INTERNATIONAL STANDARD

ISO 1070

Second edition
1992-06-15

Liquid flow measurement in open channels — Slope-area method

Mesure de débit des liquides dans les canaux découverts — Méthode de la pente de la ligne d'eau

Reference number
ISO 1070:1992(E)

Foreword

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

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

International Standard ISO 1070 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, Sub-Committee SC 1, *Velocity area methods*.

This second edition cancels and replaces the first edition (ISO 1070:1973), of which it constitutes a technical revision.

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

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Liquid flow measurement in open channels — Slope-area method

1 Scope

This International Standard specifies a method of determining liquid flow in open channels from observations of the surface slope and cross-sectional area of the channel. It is suitable for use under somewhat special conditions when direct measurement of discharge by more accurate methods, such as the velocity-area method, is not possible.

The slope-area method can be used with reasonable accuracy in open channels having stable boundaries, bed and sides (e.g. rock or very cohesive clay), in lined channels and in channels with relatively coarse material. It may also be used in alluvial channels, including channels with overbank flow or non-uniform channel cross-sections, but in these cases the method is subject to large uncertainties owing to the selection of the rugosity coefficient (such as Manning's coefficient n or Chezy's coefficient C).

Generally the method may be used to determine discharge

a) at the time of determining gauge heights from a series of gauges;

b) for a peak flow that left marks on a series of gauges or where peak stages were recorded by a series of gauges;

c) for a peak flow that left high-water marks along the stream banks.

This method is not suitable for use in very large channels, channels with very flat surface slopes and high sediment load or channels having significant curvature.

Although the accuracy of the results given by the slope-area method is less than that of the results given by the velocity-area method, the slope-area method is sometimes the only method that can be used for determining the extreme high-stage end of rating curves in cases where the magnitude of floods is such that other methods of measuring discharge cannot be used.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772:1988, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 1100-2:1982, *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation.*

ISO 4373:1979, *Measurement of liquid flow in open channels — Water level measuring devices.*

ISO 5168:1978, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

3 Definitions

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

4 Principle of the method of measurement

A measuring reach is chosen for which the mean area of the stream or river cross-section is determined and the surface slope of the flowing water in that reach is measured. The mean velocity is then established by using known empirical formulae which relate the velocity to the hydraulic mean depth, and the surface slope is corrected for the kinetic energy of the flowing water and the characteristics of the bed and bed material. The discharge is computed as the product of the mean velocity and the mean area of the stream cross-section.

5 Selection and demarcation of site

5.1 Initial survey of site

It is recommended that approximate measurements of widths, depths and surface slopes should be made in a preliminary survey to decide whether the site is suitable and conforms, as far as possible, with the conditions specified in 5.2 and 5.3. These measurements should serve as a guide only.

5.2 Selection of site

5.2.1 There should be no progressive tendency for the river to scour or to deposit sediment.

5.2.2 Ideally, the river reach should be straight, and should contain no large curvatures or meanders. There should not be any abrupt change in the bed slope in the measuring reach, as can occur in rocky channels. The cross-section should be uniform throughout the reach and free from obstructions. Preferably, vegetation should be minimal and as uniform as possible throughout the reach.

5.2.3 The bed material should be similar in nature throughout the reach.

5.2.4 Wherever possible, the length of the reach should be such that the difference between the water levels at the upstream and downstream gauges should be not less than ten times the uncertainty in the difference. When the uncertainty in the measurement of the water level at each gauge is similar, then the distance between the gauges should be sufficient for the fall to be not less than twenty times the uncertainty in measurement at one gauge.

5.2.5 The flow in the reach should be free from significant disturbances due to the effect of tributaries.

5.2.6 The flow in the channel should be contained within defined boundaries. If possible, reaches in which overbank flow conditions exist should not be selected. Where this is unavoidable, however, a reach in which there are no very shallow flows over the flood plain should be sought, but additional computations will be necessary in the determination of discharge.

5.2.7 The site should not be subject to change in the flow regime from subcritical to supercritical or from supercritical to subcritical (but see 10.6).

5.2.8 A converging reach should be selected in preference to an expanding reach. Rapidly expanding reaches should not be selected (see 10.4).

5.2.9 The physical characteristics of the reach should be such that the time lag of flow in the reach may be negligible.

5.3 Demarcation of site

Once the measuring reach has been selected, cross-sections normal to the direction of flow shall be chosen and markers which are clearly visible and identifiable shall be placed on both banks (see also 9.1). A reference gauge, levelled to a standard datum, shall be installed (see 6.1).

The site should be monitored to ensure that no physical changes occur which render it unsuitable. If changes do take place and the site cannot be successfully restored, a new site should be selected.

6 Devices for measurement of slope

6.1 Reference gauge

The reference gauge shall comprise a well gauge, where feasible, preferably incorporating a vertical gauge rather than an inclined gauge. The vertical gauge (or inclined gauge) shall comply with ISO 4373. The markings shall be clear and accurate and shall cover the range of stage to be measured.

The reference gauge shall be securely fixed to an immovable and rigid support in the stream and shall be correlated to a fixed benchmark by precise levelling to the national or another datum.

6.2 Water-level recorder

Water-level recorders (if used) shall comply with ISO 4373.

6.3 Crest stage gauge

A crest stage gauge is suitable for use where only the peak stage attained during a flood has to be determined. Peak discharges can be calculated from two or more gauges installed in a reach of the river, at locations suitable for defining cross-sectional profiles.

6.4 High-water marks

The stage and slope of peak flows can be determined by surveying high-water marks in the measuring reach. Several types of high-water mark may be found, such as drift on banks, wash lines, seed lines on trees, mud lines, and drift in bushes or trees. Each high-water mark should be rated as excellent, good, fair or poor. This information will be helpful when interpreting the high-water profile and slope.

7 Procedure for installing gauges and making observations

7.1 Installation

Gauges shall be installed, on both banks of the river, at no fewer than three cross-sections, making a total of at least six gauges. The gauges shall be referenced to a common datum.

7.2 Procedure for observation of gauges

The gauges shall be read from such a position as to avoid all parallax errors. For each measurement, the gauge shall be observed continuously for a minimum period of 2 min or for the period of a complete oscillation, whichever is the longer, and the maximum and minimum readings taken and averaged.

When using water-level recorders, an observer should check the time displayed on each recorder against an accurate clock before and after the measurement period and also during the measurement period. All gauges should be observed as frequently as is necessary to record significant changes in stage which occur during the measurement period.

7.3 Other observations

The date, time, weather conditions (especially wind speed and direction), direction of the flow, and conditions of vegetation at the time of measurement should be recorded.

8 Computation of surface slope

8.1 Computation of surface slope from gauges

The surface slope is computed from the gauge observations at the upstream and downstream gauges delimiting the measuring reach, the intermediate gauge(s) being used to confirm that the slope is uniform throughout the reach. The gauges shall be read to the smallest marking on the gauge.

8.2 Computation of surface slope from high-water marks

When accurate gauge levels do not exist or have been destroyed, the slope during the peak stage can be estimated from flood marks on the channel banks. Several reliable high-water marks for each bank shall be used to define the flow profile. Each high-water mark shall be defined by its position along a baseline and a graphical plot shall be made so as to provide a visual profile of the high-water marks. Irregularities in the profile can be easily seen from such a plot, which will aid in the interpretation of the high-water profile and the water surface slope.

9 Cross-sections of the stream

9.1 Number of cross-sections

A minimum of three cross-sections of the selected measuring reach are generally desirable. These shall be clearly marked on the banks by means of masonry pillars or easily identifiable markers. The cross-sections shall be numbered so that the cross-section furthest upstream is identified as section 1, the adjacent cross-section downstream is identified as section 2, and so on.

9.2 Measurement of cross-sectional profiles

The profile of each of the cross-sections selected shall be measured at the same time at which the gauge observations are made, or as close as possible to this time. It is often impossible to measure the cross-section during flood and therefore an error may be introduced in the flow determination owing to an unobserved and temporary change in cross-section. If the section is stable, however, it will be sufficient to observe the cross-sections before and after a flood. Three cross-sectional profiles should be observed before and after floods where there is a difference in the velocities at the two ends of the reach.

If, for any reason, it is not possible to measure more than one cross-section, the central one only may be observed.

10 Computation of discharge for non-uniform and composite cross-sections

The discharge of a stream in a particular reach shall be calculated from the formula

$$Q = KS^{1/2} \qquad \ldots (1)$$

where

Q is the discharge;

K is the conveyance;

S is the friction slope.

10.1 Computation of conveyance

10.1.1 Non-uniform section

When the channel section is in the form of a single channel but is not uniform between two cross-sections, say sections 1 and 2, (it may be either converging or slightly expanding) the conveyance K_1 and K_2 of the upstream and downstream cross-sections respectively should be calculated. The mean conveyance for the reach will then be given by the geometric mean of the two values thus

$$K = (K_1 \times K_2)^{1/2} \qquad \ldots (2)$$

where

K_1 is the conveyance of the upstream cross-section (section 1)

$$K_1 = \frac{1}{n_1} A_1 R_{h1}^{2/3}$$

K_2 is the conveyance of the downstream cross-section (section 2)

$$K_2 = \frac{1}{n_2} A_2 R_{h2}^{2/3}$$

n_1 and n_2 are Manning's coefficient of rugosity (roughness) at section 1 and section 2 respectively;

A_1 and A_2 are the cross-sectional areas at section 1 and section 2 respectively;

R_{h1} and R_{h2} are the hydraulic radii at section 1 and section 2 respectively.

10.1.2 Composite section

Rivers in the flood plain generally have composite cross-sections as illustrated in figure 1. The conveyance for each component part of the section should be evaluated and summed to obtain the conveyance factor for the whole section, i.e.

$$K = K_a + K_b + K_c \qquad \ldots (3)$$

where

$$K_a = \frac{1}{n_a} A_a R_{ha}^{2/3}$$

$$K_b = \frac{1}{n_b} A_b R_{hb}^{2/3}$$

$$K_c = \frac{1}{n_c} A_c R_{hc}^{2/3}$$

A_a, A_b and A_c are the areas of the three components of the composite section;

R_{ha}, R_{hb} and R_{hc} are the hydraulic radii for the three components of the composite section;

n_a, n_b and n_c are Manning's coefficient of rugosity for the three components of the composite section.

If the shape of the composite cross-section varies between sections 1 and 2 then the conveyance factors for both composite cross-sections 1 and 2 should be evaluated separately and the mean conveyance of the reach should then be calculated following the procedure given in 10.1.1.

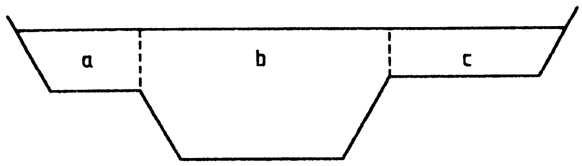

Figure 1 — Composite cross-section of a channel

10.2 Computation of the hydraulic radius

The hydraulic radius R_h at any section is the ratio of the area of flow A to the wetted perimeter P:

$$R_h = \frac{A}{P} \qquad \ldots (4)$$

The area of flow, i.e. the area of the cross-section, and the wetted perimeter are computed as follows (see also figure 2).

If the depths of flow of a channel, measured at different points along a cross-section by sounding, are d_1, d_2, d_3, ..., d_{n-1} and $d_0 = d_n = 0$ (see figure 2), the area of the cross-section may be computed as

$$A = \frac{1}{2} \sum_{i=1}^{n} b_i (d_{i-1} + d_i) \qquad \ldots (5)$$

and the wetted perimeter may be computed as

$$P = \sum_{i=1}^{n} \sqrt{b_i^2 + (d_i - d_{i-1})^2} \qquad \ldots (6)$$

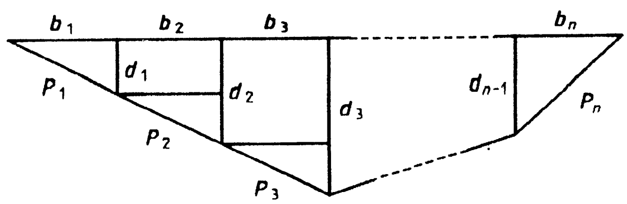

Figure 2 — Cross-section of a channel

10.3 Value of Manning's coefficient

Where a reasonable value of Manning's coefficient of rugosity can be extrapolated from discharge measurements taken in the measuring reach by accurate methods, the values obtained may be used provided that there have been no subsequent changes in the channel characteristics. It should be borne in mind that the greater the extrapolation of the data, the less reliable the result will be.

In the absence of measured data, the values given in table A.1 may be used for channels with relatively coarse bed material and not characterized by bed formations, and those given in table A.2 may be used for channels with other than coarse bed material and for channels having vegetation, clay and rocky banks, etc. Ripples, dunes, etc. may form in the sand beds of alluvial channels. Manning n and Chezy C coefficient values can be estimated approximately by applying relevant predictive equations using bed form geometry.

10.4 Evaluation of the friction slope

The friction slope S of the reach between sections 1 and 2 (see figure 3) may be defined as

$$S = \frac{(z_1 - z_2) + \left(\frac{\alpha_1 v_1^2}{2g} - \frac{\alpha_2 v_2^2}{2g} \right)(1 - K_e)}{L} \quad \ldots (7)$$

where

$z_1 - z_2$ is the measured fall;

α_1 and α_2 are velocity head coefficients;

K_e is the energy loss coefficient;

v_1 and v_2 are the mean velocities at section 1 and section 2 respectively and are given by the ratio Q/A at the two sections;

L is the length of the channel reach.

In figure 3, the numerator of formula (7) is given by h_f.

Owing to the non-uniform distribution of velocities over a channel section, the velocity head of an open channel flow is generally greater than the expression $v^2/2g$. When the energy principle is used in the computation, the true velocity head will be expressed as $\alpha v^2/2g$ where the value of α may be greater than 1 and the values of α_1 and α_2 in composite cross-sections may be calculated from

$$\alpha_1 \text{ or } \alpha_2 = \frac{\sum (K_i^3/A_i^2)}{K^3/A^2} \quad \ldots (8)$$

where

K is the conveyance of the total cross-section;

K_i is the conveyance of component i, where $i = 1$ to n;

A is the area of the total cross-section;

A_i is the area of component i, where $i = 1$ to n.

The velocity head coefficient may also be obtained from the following empirical equation

$$\alpha = 1 + 0{,}88 \left(0{,}34 + \frac{1 + \sqrt{g}/C}{2{,}3 + 0{,}3C/\sqrt{g}} \right)^2 \quad \ldots (9)$$

where C is the Chezy coefficient.

The energy head loss due to convergence or expansion of the channel in the measuring reach is assumed to be equal to the difference in the velocity heads at the two sections considered multiplied by a coefficient $(1 - K_e)$. The value of K_e is taken to be zero for uniform and converging reaches and 0,5 for expanding reaches. The energy loss coefficient of 0,5 for expanding reaches is an approximation, and therefore rapidly expanding reaches should not be selected for slope-area measurements.

For a converging reach, the friction slope to be used in the discharge calculation may therefore be calculated as

$$S = \frac{(z_1 - z_2) + \left(\frac{\alpha_1 v_1^2}{2g} - \frac{\alpha_2 v_2^2}{2g} \right)}{L} \quad \ldots (10)$$

and for expanding reaches, the friction slope is given by

$$S = \frac{(z_1 - z_2) + 0{,}5\left(\frac{\alpha_1 v_1^2}{2g} - \frac{\alpha_2 v_2^2}{2g} \right)}{L} \quad \ldots (11)$$

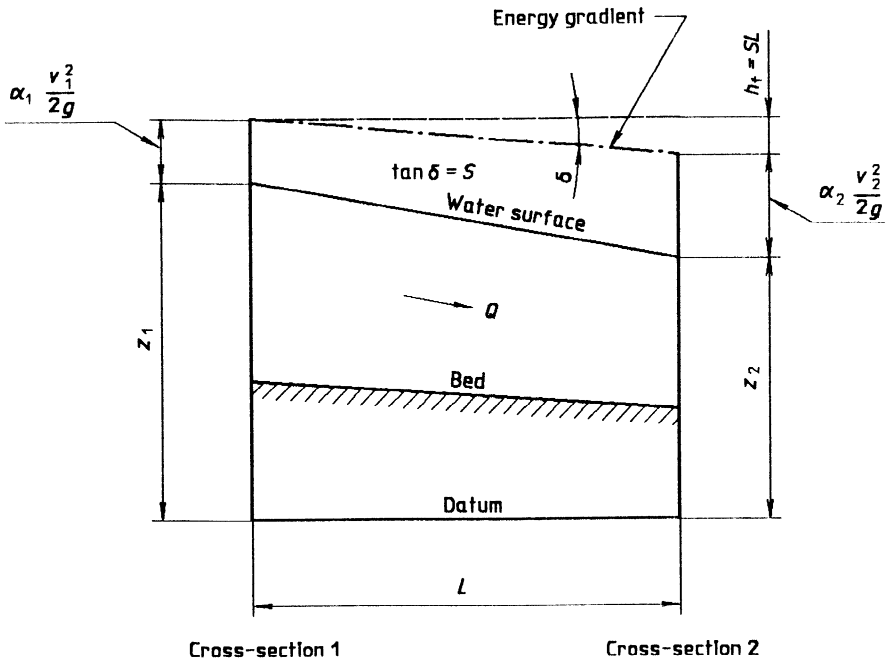

Figure 3 — Longitudinal section of a reach

The friction slope S between two adjacent cross-sections can be determined by successive approximation. First, assume a value for the discharge Q. A reasonable assumption can be made using the water-surface slope in place of the friction slope in equation (1). Then calculate v_1 and v_2 as Q/A_1 and Q/A_2, respectively. Calculate all other values in equation (7) from cross-sectional properties and water-surface elevations at sections 1 and 2. Calculate the friction slope S using equation (7). Calculate the discharge Q using the calculated value of S and the geometric mean conveyance K. If this calculated value of Q agrees with the assumed value of Q, within reasonable limits, then the calculated values of S and Q are correct.

10.5 Computation of discharge using three or more cross-sections

For reaches for which three or more cross-sections have been established, the discharge should be computed for each pair of adjacent sections. These computed discharges will most likely be different, and an average should be taken such that the energy balance is satisfied throughout the reach. This is usually a trial-and-error procedure.

Equations are available for these computations so as to avoid the trial-and-error method. The equation to be used for a reach with three cross-sections is

$$Q = K_3(z_1 - z_3)^{1/2} \left\{ \frac{K_3}{K_2}\left(\frac{K_3}{K_1}L_{1-2} + L_{2-3}\right) + \frac{K_3^2}{2gA_3^2}\left[-\alpha_1\left(\frac{A_3}{A_1}\right)^2(1-K_{e\,1-2}) + \alpha_2\left(\frac{A_3}{A_2}\right)^2(K_{e\,2-3}-K_{e\,1-2}) + \alpha_3(1-K_{e\,2-3})\right]\right\}^{-1/2} \quad \ldots (12)$$

10.6 State of flow

After the final discharge has been determined, the value of the Froude number Fr should be computed for each cross-section to evaluate the state of flow.

$$Fr = \frac{\bar{v}}{\sqrt{g\bar{d}}} \quad \ldots (13)$$

where

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

g is the acceleration due to gravity;

$\bar{d}$ is the mean depth of the cross-section, which is the ratio of the area of the cross-section and the water surface width.

NOTE 1 When $Fr = 1$ the flow is said to be in a critical state.

Although the slope-area method may be used for both subcritical ($Fr < 1$) and supercritical ($Fr > 1$) flow, if the state of flow changes in the channel reach from subcritical to supercritical or vice versa, there is cause for further examination of the data.

A change from supercritical to subcritical flow will create a hydraulic jump in the reach with its uncertain energy losses. A change from subcritical to supercritical flow might indicate a sudden contraction (with contraction losses not evaluated) or a "free fall" in the water surface (discontinuous water surface slope not related to discharge in the Manning equation). Where high-water profiles are obtained, the sharp drop or jump may be evident and will show the computed discharge to be at fault. A gradual transition from subcritical to supercritical flow is possible and might be verified by a continuous water surface profile; hence, the computed discharge may be accepted as valid.

11 Computation of discharge for uniform cross-sections

The discharge of a stream the cross-sections of which are uniform is the product of the mean cross-sectional area and the mean velocity of flow in the reach:

$$Q = \bar{v}_{1-m} \bar{A} \qquad \dots (14)$$

where $\bar{v}_{1-m}$ is the mean velocity in the reach.

11.1 Determination of the mean cross-sectional area and the mean wetted perimeter of the reach

In natural streams it is very difficult to find a reach which has a uniform cross-section throughout its length. However, if the reach is substantially uniform and there are small but significant differences in the cross-sectional areas A_1, A_2, ..., A_m, determined in accordance with 10.2 at the chosen cross-section, the mean cross-sectional area $\bar{A}$ of the reach may be taken as

$$\bar{A} = \frac{A_1 + 2A_2 + \dots + 2A_{m-1} + A_m}{2(m-1)} \qquad \dots (15)$$

where m is the number of cross-sections chosen.

The corresponding wetted perimeters shall then be determined and the mean wetted perimeter $\bar{P}$ may then be calculated as

$$\bar{P} = \frac{P_1 + 2P_2 + \dots + 2P_{m-1} + P_m}{2(m-1)} \qquad \dots (16)$$

NOTE 2 When the reach does not have a substantially uniform cross-section the use of equations (15) and (16) will not yield correct results. In such cases the conveyance for the upstream and downstream sections should be calculated as shown in 10.1.1.

11.2 Determination of the mean velocity in the reach

11.2.1 Using Manning's equation

The mean velocity between two or more cross-sections (where $A_1 \neq A_2$, ..., A_m) (see figure 3) when the flow is not significantly different from steady flow is given by the formula

$$\bar{v}_{1-m} = \frac{\bar{R}_h^{2/3} S_w^{1/2}}{\bar{n}} \qquad \dots (17)$$

where

$\bar{v}_{1-m}$ is the mean velocity in the reach $1 - m$;

$\bar{R}_h = \bar{A} / \bar{P}$

$\bar{n}$ is the arithmetic mean of the m values of Manning's rugosity coefficient for the cross-sections in the reach;

S_w is the water surface slope for the reach.

11.2.2 Using Chezy's equation

The mean velocity between two cross-sections for the same conditions as described in 11.2.1 is

$$\bar{v}_{1-m} = \bar{C} (\bar{R}_h S_w)^{1/2} \qquad \dots (18)$$

where $\bar{C}$ is the arithmetic mean of the m values of Chezy's discharge coefficient for the cross-sections in the reach.

Chezy's coefficient may be expressed in the form

$$C = \frac{1}{n} R_h^y \qquad \dots (19)$$

The value of y can be obtained from the equation specified in ISO 1100-2.

While Manning's and Chezy's formulae are well established and are generally used, there are other formulae, currently in use, which are valid over short ranges of mean velocity.

In the absence of measured data the value of C may be taken from table A.1 and table A.2 for conditions similar to those stated for Manning's coefficient n in 10.3, or it may be obtained by calculation using the relationship between C and n given in equation (19).

11.3 Correction of discharge

When the flood rise is rapid, the discharge estimated on the assumption of steady flow requires to be corrected as described in ISO 1100-2:1982, annex E.