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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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

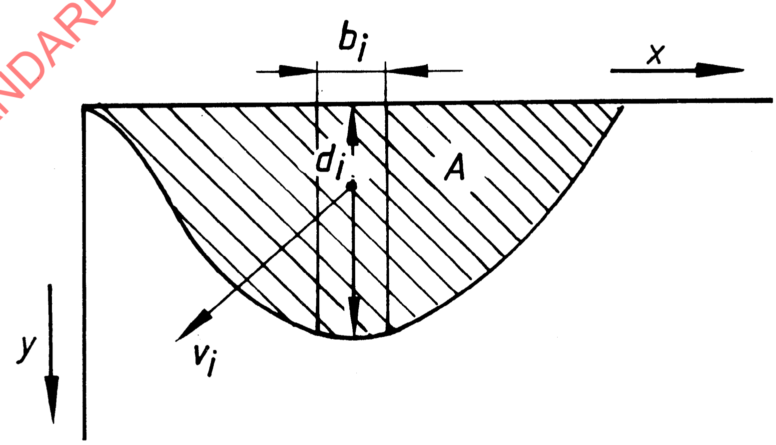

Figure 1 — Definition sketch

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

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

where

$\overline{V}$ 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 :

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

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_o, in which t_o 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_o 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 $S(t_o)$ for an initial measuring time t_o (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 :

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

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.

11.2.7 Compilation of results

The results of the calculations should be compiled in a table (see the table below) which gives an impression of the influence of the measuring time on the accuracy of the point velocities by a comparison of the various standard deviations. Uncertainties should be calculated in accordance with ISO 5168.

The percentage standard deviations are found by dividing the standard deviation by the average value of the variable and multiplying by 2 (95 % level) and by 100 (see ISO 5168).

11.3 Error-type II

11.3.1 Approximation of mean velocity in the vertical

The relative standard deviation due to the approximation of the mean velocity in the vertical caused by applying a finite number of point velocities is calculated.

11.3.2 Determination of the standard mean velocity in the vertical

As described in clause 5, the standard mean velocity in the vertical is found by determining the area of the vertical velocity profile with the use of a planimeter and taking the depth into account.

As a rule the mean velocity can be calculated with the use of the trapezium rule applied on ten point velocities :

$$\bar{V}_i = \left(V_{surf} + 2\,V_{0,2} + 2\,V_{0,3} + 2\,V_{0,4} + 2\,V_{0,5} + 2\,V_{0,6} + 2\,V_{0,7} + 2\,V_{0,8} + 2\,V_{0,9} + V_{bed}\right)\frac{1}{18} \quad \ldots (17)$$

where i is a sequence in the series of measurements.

11.3.3 Computation methods

By the application of computation rules the mean velocity in the vertical can be approximated by calculation.

Comparison of this approximate mean velocity with the standard mean velocity makes it possible to determine the sampling error for each of the computation methods. Some common formulae are (see also ISO 748) :

a) $\bar{v} = v_{0,6}$

b) $\bar{v} = 0,5\,(v_{0,2} + v_{0,8})$

c) $\bar{v} = 0,25\,v_{0,2} + 0,5\,v_{0,6} + 0,25\,v_{0,8}$

d) $\bar{v} = \frac{1}{3}\,(v_{0,2} + v_{0,6} + v_{0,8})$

e) $\bar{v} = 0,1\,v_{surf} + 0,3\,v_{0,2} + 0,3\,v_{0,6} + 0,2\,v_{0,8} + 0,1\,v_{bed}$

f) $\bar{v} = 0,1\,v_{surf} + 0,2\,v_{0,2} + 0,2\,v_{0,4} + 0,2\,v_{0,6} + 0,2\,v_{0,8} + 0,1\,v_{bed}$

The calculated mean velocity is standardized by dividing it by the standard mean velocity obtained according to 11.3.2.

11.3.4 Sampling error due to velocity fluctuations and computation rule

From the results of ten measurements under identical conditions of the standardized velocities, the mean and the standard deviation are calculated assuming

$$\bar{V}_{rel} = \frac{1}{J}\sum_{i=1}^{J} \bar{V}_{rel_i} \quad \ldots (18)$$

$$S_{rel}^2 = \frac{1}{J-1}\sum_{i=1}^{J} (\bar{V}_{rel_i} - \bar{V}_{rel})^2 \quad \ldots (19)$$

where

J is the number of observations in a series;

$\bar{V}_{rel}$ is the mean relative velocity in a series;

$\bar{V}_{rel_i}$ is the mean relative velocity in a vertical;

S_{rel} is the standard deviation of the mean relative velocities.

The sampling error, $\hat{S}_i$, due to the computation rule is equal to $(1 - \bar{V}_{rel})I$ if a series of I sets of measurements are considered.

Table — Compilation of results

Location of measuring point h_{rel}	$\bar{V}$ m/s	S_{abs} m/s	X_S %	$\hat{\varrho}$ (1)	$\hat{\varrho}$ (2)	.....	$\hat{\varrho}$ (k)	$X_S\,(t_o)$ %	$X_S\,(2\,t_o)$ %	.....	$X_S\,(k\,t_o)$ %
0,2											
0,3											
0,4											
0,5											
0,6											
0,7											
0,8											
0,9											

The systematic part of the sampling error can be estimated by

$$\hat{\mu}_s = \frac{1}{I} \sum_{i=1}^{I} \hat{S}_i \qquad \ldots (20)$$

where $\hat{\mu}_s$ represents the standard deviation of the sampling error due to the velocity fluctuations under steady conditions.

The mean standard deviation of all sets of measurements due to velocity fluctuations can be determined from

$$S_F^2 = \frac{1}{I} \sum_{i=1}^{I} S_{rel}^2 \qquad \ldots (21)$$

11.3.5 Sampling error due to computation rule

Of a series of I sets of measurements the standard deviation of the sampling error due to the computation rule can be calculated :

$$S_{sv}^2 = \frac{1}{I-1} \sum_{i=1}^{I} (\hat{S}_i - \hat{\mu}_s)^2 - \frac{S_F^2}{J} \qquad \ldots (22)$$

where

S_{sv} is the standard deviation of the sampling error due to the computation rule;

$\hat{S}_i$ is the sampling error in mean velocity in vertical due to the computation rule per series;

$\hat{\mu}_s$ is the mean sampling error for all series together;

S_F is the mean standard deviation of all series together due to velocity fluctuations;

I is the number of sets of measurements in a series;

J is the number of measurements in a series.

11.4 Error-type III

11.4.1 Restricted number of verticals

The standard deviation of the error of the discharge due to measurement in a restricted number of verticals is calculated.

11.4.2 True discharge

Using velocities, from which non-steady trends have been removed, and the corresponding depths and applying the mid-section method, the discharge in a cross-section is calculated according to ISO 748.

For the purpose of determination of error-type III, this discharge is assumed to be the true discharge.

11.4.3 Omission of verticals

Omitting verticals from use for the calculation of the discharge, the absolute error can be determined by comparison with the true discharge.

The calculation of the discharge shall be based either on the mid-section method or on the mean-section method, as described in ISO 748. As is proved in ISO/TR 7178, the results obtained by use of these methods show differences which are negligible. The mid-section method, however, shows a time saving and cost saving over the mean-section method.

The error is standardized by dividing the absolute error by the true discharge.

11.4.4 Mean and standard deviations of error

The relative mean error and its standard deviation due to the omission of verticals are determined from a number of series of measurements in the same cross-section.

$$\hat{\mu}(m) = \frac{1}{I} \sum_{i=1}^{I} \left[\frac{Q_i(m)}{Q_i} - 1 \right] \qquad \ldots (23)$$

and

$$S_{s_{hd}}(m) = \sqrt{\frac{\sum_{i=1}^{I} \left[\frac{Q_i(m)}{Q_i} - 1 \right]^2}{I-1}} \qquad \ldots (24)$$

where

$\hat{\mu}(m)$ is the relative mean error in the discharge due to the restricted number of verticals;

m is the number of verticals considered for the determination of discharge;

$Q_i(m)$ is the calculated discharge applying m verticals using the ith measurement;

Q_i is the approximated true discharge using the ith measurement;

$S_{s_{hd}}(m)$ is the relative standard deviation of error due to error-type III, applying m verticals $S_{s_{hd}}^2 = S_{s_h}^2 + S_{s_d}^2$;

I is the number of measurements.

The mean error or its standard deviation is plotted against the number of verticals or the mean of groups of verticals considered. From these graphs the relation between the uncertainty and the number of verticals applied may be deduced.

11.4.5 Criteria applied in choosing the verticals

The distances between adjacent verticals on a cross-section may be

a) equal;

b) varied, to make the area of all segments equal;

c) varied, to make the discharge through all segments similar;

d) varied, to minimize the influence on the discharge of changes in velocity and depth.

Items a) and b) need no explanation.

Item c) can be explained as follows: The true total discharge being 100 %, the discharge per segment will be $\frac{100}{m}$ % when m segments are considered. The cumulative discharge is plotted against the percentage of total discharge, as shown in figure 2, to establish the position of successive verticals.

As soon as the location of the ith vertical is fixed, and the number of verticals to be applied and therefore also the percentage of the discharge which should flow through each segment are determined, the location of the $(i + 1)$th vertical may be found. In figure 2 an example is given for a discharge of 8,5 %.

Item d) can be explained as follows: Based on the equation for the total discharge according to the mid-section method

$$Q = \sum_{i=1}^{m} \left(b_i \overline{v}_i d_i + \frac{b_i \overline{v}_i \Delta d_i}{2} + \frac{b_i d_i \Delta \overline{v}_i}{2} + \frac{b_i \Delta d_i \Delta \overline{v}_i}{2} \right) \quad \ldots (25)$$

where

Δd_i is the difference in depth in the verticals i and $i + 1$ respectively;

$\Delta \overline{v}_i$ is the difference in velocity in the verticals i and $i + 1$ respectively.

The optimal selection of the verticals as affected by differences in velocity is based on the product $b_i d_i \Delta \overline{v}_i$, and as affected by differences in depth on the product $b_i \overline{v}_i \Delta d_i$.

In the first case the depth in **all** verticals is used in the calculation of the discharge. In that way the error due to interpolation of the velocity between the verticals can be estimated. In the second case, the error due to interpolation of the depth between the verticals can be determined.

The magnitude of the product indicates the influence on the total discharge of differences in velocity and depth respectively.

Verticals are omitted, starting with the smallest, depending on the magnitude of the product.

12 List of symbols

a coefficient of linear regression;

b coefficient of linear regression;

b_i unobservable true width of section i;

d_i unobservable true depth in vertical of section i;

I number of series of measurements (error-types II and III);

J number of measurements per series (error-type II);

k time displacement autocorrelation function (of time interval, etc.);

m number of verticals or sections per cross-section;

n number of time intervals of measured velocities (error-type I);

Q total discharge;

Q_i discharge of section i;

S_i stochastic sampling error of mean velocity in vertical (error-type II);

t_i time i;

t_o initial measuring time (basic time interval);

v_i velocity at time i or in section i;

V_i actual velocity at time i or in section i;

V_{corr_i} actual velocity from which trend is removed;

b_i width of the ith section;

d_i depth of the ith section;

$\overline{V}_i$ calculated mean velocity;

$\overline{v}_i$ unobservable true mean velocity;

$\delta \overline{V}_i$ unobservable random instrumental error of mean velocity;

$\overline{F}_i$ total unobservable random fluctuation error of mean velocity (error-type I);

$S_{\overline{v}_i}$ unobservable random sampling error of mean velocity (error-type II);

$\hat{\mu}_s$ mean sampling error (error-type II);

$\hat{\mu}(m)$ mean error when m verticals are applied (error-type III);

$\hat{\varrho}(k)$ autocorrelation function with time displacement k;

X percentage uncertainty (general);

X' percentage random uncertainty;

X'' percentage systematic uncertainty;

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

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

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

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

NOTE — Due to the statistical nature of this International Standard, it is necessary to have symbols representing observed values and true values of variables. The symbols may therefore not conform to ISO 772.

Observations or results of calculations using observations are indicated by a capital letter. Statistical quantities obtained from observations are indicated by a small letter with caret. A mean value is indicated by a bar.

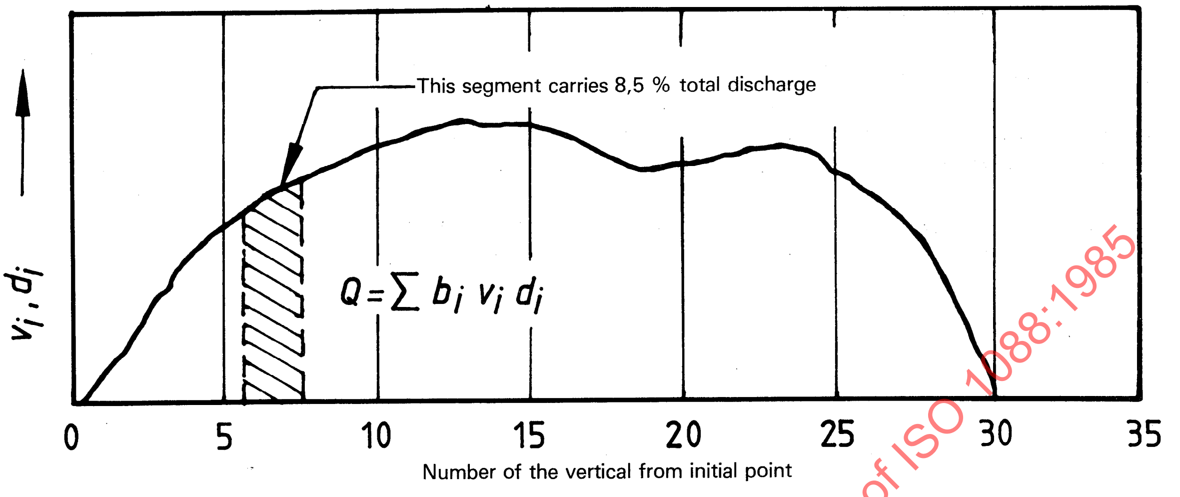

Figure 2 a — $\overline{V}d$ curve

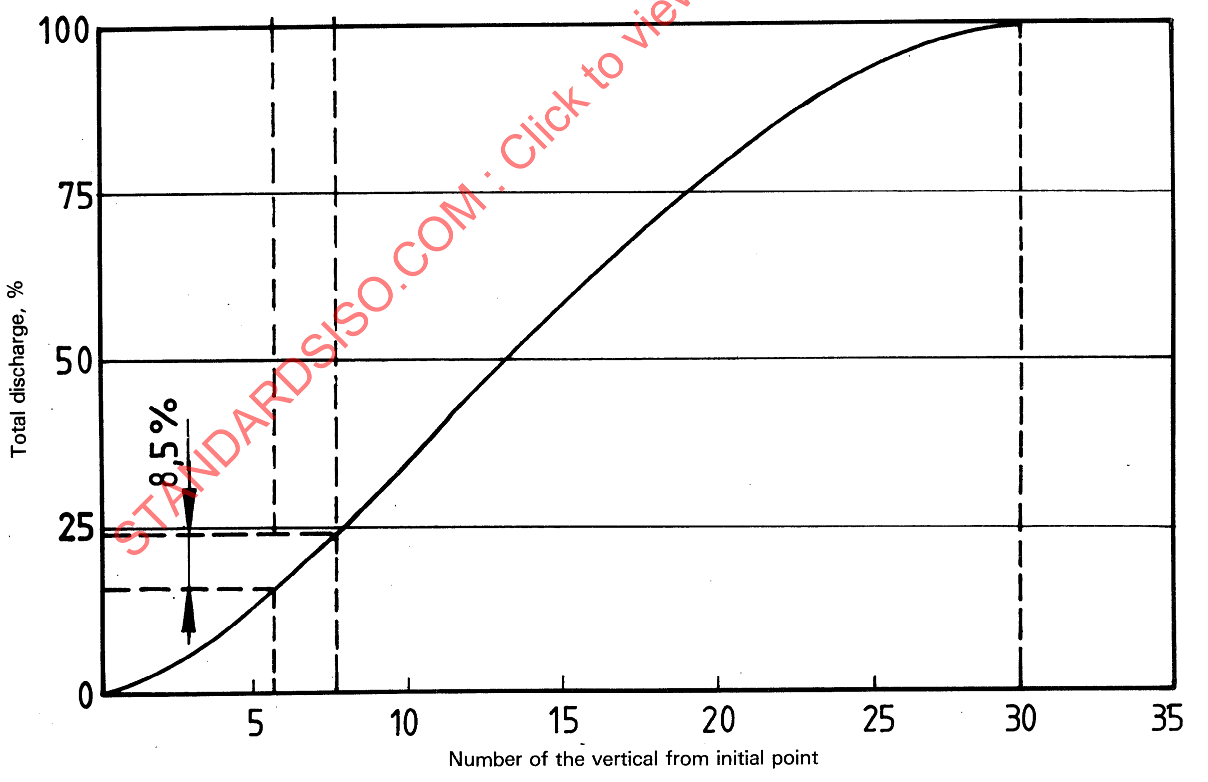

Figure 2 b — Cumulative discharge curve

Figure 2 — Computation of discharge

Annex A

Local point velocity measurements — Report form

(See clause 4)

NOTE — All values should be converted if necessary to metres and seconds, where appropriate.

Measurements carried out
under the responsibility of ....

Address : ....

....

Please refer inquiries to : ....

River concerned : ...., at (location) : ....

Country : ....

1 General data on the river during measuring period

Discharge	....	m^3/s
Area of cross-section of stream	....	m^2
Average velocity	....	m/s
Water surface width	....	m
Maximum depth	....	m
Average depth (area/width)	....	m
Slope of stage-discharge curve (sensitivity in steady-stage condition)	....	$m^3/s\cdot m$
Water temperature	....	°C

2 General data on measuring verticals

Measuring verticals	Average velocity	Depth at vertical	Distance from right/left bank
	m/s	m	m
A Maximum depth B 0,6 times maximum depth C 0,3 times maximum depth			

3 Method of velocity measurement (Please tick as appropriate)

☐ a) Number of pulses, counted every 10 s.

☐ b) Time (average 10 s) for a constant number of pulses, being for

A : .... pulses.
B : .... pulses.
C : .... pulses.

☐ c) Continuous velocity record :

Speed of paper at recorder : .... mm/s
Response characteristics of the electronic instrumentation : ....

☐ d) Integration method.

4 Measuring apparatus

Type of current-meter (Please give details, such as diameter of propeller and pitch or size of cup, cup distance and number of cups) :

. . . .

Serial number : . . . .

Type of suspension : . . . .

Date of calibration (Please add rating-curve and equations for calculation of velocity and indicate whether group calibration or direct calibration is intended. Check whether the water temperature during calibration has been indicated on the rating-curve.) . . . .

Method of timing and associated uncertainty . . . .

5 Measurements at verticals

5.1 Vertical at maximum depth

5.1.1 General data

	Depth				Units
	0,2	0,6	0,8	0,9	
Date of measurement					—
Hour of measurement (local time)					—
Water-level at start (local units)					—
Water-level at end (local units)					—
Water-depth during measurement					m
Depth of instrument under surface					m
Average velocity over a period of 2000 s					m/s
Minimum velocity					m/s
Maximum velocity					m/s
Method of velocity measurement : a) or c) (see clause 3 of this annex)					
Time interval of readings	10	10	10	10	s
Method b)					
Number of pulses					—
Average time interval of readings					s

5.1.2 Description of bed conditions

Bed material (size, shape, density)[1] : . . . .

Bed form (smooth, ripples, dunes) : . . . .

Sediment transport : yes/no; if yes, type of transport : bed load/suspended load.

Bed roughness (preferably expressed in Chezy coefficient C) : . . . .

$$C = \frac{\overline{v}}{\sqrt{R_h S}}$$

where

C is the Chezy coefficient;

$\overline{v}$ is the mean velocity;

R_h is the hydraulic mean depth (area of cross-section of stream over wetted perimeter);

S is the energy slope.

Remarks : . . . .

. . . .

1) See ISO 4363 and 4364.

5.1.3 Velocity observations

a) Velocity at 0,2 depth every 10 s.

Serial No.	Reading	Velocity	Serial No.	Reading	Velocity	Serial No.	Reading	Velocity	Serial No.	Reading	Velocity
1 50			51 100			101 150			151 200		
Average velocity Maximum velocity Minimum velocity			Average velocity Maximum velocity Minimum velocity			Average velocity Maximum velocity Minimum velocity			Average velocity Maximum velocity Minimum velocity		

NOTE — Please indicate special circumstances influencing the measurements, such as passing of ships.

b) For measurements at 0,6 – 0,8 and 0,9 depths, give details in the form shown at a) above.

5.2 Vertical at 0,6 times the maximum depth

Give details in the form shown under 5.1.

5.3 Vertical at 0,3 times the maximum depth

Give details in the form shown under 5.1.

Annex B

Average velocity measurements — Report form

(See 5.5)

NOTE — All values should be converted if necessary to metres and seconds, where appropriate.

Measurements carried out
under the responsibility of . . . .

Address : . . . .

. . . .

Please refer inquiries to : . . . .

River concerned : . . . . , at (location) : . . . .

Country : . . . .

1 General data on the river during measuring period

Discharge	. . . .	m^3/s
Area of cross-section of stream	. . . .	m^2
Average velocity	. . . .	m/s
Water surface width	. . . .	m
Maximum depth	. . . .	m
Average depth (area/width)	. . . .	m
Slope of stage-discharge curve (sensitivity in steady-stage condition)	. . . .	$m^3/s\cdot m$
Depth at vertical	. . . .	m
Average velocity on vertical	. . . .	m/s
Distance of vertical from right bank	. . . .	m
Water temperature	. . . .	°C

2 Method of velocity measurement (Please tick as appropriate)

☐ a) Number of pulses counted every 60 s.

☐ b) Time (average 60 s at 0,6 depth) for a constant number of pulses, i.e. . . . . pulses.

☐ c) Continuous velocity record :

Speed of paper at recorder : . . . . mm/s

Response characteristics of the electronic instrumentation : . . . .

☐ d) Integration method.

3 Measuring apparatus

Type of current-meter (Please give details, such as diameter of propeller and pitch or size of cup, cup distance and number of cups) :

. . . .

Serial number : . . . .

Type of suspension : . . . .

Date of calibration (Please add rating-curve and equations for calculation of velocity and indicate whether group calibration or direct calibration is intended. Check whether the water temperature during calibration has been indicated on the rating-curve.) . . . .

4 Measurements at verticals

4.1 Vertical at maximum depth

4.1.1 General data

	1	2	3	4	5	Units
Date of measurement						—
Hour of measurement (local time)						—
Water-level at start (local units)						—
Water level at end (local units)						—
Water-depth during measurement						m
Duration of the local point velocity measurements using method a) or c) (see clause 2 of this annex)	60	60	60	60	60	s
Number of pulses using method b) based on a duration of 60 s at 0,6 depth of the local point velocity measurements						—

4.1.2 Description of bed conditions

Bed material (size, shape, density) [1] : . . . .

Bed form (smooth, ripples, dunes) : . . . .

Sediment transport : yes/no; if yes, type of transport : bed load/suspended load.

Bed roughness (preferably expressed in Chezy coefficient, C) : . . . .

$$C = \frac{\overline{v}}{\sqrt{R_h S}}$$

where

C is the Chezy coefficient;

$\overline{v}$ is the mean velocity;

R_h is the hydraulic mean depth (area of cross-section of stream over wetted perimeter);

S is the energy slope.

Remarks : . . . .

. . . .

1) See ISO 4363 and 4364.

4.1.3 Velocity observations

Velocities	1		2		3		4		5	
	Reading	Velocity	Reading	Velocity	Reading	Velocity	Reading	Velocity	Reading	Velocity
1) near surface[1]										
2) 0,2 depth										
3) 0,3 depth										
4) 0,4 depth										
5) 0,5 depth										
6) 0,6 depth										
7) 0,7 depth										
8) 0,8 depth										
9) 0,9 depth										
10) near bed[2]										
Average velocity determined graphically	X		X		X		X		X	

1) The observation near the surface has been taken . . . . . . m below the surface.

2) The observation near the bed has been taken . . . . m above the bed.

NOTE — Please indicate special circumstances influencing the measurements, such as passing of ships.

4.2 Vertical at 0,6 times the maximum depth

Give details in the form shown under 4.1.

4.3 Vertical at 0,3 times the maximum depth

Give details in the form shown under 4.1.