in the selected length should, at low stages of flow, be sufficient to provide for the effective immersion of current meters (ISO 748). This also applies to ADVMs.

d) The view from the gauging site should be unobstructed by trees or other obstacles.

e) The bed of the channel should not be subject to significant changes during the tidal cycle.

f) The location of cross-sections, particularly the measuring cross-section, should be marked with clearly visible and readily identifiable markers of sufficient durability to last the lifetime of the gauging station.

g) One or more staff gauges should be installed to provide a means of measuring all stages of flow. The gauge should be related by precise levelling to the standard datum.

h) Where there might be a significant difference in the level of the water surface between the two banks, an auxiliary gauge should be installed on the opposite bank, particularly in the case of wide rivers. The mean of the measurements taken from the two gauges should be taken as the mean level of the water surface.

7.1.1.2 Measurement of cross-sectional area

ISO 748 shall be applied without alteration.

7.1.1.3 Measurement of velocity by fixed current meter method

7.1.1.3.1 Measurement procedure

ISO 748, ISO 4375 and ISO 5168 provide details of the method, equipment and uncertainties in the results.

When using a current meter to measure velocities at chosen locations across a channel subject to tidal flow, speed of measurement is important. Many procedures considered essential to achieve accuracy in unidirectional flow measurements might have to be abandoned for practical and economic reasons in favour of those that will accelerate the gauging procedure.

If the equipment is available, it is recommended that an acoustic Doppler profiler be used for measurements at tidal sites.

To limit the risk of error due to changes in the direction of flow, the use of a direction-indicating current meter is recommended. Since the direction of flow might not be the same at different levels in the vertical, the depths at which the directions of flow are measured should also be recorded, and the measurement made at a number of points (at least surface, mid-depth and bed) in the vertical. An alternative but less reliable method of determining the direction of flow is to use a subsurface float.

Velocity measurements should be made at as many verticals as practicable depending on the availability of staff, instruments and equipment. Measurements should be made at not less than three verticals, using the following procedure.

a) Synchronize the watches and clocks of all sensors and observers.

b) Survey the gauging cross-section.

c) Mark the positions of the selected verticals with mooring buoys using both flood and ebb anchors to restrict the movement of the buoy, if the gauging is to be carried out from a boat. If gauging is to be carried out from a bridge or cableway, the positions should be marked on the structures. If gauging is by wading (rarely possible except in the upper reaches of small tidal rivers), stakes should be driven into each bank of the river to denote the measurement section and each gauging position related to such stakes.

d) Measure the depth of water and the clock time at the first vertical.

e) Measure velocities, in magnitude and direction, near the surface, at depths of 0,2, 0,4, 0,6 and 0,8 of the total depth and near the bed. Repeat the measurement near the surface. If the depth exceeds about 15 m, measure velocities at intervals of one tenth of the depth between 0,1 and 0,9 of the total depth, and repeat the measurement at 0,1 of the depth. Record the clock time of every measurement.

f) Measure depth of water and clock time at the first vertical again, and then move the gauging equipment as quickly as possible to the second vertical.

g) Repeat the measurements of depth, velocity and time at the second vertical as specified in d), e) and f), before proceeding to the third vertical to repeat the procedure. Continue this procedure until measurements have been made at all verticals. Return to the first vertical to repeat the procedure.

h) If more than one gauging team is available, measurements may be made at two or more verticals simultaneously. Each team should carry out observations on preselected verticals to avoid interfering with one another as specified in d) to g).

i) The measurements of depth, velocity and time at the verticals should be continued for a period of at least 2 h longer than the tidal cycle (i.e. 1 h before and 1 h after the tide cycle). Where there is diurnal inequality, observations should be taken over at least 25 h.

j) At intervals of not more than 15 min, observe water level and clock time. These observations should begin before the survey of the cross-section is started, and should continue until after the last measurement on a vertical has been made.

k) Resurvey the cross-section.

l) Where oblique flow is unavoidable, the angle of the direction of flow to the perpendicular to the cross-section shall be measured and the measured velocity corrected. Special instruments are available for measuring both angle and velocity at a point simultaneously.

Where these instruments are not available and there is insignificant wind, the angle of flow throughout the vertical may be taken to be the same as that observed on the surface. If the channel is very deep, or if the local bed profile is changing rapidly, this assumption shall not be accepted without checking. If the measured angle to the perpendicular is γ, then:

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

7.1.1.3.2 Computation of discharge for fixed current meter method

For each set of verticals, the following calculations and plots are necessary.

a) Choose a convention for flow direction. For each vertical, adjust the values of measured velocities to the time of the first velocity measurement, and calculate the mean velocity over the vertical.

$$V_{n_\text{a}} = V_n + \frac{V_1 - V_r}{V_r} \cdot \frac{t_n - t_1}{t_r - t_1} \cdot V_n$$

$$V_m = \frac{1}{r-1}\left[V_{1a} + V_{2a} + \ldots + V_{(r-1a)}\right]$$

where

t_1 is the time of first observation at surface;

t_n is the time of nth observation;

t_r is the time of repeat observation at surface;

V_1 is the first measured velocity at surface;

