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Measurement of liquid flow in open channels under tidal conditions

Mesure de débit des liquides dans les canaux découverts — Mesurages dans des conditions de marée

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

International Standard ISO 2425 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations,* Subcommittee SC 1, *Velocity area methods.*

This second edition cancels and replaces the first edition (ISO 2425:1974), which has been technically revised.

Annexes A, B and C of this International Standard are for information only.

Introduction

The measurement of flow in tidal channels poses problems additional to those encountered in unidirectional streams. A tidal river reach will exhibit a range of conditions, from the backwater effect, when the flood tide impedes the freshwater river flow, through to the complete flow reversal.

The duration and extent of the tidal influence in an estuarial measurement station depend on the actual location of the station in the estuary.

Measurement of liquid flow in open channels under tidal conditions

1 Scope

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

Reference is also made, where appropriate, to methods developed for measurement in non-tidal channels, but in such cases attention is drawn to their limitations with respect to practicality and/or accuracy.

This International Standard does not describe alternative methods, such as weirs, flumes, dilution gauging, salt velocity and floats, although they may 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.

The standard comprises two parts:

a) techniques for single measurements of tidal flow;

b) techniques appropriate for continuous measurement of tidal flow.

The cubature method of measurement, although currently not used, is included in annex A. Annex B presents methods suitable for measurement for tidal conditions, and annex C gives an example of the computation for a single vertical. Similar computations may be made for other verticals.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 748:1997, *Measurement of liquid flow in open channels — Velocity-area methods.*

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

3 Terms and definitions

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

4 Principles of methods of measurement

4.1 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, ISO 4369, ISO 9123, ISO 9823 and ISO 9825 cannot therefore always be applied to tidal channels. Any change in water quality brought about by tidal conditions may affect the methods specified in ISO 6416 and ISO 9213.

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

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

4.2 Single measurement methods

4.2.1 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) current meter from a moving station (moving boat).

4.2.2 Cubature method

In an area which 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).

4.3 Continuous measurement methods

4.3.1 Ultrasonic method (ISO 6416)

Transducers are positioned on each bank of the river channel, such that the flight 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 mean velocity can be computed.

4.3.2 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 measuring the discharge.

4.3.3 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.

5 Special considerations and choice of method

5.1 Special considerations

Changes in water level at the mouth of a river due to tidal action cause backwater effects in the channel. These may alter water level only, or both water level and direction of flow. The whole flow may be reversed in direction, or only some of the flow may be reversed due to differences in density.

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

a) At any section, water levels continuously change;

b) at any point on a vertical, velocities continuously change either with or without change in direction;

c) in any vertical, the continuously changing velocities usually 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 occurs at a succession of points over the changing velocity profile;

e) high water and low water may not take place at the same time as the reversal in flow direction;

f) the change in direction of flow does not take place at the same time throughout the wetted cross-section;

g) when the direction of flow changes, the characteristics of the approach conditions from the upstream and the downstream may be different and may 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 may be stratified, with liquids of different densities in each layer. While the liquid in the upper stratum may flow in one direction, the more dense liquid in the lower stratum may flow at a different speed in the same or opposite direction. When such density difference due to a salt water wedge occurs, the maximum velocity in each layer may occur at different times;

i) at any section in a channel, variations in water level may cause changes in width and cross-section of flow;

j) an increase in the number of measurements required to make an estimate of discharge;

k) during a tidal cycle there may be variations in salinity leading to changes in the speed of sound and conductivity of the water, and these may adversely affect ultrasonic and electromagnetic methods.

5.2 Choice of method

5.2.1 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 occasionally, often once only (occasional measurements). Under variable or unsteady conditions, the frequency of measurement, although affecting the cost of each gauging and important economically, may not be compromised. The physical conditions of flow and waterway dominate the choice.

5.2.2 Physical conditions

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

a) tidal range;

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 ebb tide or flood tide;

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. the velocity-area method requires a considerable number of observations at one cross-section;

p) flow reversal or only a backwater effect.

The principal methods of measurement and the effect of physical conditions on the selection of the gauging method are summarized in annex B, table B.2.

5.2.3 Selection and demarcation of site

5.2.3.1 General

The site should contain all stages of flow which occur or which need to be measured.

Ideally, sites should conform to the following requirements.

a) Sites where weeds grow should be avoided or kept free from weeds to ensure there is no obstruction to the gauging operation, unless the method is tolerant to the presence of weeds, 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 staff and equipment at all stages of flow.

5.2.3.2 Preliminary reconnaissance surveys

A preliminary reconnaissance survey of all potential sites should be made to eliminate those which 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 may be necessary to ensure that conditions unsuitable for the method of measurement do not occur when observations are being made.

5.2.3.3 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 Measurement of tidal flow

6.1 Techniques for single measurements of tidal flow

6.1.1 Measurement of tidal flow by velocity-area methods

6.1.1.1 Site requirements

The following International Standards provide details of the methods: ISO 748, ISO 1100-1, ISO 3454, ISO 4366, ISO 4369, ISO 4375, ISO 7178, ISO 8363 and ISO 9209.

The conditions indicated in ISO 748 for selection of site may be difficult to achieve for tidal rivers, since the flow is unsteady and may 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);

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 may 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.

6.1.1.2 Measurement of cross-sectional area

ISO 748 shall be applied without alteration.

6.1.1.3 Measurement of velocity by the fixed current-meter method

6.1.1.3.1 Measurement procedure

International Standards 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 may have to be abandoned for practical and economic reasons in favour of those which will accelerate the gauging procedure.

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

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 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), each gauging position should be marked by driving a stake into the river bed;

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 described 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 pre-selected verticals to avoid interfering with one another as specified in items d) to g);

i) the measurements of depth, velocity and time at the verticals should be continued for a period of at least two hours longer than the tidal cycle (i.e. one hour before and one hour 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:

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

6.1.1.3.2 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.

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

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

where

t_1= time of first observation at surface;

t_n = time of nth observation;

t_r = time of repeat observation at surface;

V_1 = first measured velocity at surface;

V_n = measured velocity at time t_n;

V_r = repeat measured velocity at surface;

V_{na} = adjusted value of measured velocity V_n;

V_m = mean of adjusted velocities;

r–1 = number of points in the vertical.

b) plot cross-sections;

c) plot depth of each vertical against time;

d) tabulate mean velocities for each vertical against clock times of first and last observations of velocity in that set;

e) for each vertical, plot mean velocity against the mean of the clock times for each set of velocity measurements;

f) for clock times at intervals of not more than 30 min, tabulate:

1) clock time;
2) water level;
3) area of cross-section (computed from cross-section and water level);
4) mean velocity on each vertical [interpolated from plot in e) above]; and