International Standard ISO 1088

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Liquid flow measurement in open channels — Velocity-area methods — Collection and processing of data for determination of errors in measurement

Mesure de débit des liquides dans les canaux découverts — Méthodes d'exploration du champ des vitesses — Recueil et traitement des données pour la détermination des erreurs de mesurage

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 1088 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

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Annexes

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Liquid flow measurement in open channels — Velocity-area methods — Collection and processing of data for determination of errors in measurement

1 Scope and field of application

This International Standard specifies a standard basis for the collection and processing of data for the determination of individual components of the total error in the measurement of liquid flow in open channels by velocity-area methods.

For determining the discharge in open channels by the velocity-area method, components of the flow need to be measured. The total uncertainty in discharge is a combination of the uncertainties in these components. This International Standard specifies a standard basis for collecting and processing the data required to compute the component uncertainties for determining the total uncertainty in discharge. This International Standard may be used when carrying out an investigation of component uncertainties from data taken from a large sample of rivers in a basin or in a country or for international investigations.

2 References

ISO 748, *Liquid flow measurement in open channels — Velocity-area methods.*

ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 4363, *Liquid flow measurement in open channels — Methods for measurement of suspended sediment.*

ISO 4364, *Liquid flow measurement in open channels — Bed material sampling.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO/TR 7178, *Liquid flow measurement in open channels — Velocity-area methods — Investigation of total error.*

3 General

3.1 Principle

The principle of the velocity-area method consists in determining from measurements the distribution of the flow velocity in the cross-section and the cross-sectional area, and using these observations for the computation of the discharge.

The measurements of the flow velocity are made in a number of verticals. In each vertical the mean velocity is determined from measurements at a selected number of points. The discharge per unit width may be found by multiplying the mean velocity by the depth in the vertical considered.

Each vertical is assumed to be representative of a segment of the cross-sectional area. The selection of the number and location of the verticals determines the width of these segments. Assuming that the discharge has remained constant during the measurements, summation of the discharge in the various segments gives the total discharge through the section.

3.2 Occurrence of error

When measuring width, depth and flow velocity, errors occur. The application of certain computational methods also introduces errors depending on the assumptions made.

A distinction shall be made between random and systematic errors, resulting from the instruments used, the measuring procedures and the processing of data. Random errors are also influenced by the nature of turbulent flow. The magnitude of random errors can be influenced favourably by the proper selection of instruments and methods. Systematic errors may be constant or variable and they cannot be eliminated by repeating the measurements or by increasing the duration of a measurement. There are, in addition, mistakes due to misreading an instrument or to instrument malfunction.

3.3 Sources of error (see figure 1)

Theoretically the discharge

$$q = \int \int_A v\,(x, y)\, dx\, dy \qquad \ldots (1)$$

where

q is the unobservable true discharge;

A is the cross-sectional area;

$v\,(x, y)$ is the velocity field over width, x, and depth, y.

In practice, the integral is approximated by the summation

$$Q = \sum_{i=1}^{m} b_i d_i \overline{v}_i \qquad \ldots (2)$$

where

Q is the calculated discharge;

b_i is the width of the i^{th} section;

d_i is the depth of the i^{th} section;

$\overline{v}_i$ is the mean velocity in the i^{th} vertical;

m is the number of sections.

The error in Q is due to

a) errors in the measurement of the quantities b_i, d_i and of the individual measurements of the flow velocity necessary for the determination of $\overline{v}_i$, and

b) the approximation of the integral (1) by the summation (2).

3.4 Determination of the individual components of the error

3.4.1 Errors in width

The measurement of the width between verticals is normally made by measuring distances from a reference point on the bank. When a tape or tag-line is used, or the movement of the wire attached to a trolley is observed, the error depends on the distance but is usually negligible. Where optical means are used, the errors also depend on the distance measured but may be greater.

Where the distance is measured by electronic means, a constant error and an error depending on the distance measured occur.

The errors are mainly instrument errors.

3.4.2 Errors in depth

In ISO 748, clause 10, a number of sources of error in the measurement of depth is mentioned.

Some errors depend on the type and use of the instruments applied. Such errors are not included in this International Standard.

Errors arise due to the interpolation of the depth between the verticals at which depths are measured. These are included in 3.4.3 c) as "error-type III".

3.4.3 Errors in determination of the mean velocity

These errors consist of three components :

a) The error due to the restricted measuring time of the local point-velocity in each vertical. Because of turbulence the velocity fluctuates continuously over the wet cross-section. The mean velocity at any point, determined from a

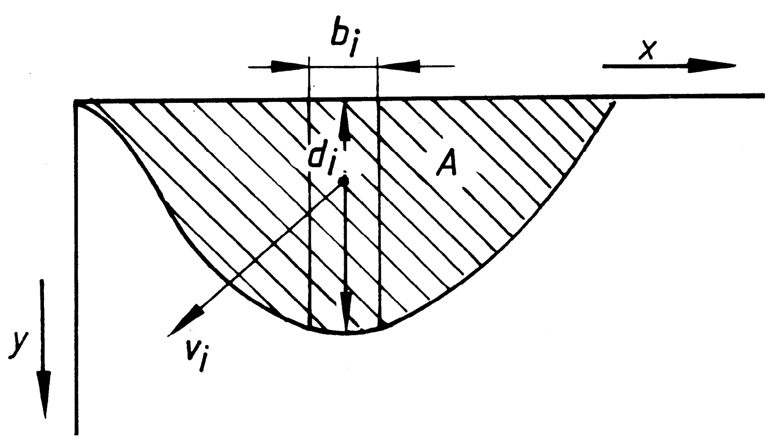

Figure 1 — Definition sketch

measurement during a certain time interval, is an approximation of the true mean velocity at that particular point. In this International Standard, errors of this nature are referred to as "error-type I"[1].

b) The error arising from the use of a limited number of sampling points in a vertical. Computation of the mean velocity in a vertical as an average or a weighted average of a number of point velocities results in an approximation of the true mean velocity in the vertical considered. In this International Standard, errors of this nature are referred to as "error-type II"[1].

c) The error arising from the restricted number of verticals in which velocities are measured. The horizontal velocity profile between two verticals has to be determined by interpolation which introduces an error.

The values of depth d_i and the mean velocity $\bar{v}_i$ in the vertical are used to determine the discharge per unit width and the discharge through the section i. Summation of the discharges through each section according to equation (2) results in an approximation of the true total discharge. Errors of this nature are referred to as "error-type III"[1].

3.4.4 Symbols

The symbols used are given in the table below.

Quantity	Percentage uncertainty[1]	
	random	systematic[2]
Width	X'_{b_i}	X''_b
Depth	X'_{d_i}	X''_d
Mean velocity	$X'_{\bar{v}_i}$	$X''_{\bar{v}}$

1) All the uncertainties used in this International Standard are in terms of percentages expressed at the 95 % confidence limits. In this International Standard, X with a subscript refers to percentage uncertainty, X' refers to percentage random uncertainty and X'' refers to percentage systematic uncertainty.

2) The major source of the systematic uncertainty in the velocity will arise from errors in the calibration of the current-meters.

3.5 Description of the uncertainty

For the determination of the influence on the total uncertainty, the individual components are sufficiently described by their relative mean and relative standard deviations.

3.6 Total uncertainty in discharge

It can be shown (see ISO/TR 7178) that the total percentage random uncertainty in discharge, X'_Q, may be found from the following

$$X'_Q = \pm \left[X'^2_{S_d} + X'^2_{S_h} + \sum_{i=1}^{m} \left\{ (b_i d_i \bar{v}_i)^2 / Q \right\} \left\{ X'^2_{\bar{v}_i} + X'^2_{F_i} + X'^2_{S_{\bar{v}_i}} + X'^2_{d_i} + X'^2_{b_i} \right\} \right]^{1/2} \quad \ldots (3)$$

where

X'_{S_d} is the percentage uncertainty due to random sampling error of the depth profile (error-type III);

X'_{S_h} is the percentage uncertainty due to the random sampling error of the horizontal velocity profile (error-type III);

$X'_{\bar{v}_i}$ is the percentage uncertainty of the mean velocity due to the random instrumental error;

X'_{F_i} is the percentage uncertainty due to the random fluctuation in velocity error (error-type I);

$X'_{S_{\bar{v}_i}}$ is the percentage uncertainty due to the random sampling error of the mean velocity in the vertical (error-type II);

X'_{d_i} is the percentage uncertainty due to the random instrumental error determining the depth of section;

X'_{b_i} is the percentage uncertainty due to the random instrumental error determining the width of section;

b_i is the width of section i;

d_i is the depth of section i;

$\bar{v}_i$ is the mean velocity in section i;

Q is the total discharge.

The total systematic uncertainty is as follows:

$$X''_Q = \pm \left(X''^2_b + X''^2_d + X''^2_{\bar{v}} \right)^{1/2} \quad \ldots (4)$$

The total uncertainty in the discharge is given by

$$X_Q = \pm \left(X'^2_Q + X''^2_Q \right)^{1/2} \quad \ldots (5)$$

If it is assumed that the discharge in the respective sections are almost equal, then equation (3) simplifies with certain approximations (see ISO/TR 7178 and ISO 748) to:

$$X'_Q = \pm \left[X'^2_m + \frac{1}{m} \left(X'^2_b + X'^2_d + X'^2_e + X'^2_p + X'^2_c \right) \right]^{1/2} \quad \ldots (6)$$

where

X'_Q is the total random uncertainty in discharge at 95 % confidence level;

X'_m is the percentage random uncertainty due to the restricted number of verticals used;

1) Error-types I, II and III used in this International Standard have no connection with the statistical type I and type II errors.

X'_b is the percentage random uncertainty in the width measurement;

X'_d is the percentage random uncertainty in the depth measurement;

X'_e is the percentage random uncertainty due to the restricted time of exposure used;

X'_p is the percentage random uncertainty due to the restricted number of velocity points taken in the vertical;

X'_c is the percentage random uncertainty in the current meter rating of velocity.

NOTE — From equation (3) or (6), it can be seen that in order to reduce the total random uncertainty the number of verticals would need to be increased or an improvement made in the measurement of the individual components, or both.

3.7 Evaluation of the error in the individual components

The evaluation of the uncertainty in the individual components of the total uncertainty can be obtained by a statistical analysis of a large number of observations for a particular component under operating conditions. Incorporating this procedure into the normal routine measurement is not feasible, therefore centralized processing of collected data according to standardized programmes, as indicated in this International Standard, is recommended with a view to providing a general standard on the uncertainties of the components within the practical range of measurements.

4 Data on the local point velocity [1)]

To judge the value of a single velocity measurement the following procedure is required.

At each point of measurement on a vertical, an uninterrupted observation of the velocity over a period of 2 000 s, or for a period during which the discharge does not change by more than 5 % of the initial value, whichever is the less, shall be made with a current-meter. Every 10 s a reading of the instrument should be taken, thus giving 200 readings altogether. When pulses are emitted by the current-meter, the number of pulses should be recorded every 10 s; or, when the time is measured at a fixed number of pulses, this time interval should average 10 s. When a continuous record is produced, the complete record should be given and the response characteristics of the electronic instrument stated.

The verticals to be taken for this measurement should be the vertical situated at the deepest point and the verticals situated at places where the depths are 0,6 and 0,3 times the maximum depth, both located on the side of the greater segment of the width from the deepest point.

In each vertical this procedure should be carried out at 0,2 — 0,6 — 0,8 and, where possible, 0,9 times the depth measured from the surface. Where possible the data should be obtained during the same 2 000 s period.

The measurements should be repeated for different discharges.

The data thus obtained should be indicated in the report form given in annex A. In the case of a continuous recorder, the values at intervals of 10 s should be given, indicating the method of determination.

5 Data on the average velocity [1)]

The average velocity in a vertical may be obtained in various ways. The velocity distribution method is, however, taken as a basis for comparison with the results of other methods generally used or special methods adopted owing to special circumstances.

The following procedure is required.

5.1 Location of the vertical

The vertical chosen for this measurement shall normally be determined from the known velocity distributions in the gauging cross-section, so as to give velocities which are representative of the whole cross-section.

When the velocity distributions in the gauging cross-section are not known, the vertical taken for this measurement shall be that at maximum depth in the cross-section and at places where the depths are 0,6 and 0,3 times the maximum depth respectively, at the side of the greater segment and not too close to the bank.

5.2 Distribution of measuring points

The velocity should be measured at the following points in the vertical :

1) immediately below the surface;
2) at 0,2 times the depth;
3) at 0,3 times the depth;
4) at 0,4 times the depth;
5) at 0,5 times the depth;
6) at 0,6 times the depth;
7) at 0,7 times the depth;
8) at 0,8 times the depth;
9) at 0,9 times the depth;
10) near the bed.

1) Reference may also be made to ISO 748 and ISO/TR 7178.

In channels containing weed growth great care shall be taken to ensure that measurements made in the vicinity of the bed are not affected by weed fouling the current-meter.

5.3 Period of measurement of local point velocities

The period of measurement of local point velocity at any point should be 60 s, or the number of pulses should be that observed in 60 s at 0,6 times the depth.

5.4 Number of measurements

The measurements in each of the verticals should be made at least five times, preferably consecutively. Measurements affected by navigation should be indicated.

These sets of observations should be made for various discharges.

5.5 Presentation of data

The mean velocity should be determined with the use of a planimeter from an adequately large graphical plot (preferably not less than 300 cm^2). The type and accuracy of the planimeter should be given, together with the scale of the discharge. The accuracy of the graph paper should be checked.

The velocity profiles should be drawn to a scale in such a way that the maximum velocity and the depth are represented by 0,10 m and 0,20 m respectively.

Compilation of data should be made in the form shown in annex B.

6 Data on the velocity-area method[1]

There are two possible ways of determining the accuracy of the velocity-area method, one requiring special measurements, the other mainly using routine measurements.

Wherever possible, data for both should be produced.

6.1 Measurement at 0,6 times the depth

In this method, the continuous profile of the cross-section at the measuring site is required. This can be obtained by echo-sounder measurements or by measuring the depth with a rod at intervals in wide rivers of not more than 1/50 of the total width.

The horizontal velocity distribution shall be observed by taking velocity readings at 0,6 times the depth at intervals in wide rivers of 1/50 of the total width. The readings of the current-meter shall be made over a period of 120 s.

In addition, readings shall be taken from a reference current-meter at a fixed point, preferably at 0,6 times the depth in the vertical at maximum depth. It shall be read every 60 s.

6.2 Velocity-distribution method

In this method, the normal procedure for discharge measurement may be used provided the velocity-distribution method or integration method is used for the determination of the average velocity in the vertical.

Readings shall be taken every 60 s, from a reference current-meter at a fixed point, preferably at 0,6 times the depth in the vertical at maximum depth.

In addition to the data on the depth obtained by the normal discharge measurement, a continuous profile of the cross-section at the measuring site shall be provided, as indicated in 6.1.

6.3 Presentation of data

For the compilation of data, the form shown in annex C should be used. Correction factors in the table on velocity at the reference point can best be based on the average value of velocity at the reference point. In this table, the factors are set as a function of time. To obtain the corrected velocity in the table "Mean velocity at verticals", the velocity column shall be multiplied by this correction factor.

A graphical representation of the cross-section shall be drawn to an adequate scale; the width of the river on the drawing shall be not less than 0,5 m. The representation shall indicate the numerical values of depth at the measuring points when a rod has been used, and shall show the location of the verticals and of the reference current-meter.

A graphical representation of the measured velocity profiles should also be given. This should indicate the numerical values of the velocities at the measuring points.

6.4 General data

To facilitate the interpretation of deviations from the normal pattern of the various errors, relevant information on the geometry and morphology of the river concerned is required, for example a map of scale 1/10 000 of the river approximately 50 times the width of the river upstream and downstream of the measuring site.

7 Integration method

To determine the standard error in the mean velocity in the verticals obtained by the integration method, a sufficient number of measurements (for example, 50) should be carried out at steady stage in three verticals and the results should be tabulated.

The verticals to be taken for this measurement should be the vertical situated at the maximum depth and the verticals situated at places where the depths are 0,6 and 0,3 times the maximum depth, both located on the side of the greater segment of the width from the deepest point.

The measurements should be repeated for different discharges. Data of a general character can be compiled in a report form similar to that given in annex A.

1) Reference may also be made to ISO 748.

8 Calibration curves

In connection with the study of the instrument error, calibration curves together with all calibration points should be given, especially data of successive calibrations of a representative current-meter with dates and years of calibration and the intensity of use.

9 Distance measurements

No generally applicable method of determining the accuracy of distance measurements can be given at present. Detailed description of the method of distance measurement should be given, together with the distances involved, and other relevant factors should be given for theoretical examination.

Electronic distance measuring devices give an almost absolutely accurate standard of comparison for distance measurements. Where these instruments are available, independent research programmes, concerning the uncertainty of different methods of distance measurement, may be carried out and the results stated.

The conditions under which the study is carried out should be similar to normal operating conditions in the field.

10 Depth measurements

The accuracy of depth measurement is dependent on the channel conditions and the method of measurement. In the case of lined channels the bed conditions are not likely to influence the accuracy of the measurement.

In natural channels, for example rivers, the configuration of the bed varies in longitudinal as well as transverse directions.

In relation to the measuring procedure, it is important to know whether the measurement is carried out from a rigid position or from an anchored launch. In the latter case the influence of the irregularity of the bed may result in a greater contribution to the total error of the depth measurement.

Owing to the complex nature of the depth measurements, general directives cannot be given. In carrying out a study, the following considerations may give guidance.

10.1 In a river with a shifting bed, consecutive measurements at one point should be avoided.

10.2 It is advisable to study the bed configuration in the vicinity of the actual measuring point by determining longitudinal and transverse sections.

10.3 For all instruments the accuracy of the reading in relation to the scale intervals should be determined.

10.4 Sounding rods yield errors due to

a) penetration into the bed;

b) deviation from the vertical position;

c) built-up head due to velocity.

10.5 Sounding lines (including suspended current-meters) yield errors due to

a) penetration into the bed;

b) deviations from the ideal conditions for which the correction for downstream drift has been calculated;

c) shape and suspension point of the lead.

10.6 Echo-sounders yield errors due to

a) beam width of the transmitted pulse at the bottom;

b) penetration of the pulse into the bed, which is a function of the frequency of the pulse and of bed consistency.

11 Data processing

11.1 General

The method of data processing for the determination of the total random error in the discharge measurement by velocity-area methods is given. Although the availability of computers is assumed, it is possible to perform the computation process with less advanced means. Some of these alternatives are indicated.

When processing the data, steady-flow conditions are assumed, which means that the true mean value of each of the various quantities remains constant with time. Non-steady trends shall be removed from the data before processing (see 11.2.2).

11.2 Error-type I

11.2.1 Finite measuring time and distribution of results

The standard deviation of the fluctuation error due to a finite measuring time is calculated.

It is assumed that the means found from the actual measurements are equal to the hypothetical means over infinite measuring time and that the distribution of the results is of normal (Gaussian) nature.

11.2.2 Correction for non-steady conditions

The mean velocity is calculated from

$$\bar{V} = \frac{1}{n} \sum_{i=1}^{n} V_i \qquad \ldots (7)$$

where

$\bar{V}$ is the mean velocity during the time interval of measurements;

V_i is the observed instantaneous velocity;

n is the number of observations.

When the velocity V_i is plotted against time t_i, it can be seen from the graph whether the magnitude of V_i shows a certain trend which indicates that the conditions during the measurements were not steady. If so, the observed velocities shall be corrected using

$$V_i = a(t_i - \bar{t}) + b \qquad \ldots (8)$$

where t_i is the time when the velocity is V_i and in which the constants a and b are determined from the following equations :

$$b = \frac{1}{n} \sum_{i=1}^{n} V_i = \bar{V} \qquad \ldots (9)$$

and

$$a = \frac{\sum_{i=1}^{n} V_i (t_i - \bar{t})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} = \frac{\sum_{i=1}^{n} V_i t_i - n \bar{t} \bar{V}}{\sum_{i=1}^{n} t_i^2 - 1/n \left(\sum_{i=1}^{n} t_i \right)^2} \qquad \ldots (10)$$

The observed instantaneous velocity V_i is thus corrected :

$$V_{\mathrm{corr}_i} = V_i - (v_i - \bar{V}) \qquad \ldots (11)$$

where V_{corr_i} is the corrected velocity assuming a linear trend in the observed velocities (in the following equations V_i denotes V_{corr_i} if correction has been applied).

11.2.3 Standard deviation[1] of velocity fluctuations

The standard deviation of the velocity fluctuations is calculated by using

$$S_F = \sqrt{\frac{\sum_{i=1}^{n} (V_i - \bar{V})^2}{n - 1}} \qquad \ldots (12)$$

The computation procedure can be simplified by using the equation

$$S_F = \sqrt{\frac{\sum_{i=1}^{n} V_i^2 - \frac{\left(\sum_{i=1}^{n} V_i \right)^2}{n}}{n - 1}} \qquad \ldots (13)$$

$\frac{\left(\sum_{i=1}^{n} V_i \right)^2}{n}$ $(= n \bar{V}^2)$ is already known from previous calculations [see equation (7)].

11.2.4 Autocorrelation function

The autocorrelation function can be determined from the equation

$$\hat{\varrho}(k) = \frac{n}{n - k} \; \frac{\sum_{i=1}^{n-k} (V_i - \bar{V})(V_{i+k} - \bar{V})}{\sum_{i=1}^{n} (V_i - \bar{V})^2} \qquad \ldots (14)$$

where

$\hat{\varrho}(k)$ is the autocorrelation function;

k is the time displacement of function;

$\sum_{i=1}^{n} (V_i - \bar{V})^2$ is already known from previous calculations [see equation (12)].

The autocorrelation function is used for the calculation of the standard deviation, as described in 11.2.6.

11.2.5 Effect of measuring time on standard deviation (1)

If no computer is available, the influence of the measuring time for the interval kt_0, in which t_0 is the initial measuring time and k is an integer, the standard deviation can be determined. For that purpose the mean velocity over an interval kt_0 is calculated from :

$$\frac{\bar{V}_{2i+k-1}}{2} = \frac{V_i + V_{i+1} + \ldots\ldots + V_{i+k-1}}{k} \qquad \ldots (15)$$

The magnitudes of $\frac{\bar{V}_{2i+k-1}}{2}$ are used to calculate the standard deviation [see equation (12)].

This method is less common than the procedure described in 11.2.6.

11.2.6 Effect of measuring time on standard deviation (2)

Using the standard deviation $S(t_0)$ for an initial measuring time t_0 (see 11.2.3) and the autocorrelation function $\hat{\varrho}(k)$ (see 11.2.4), the standard deviation of the velocity fluctuations can be calculated from :

$$S^2(n\,t_0) = \frac{S^2(t_0)}{n} \left[1 + 2 \sum_{k=1}^{n} \left(1 - \frac{k}{n} \right) \hat{\varrho}(k) \right] \qquad \ldots (16)$$

In this equation, the influence of the measuring time on the accuracy of the point velocity is characterized.

1) For the relationship between standard deviation and uncertainty, see ISO 5168. In general, uncertainties are expressed at the 95 % confidence level and usually as percentages. For large values of n, standard deviations should be multiplied by 2 and by 100 to obtain percentage uncertainties. The factor is greater than 2 for small samples.