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ISO RECOMMENDATION

R 748

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS BY VELOCITY AREA METHODS

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BRIEF HISTORY

The ISO Recommendation R 748, *Liquid flow measurement in open channels by velocity area methods*, was drawn up by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, the Secretariat of which is held by the Indian Standards Institution (ISI).

Work on this question by the Technical Committee began in 1956 and led, in 1965, to the adoption of a Draft ISO Recommendation.

In June 1966, this Draft ISO Recommendation (No. 948) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies:

Argentina	Greece	New Zealand
Belgium	India	Romania
Brazil	Ireland	South Africa, Rep. of
Canada	Israel	Switzerland
Chile	Italy	Turkey
Czechoslovakia	Japan	United Kingdom
France	Korea, Rep. of	
Germany	Netherlands	

No Member Body opposed the approval of the Draft.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in June 1968, to accept it as an ISO RECOMMENDATION.

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LIQUID FLOW MEASUREMENT IN OPEN CHANNELS BY VELOCITY AREA METHODS

1. SCOPE

This ISO Recommendation deals with the methods for determining the velocity and cross-sectional area of water flowing in open channels, and of computing the discharge therefrom.

It covers methods of employing current meters and floats to measure the velocities. Although, in most cases, these measurements are intended to determine the stage-discharge relationship by means of readings at several stages, this ISO Recommendation deals only with single measurements of the discharge; the continuous recording of discharges over a period of time will be covered in a separate ISO Recommendation.

NOTE. — Measurements for the purpose of determining the discharge in efficiency tests of hydraulic turbines are specified in Publication 41, *International code for the field acceptance tests of hydraulic turbines*, of the International Electrotechnical Commission.

2. TERMINOLOGY

For the purposes of this ISO Recommendation, the definitions given in ISO Recommendation R 772, *Vocabulary of terms and symbols used in connection with the measurement of liquid flow with a free surface*, apply.

3. UNITS OF MEASUREMENT

The units of measurement used in this ISO Recommendation are seconds, metres (or feet), kilogrammes and degrees Celsius (or Fahrenheit).

4. PRINCIPLE OF THE METHODS OF MEASUREMENT

- 4.1 The principle of these methods consists in effectively measuring the flow velocity and cross-sectional area. A gauging site is chosen conforming to the specified requirements; the width is measured either by means of a steel tape or by some other surveying method, depending on its magnitude, and the depth is measured at a number of verticals along the width, sufficient to determine the shape and area of cross-section.

Velocity observations are made at the same time as measurement of depth, especially in the case of unstable beds; they are made by any one of the standard methods by the use of current meters, the principle of which is based on the proportionality between the local flow velocity and the speed of the rotor. Velocity observations are also made by the use of surface floats and velocity rods under certain circumstances. From the individual observations the mean velocity is generally computed; however, in certain methods such as the integration method, the mean velocity is directly obtained.

- 4.2 The discharge is computed by summing the products, either arithmetically or graphically, of the velocity and corresponding area for a series of observations in a cross-section.

5. SELECTION AND DEMARCATION OF SITE

5.1 Initial survey of site

It is desirable that approximate measurements of widths, depths and velocities should be made in a preliminary survey to decide on the suitability of a site conforming as far as possible with the conditions given in clause 5.2. It is only intended that these measurements should serve as a guide that both the longitudinal and transverse bed profiles and the velocity distribution are acceptable for the purpose of discharge measurement.

5.2 Selection of site

The accuracy of the determination of the discharge by the velocity area method is increased if

- (a) the conditions of flow do not change within the period of measurement;
- (b) the velocities at all points are parallel to one another and at right angles to the measuring cross-section;
- (c) the curves of the distribution of the velocities are regular in the vertical and horizontal planes on which they are measured;
- (d) the geometrical dimensions of the cross-section of the open channel are clearly defined.

Hence, the most favourable conditions for accurate measurements are to be found where the cross-section is in a straight reach. On this basis, therefore, the site should be selected such that, as far as possible, the requirements and points given in clauses 5.2.1 and 5.2.2 are met.

5.2.1 The site selected should comply, as far as possible, with the following requirements:

- (a) the open channel at the gauging site should be straight and of uniform cross-section and slope, as far as possible, in order to avoid an abnormal velocity distribution. When the length of the straight channel is restricted, it is recommended for current meter measurements that the straight length upstream of the measuring cross-section should be twice that downstream;
- (b) the depth of water in the selected reach should be sufficient to provide for the effective immersion of either the current meters or floats, whichever are to be used;
- (c) the view of the gauging site should be clear and unobstructed by trees or other obstacles.

5.2.2 In addition to the requirements specified in clause 5.2.1, the following points should be taken into consideration when selecting the gauging site:

- (a) the bed of the reach should not be subject to changes during the period of measurement;
- (b) irrespective of the flow, all discharges should be contained within a defined channel or channels, or within an unobstructed floodway having substantially stable boundaries, with well-defined geometrical dimensions;
- (c) the site should be remote from any bend or natural or artificial obstruction if disturbance of the flow is likely to be caused thereby;
- (d) the gauging site should be kept clear of aquatic growth during the period of measurement;
- (e) sites at which vortex, backward flow, or dead zones tend to develop should be avoided;
- (f) measurement with converging, and more so with diverging, flow over an oblique measuring section should be avoided as it is difficult to allow for the systematic errors that can arise;
- (g) the orientation of the reach should be such that the direction of flow is as closely as possible normal to that of the prevailing wind.

Where these requirements cannot be met (for instance, when in alluvial rivers the river bed is changing during the period of measurement, or when, under flood conditions, the river is not confined to a single channel in embankments), a gauging site should be chosen such that the bed change and/or overflow is a minimum. Flood plains—if they cannot be avoided—should be of minimum width, as smooth as possible, without a distinct channel, and clear of bushes and trees.

In those instances where it is necessary to make measurements in the neighbourhood of a bridge, it is preferable that the gauging site should be upstream of the bridge. However, in special cases and where accumulation of ice, logs or debris is liable to occur, it is preferable that the gauging site should be downstream of the bridge.

NOTE. — If, after the site has been selected, unacceptable changes occur in the channel conditions, another site should be selected for the measurements.

5.3 Demarcation of site

The site, after selection, should be provided with means for demarcation of the cross-section and for determination of the stage.

- 5.3.1 The position of each cross-section, normal to the mean direction of flow, should be defined on the two banks by clearly visible and readily identifiable markers.
- 5.3.2 The stage should be read from a gauge at intervals throughout the period of measurement and the gauge datum should be related by precise levelling to a standard system of levels.
- 5.3.3 An auxiliary gauge on the opposite bank should be installed where there is likelihood of a difference in the level of water surface between the two banks. This is particularly important in the case of very wide rivers. The mean of the measurements taken from the two gauges should 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

The cross-sectional profile of the open channel at the gauging site should be determined by measuring, at the cross-section, the depth relative to the water surface at a sufficient number of points to establish the shape of the bed.

The location of these points should be determined by measuring their horizontal distance to a fixed reference point in the cross-section. In practice, these measurements determine the cross-sectional area of the individual segments between successive verticals where velocities are measured.

6.1 Measurement of widths

The measurements of the width of the channel and the widths of the individual segments may be obtained by measuring the distances from or to a fixed reference point, which should be in the same plane as the cross-section at the gauging site.

- 6.1.1 Where the width of the channel permits, or when the surface is covered by ice, these distances should be measured by direct means, e.g. a steel tape or suitable marked wire, care being taken to apply the necessary corrections given in Annex A. The intervals between the verticals, i.e. the widths of the segments, should be similarly measured.
- 6.1.2 Where the channel is too wide for the above methods of measurement, the distances should be determined by optical or electrical distance meters, or by one of the surveying methods given in Annex B.

6.2 Measurement of depth

- 6.2.1** Measurements of depth should be made at intervals close enough to define the cross-sectional profile accurately. In general, the intervals should not be greater than 1/15 of the width in the case of regular bed profiles, and should not be greater than 1/20 of the width in the case of irregular bed profiles.

NOTE. — For small channels with a regular bed profile, the number of intervals may be reduced. This may, however, affect the accuracy of the determination of the bed profile (see section 9).

- 6.2.2** The depth should be measured employing either sounding rods or sounding lines, or other suitable devices. Where the channel is of sufficient depth an echo-sounder may be used. If the velocity is high, it is preferable to use an echo-sounder or other device which will not require large corrections.

NOTE. — When measuring the depth under an ice cover on the water, it is necessary to determine the space, if any, between the water surface and the underside of the ice by using special devices such as L-shaped scales. If there is a layer of frazil ice its thickness should also be determined.

- 6.2.3** When a sounding rod or sounding line is used, at least two readings should be taken at each point and the mean value adopted for calculations, unless the difference between the two values is more than 5%, in which case two further readings should be taken. If these are within 5%, they should be accepted for the measurement and the two earlier readings discarded. If they are again different by more than 5%, no further readings should be taken, but the average of all four readings should be adopted for the measurement, noting that the accuracy of this measurement is reduced.

When an echo-sounder is used, the average of several readings should preferably always be taken at each point, but regular calibrations of the instrument are required under the same conditions of salinity and temperature of the water.

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

NOTES

- Where measurements of the depths are made separately from the velocity measurements and the water level is not steady, it should be observed at the time of each measurement of depth. If this is not possible, the water level should be observed at intervals of 15 minutes and the value of the level at the time of each determination of depth should be obtained by interpolation.
- If the bed is composed of unstable material (shifting sand, silt) repeated measurements by a rod or line of the depth at one point are not recommended with a view to avoiding disturbance of the bed.
- When, during the measurement of discharge, the bed profile changes appreciably, depth measurements should be carried out by taking one reading at each point at the beginning and one at the end of each measurement of velocity verticals, and the mean value of these two measurements should be taken as the effective depth.
- Inaccuracies in soundings are most likely to occur
 - owing to the departure from the vertical of the sounding rod or line, particularly in deep water, when the velocity is high;
 - owing to the penetration of the bed by the sounding lead or rod;
 - owing to the nature of the bed when using an echo-sounder.

Difficulties due to (a) may be avoided by the use, where practicable, of an echo-sounder, or pressure-measuring device. The effects of drag on a sounding line may be reduced by using a streamlined lead weight at the end of a fine wire. A correction should be applied to the wetted length of wire if the wire is not normal to the water surface. It is recommended that the angle should not be greater than 30° in view of the inaccuracies involved. Methods of applying the correction are given in Annex C.

Difficulties due to (b) may be overcome by fitting a baseplate to the lower end of the sounding rod, or by fastening a disk to the end of the sounding line, when they will not cause scour of fine bed material due to high velocities.

5. In certain cases, for example floods, it may be impossible to determine an adequate profile of cross-section during the measurement. For those cases the full profile should be determined by surveying methods, either before or after the measurement; however, it should be recognized that this method is subject to errors due to possible erosions or deposits in the cross-section between the time the profile is determined and the time of measurement.

7. MEASUREMENT OF VELOCITY

7.1 Measurement of velocity using current meter

7.1.1 Calibration of current meter

The current meters should be individually rated to cover the range of velocities of the flow in the channel, taking care that the calibration is carried out under similar conditions of suspension to those used during the discharge measurement. If an individual calibration is not possible, a mean rating may be adopted, determined from a number of current meters of the same type, but particular regard should then be paid to the question of the tolerance to be used in the estimation of errors.

NOTE. — The rating of the current meter can be effected by drawing it through still water and noting the angular velocity of the rotor of the current meter for known speeds of the carriage. The rating of the meter should be checked by repetition of the rating operation or by comparison with a standard current meter at sufficiently frequent intervals to ensure that the rating has not changed.

- 7.1.1.1 The current meter should be kept in good condition by thorough cleaning after each use, and by timely replacement of all worn or damaged parts. Where important parts are replaced, recalibration of the current meters is necessary.

- 7.1.1.2 Cup-type meters should be tested by the “spin test” as specified by the manufacturer before and after each use. The bucket wheel should come to rest slowly and evenly and should revolve throughout in the same horizontal plane. Propeller-type current meters should be tested before and after each use as specified by the manufacturer; it may be useful to check, with the help of moulds or metal calipers, that the propellers are not deformed since their calibration.

7.1.2 Measuring procedure

Velocity observations are normally made at the same time as measurements of the depth. This method should be used in the case of unstable beds. Where, however, the two measurements are made at different times, the velocity observations should be taken at a sufficient number of places, ordinarily in fifteen to twenty verticals, and the intervals should be measured as described in clauses 6.1.1 and 6.1.2.

At least eight verticals should be used, provided that this does not necessitate the distance between the verticals being less than one diameter of the current meter rotor. A smaller number of verticals may be used if the width is less than eight diameters of the current meter rotor, or the depth and velocity profile are uniform.

The measuring verticals, as well as the number of observation points on these verticals, should be chosen such that each measuring point controls a fairly equal portion of the flow.

NOTE. — If conditions arise in which water runs both over and under the ice, the measurement of discharge should be carried out in the two parts separated by the ice.

- 7.1.2.1** The current meter should be held in the desired position in any vertical by means of a wading rod in the case of shallow channels, or by suspending it from a cable or rod from a bridge, trolley or boat in the case of deeper channels. When a boat is used, the current meter should be held so that it is not affected by disturbances of flow caused by the boat. After the current meter has been placed at the selected point in the vertical, it should be permitted to become adjusted to the flow before the readings are started.

NOTES

1. Care should be taken to ensure that the current meter observations are not affected by random surface waves and wind.
 2. When a number of segments having sensibly the same flow of water are to be explored, a battery of current meters fixed to the same rod can be used to measure corresponding velocities simultaneously, ensuring that there is no mutual interference.
 3. If there is any appreciable deflection of the cable on which the meter is suspended, a correction should be applied for the depth of the measuring point. No generally applicable correction factor can be given, but it should be determined by the user for his particular instrument and conditions of measurement.
- 7.1.2.2** The current meter should be exposed at each selected point for a minimum of 40 seconds. If the water velocity is known to be subject to periodic pulsations, it is advisable that the current meter should be exposed at each selected point for at least three consecutive periods of 1 minute, or for periods of sufficient duration to cover at least two periods of the pulsation. The velocity at the point should then be taken to be the average of all the separate readings, unless it is apparent that the difference is due to some cause other than pulsation of the flow.
- 7.1.2.3** The current meter should be removed from the water at intervals for examination, usually when passing from one vertical to another.
- 7.1.2.4** More than one current meter may be used in determining velocities in the individual verticals, different current meters being used for consecutive verticals. The averaging effect will tend to reduce the systematic error of measurement.
- 7.1.2.5** In channels where the flow is unsteady, it is useful 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. Experience has shown that, provided the variations in the discharge are small, the velocity distribution is not modified significantly.

A reference current meter can be positioned in the main current and the velocity at this point measured, if possible, at the same time as each local point velocity measurement in the cross-section is made. All the individual measurements during the test can then be referred to the corresponding reference reading. The *mean reference velocity*, defined as the average of all the readings of the reference current meter, can be calculated precisely. Each reading of the local point velocity can then be corrected by multiplying by the ratio of the mean reference velocity to the reference velocity reading at the instant being considered. If the reference current meter measurements are not made at the same time as the individual measurements, they should be taken at regular intervals as frequently as possible throughout the measurement and the reference reading appropriate to a local point velocity measurement obtained by interpolation.

7.1.3 *Oblique flow*

If oblique flow is unavoidable, the angle of the direction of the flow to the perpendicular to the cross-section must be measured and the measured velocity corrected. 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 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 should not be accepted without checking.

If the measured angle to the perpendicular is γ , then

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

7.1.4 *Method for mean velocity measurement in each vertical*

The mean velocity of the water in each vertical can be determined by any of the following methods, depending on the time available and having regard to the width and depth of the water, to the bed conditions, and to changing stage and whether there is ice cover, as well as to the accuracy which is to be obtained.

- (a) Velocity-distribution method (see clause 7.1.4.1).
- (b) Reduced-point methods (see clause 7.1.4.2).
- (c) Integration method (see clause 7.1.4.3).
- (d) Other methods (see clause 7.1.4.4).

In the neighbourhood of the minimum velocity of use, the error in determining the velocity increases appreciably. With normal current meters, the minimum velocity for reliable measurements is 0.15 m/s. Special current meters giving reliable measurements below this velocity may be used if they have been tested in this range of velocities for repeatability and accuracy, prior to the measurement.

The horizontal axis of the current meter should not be situated at a distance less than one and a half times the rotor height from the water surface, nor should it be at a distance less than three times the rotor height from the bottom of the channel. Besides, no part of the meter should break the surface of the water.

When the current meter is used close to the bed or surface, particularly when there are ripples or waves, additional calibrations should be made under immersed conditions similar to those encountered during the measurement.