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Hydrometry — Slope-area method

Hydrometrie — Methode de la pente de la ligne d'eau

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 113, *Hydrometry*.

This third edition cancels and replaces the second edition (ISO 1070:1992), which has been technically revised. It also incorporates the amendment ISO 1070:1992/Amd.1:1997. The main changes compared to the previous edition are as follows:

— the document has been reorganized to first present two-section computations followed by multiple reach computations;

— a third governing formula has been added;

— three annexes have been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The slope–area method is an indirect method of determining discharge in open channels when direct measurement of the flow is not possible because of the timing of the flow or because the site is too hazardous for direct measurement techniques. The method is usually used to document the discharge of a flood and to extend the stage–discharge rating of a stream flow gauging station above direct measurements of discharge. The method can also be used at locations where bridge, cableway or boat measurements are not possible. Water discharge is computed using flow resistance formulae based on channel characteristics, water-surface profiles, and a roughness or friction coefficient.

Hydrometry — Slope-area method

1 Scope

This document specifies a method of determining discharge in open channels from observations of the surface slope and cross-sectional area of the channel.

It is applicable to use under special conditions when direct measurement of discharge by typically more accurate methods, such as the velocity-area method, is not possible. Generally, the method can be used to determine discharge

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

b) for a peak flow that left marks on a series of water-level gauges or where peak stages were recorded by that series of gauges, and

c) for flow observed at the time of determining gauge heights from a series of gauges.

The method is commonly used to undertake the extension of stage–discharge relationships above the highest gauged flows.

It does not apply to determining discharges in tidal reaches.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 4373, *Hydrometry — Water level measuring devices*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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 using known empirical formulae that relate the velocity to the hydraulic radius. The surface slope is corrected to account 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.

Hydraulic assumptions of the method limit its suitability for use in very large channels with very flat surface slopes, steep mountainous channels where free fall over riffles and boulders occurs, or channels having significant curvature. Such conditions require experienced judgement to determine whether the method is applicable.

The most common governing formulae for flow resistance are the Manning and Chezy formulae. The Manning formula is shown by Formula (1):

$$Q = \frac{A R_h^{\frac{2}{3}}}{n} S^{\frac{1}{2}} \tag{1}$$

where

- Q is the discharge, in cubic metres per second;
- A is the cross-sectional area, in square metres;
- R_h is the hydraulic radius, in metres;
- S is the friction slope;
- n is the channel roughness, in seconds per metres to the one-third power.

The Chezy formula is shown by Formula (2):

$$Q = C A R_h^{\frac{1}{2}} S^{\frac{1}{2}} \tag{2}$$

where C is the Chezy form of roughness, in metres to the one-half power per second.

NOTE Manning n and Chezy C values of roughness for various open channel conditions are given in Annex A. The Strickler coefficient, K_s, is the reciprocal of n and it is used in some countries (see Annex B).

Another flow resistance formula is the Darcy-Weisbach (Colebrook-White) formula, which is a theoretically based formula commonly used in the analysis of pressure pipe systems. It applies equally well to any fluid flow rate and is general enough to be applied to open-channel flows. Although it has not been widely used (because the solution to the formula is difficult), it is gaining more acceptance because it successfully models the variability of effective channel roughness with respect to channel material, geometry and velocity. The Darcy-Weisbach (Colebrook-White) formula is shown by Formula (3):

$$Q = \left(\frac{8g}{f} \right)^{\frac{1}{2}} A R_h^{\frac{1}{2}} S^{\frac{1}{2}} \tag{3}$$

where

- f is the Darcy-Weisbach friction factor;
- g is the acceleration due to gravity, in metres per second squared.

The Darcy-Weisbach friction factor, f, can be determined using the Colebrook-White formula for fully developed turbulent flow, as shown by Formula (4):

$$\frac{1}{\sqrt{f}} = -\log_{10} \left(\frac{k}{14{,}83\, R_h} + \frac{2{,}52}{R_e \sqrt{f}} \right) \tag{4}$$

where

k is roughness height, in metres;

R_e is the Reynolds number.

Since the Darcy-Weisbach friction factor is on each side of the formula, an iterative computation algorithm is required to solve for f.

The three formulae and associated friction coefficients are employed best in streams or rivers with a uniform or slightly constricting reach in which the cross-sectional profile and bed material are consistent throughout the reach. The use of this method in non-uniform reaches, composite cross sections (a main channel and one or more overflow sections), and/or changes in channel geometry and roughness factors will introduce additional uncertainty in the computations.

5 Selection and demarcation of site

5.1 Initial survey of site

It is recommended that approximate measurements of widths, depths and surface slopes be made in a preliminary survey to decide whether the site is suitable and conforms (to the extent possible) with the conditions specified in 5.2 and 5.3. Interviews with witnesses, if any, should be done to get information about the flood timing, flow paths, high water levels, and possible bed changes during the event, and to ascertain the availability of photographs or videos of the flood event.

5.2 Selection of site

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 steep, rocky channels. The cross section should be as uniform as possible or slightly constricting throughout the reach and free from obstructions. Preferably, vegetation should be minimal and distributed uniformly throughout the reach. Ideal reach conditions are rare, so a reach with the best combination of desirable characteristics should be chosen.

Good high-water mark definition is essential to the slope–area method. The presence and quality of high-water marks are therefore key factors in selecting the measurement site.

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

Wherever possible, the length of the reach should be such that the difference between the water levels at the upstream and downstream ends of the reach is at least 0,25 m.

Flow in the reach should be free from significant tributary inflows (or distributary outflows), and from disturbances in the high-water profile caused by any tributaries or distributaries.

The flow in the channel should be contained within defined boundaries. If possible, reaches in which over-bank flow conditions exist should not be selected. Where this is unavoidable, however, a reach in which there are no very shallow flows over the floodplain should be sought. This will require additional computations for determining the discharge.

The site should not be subject to change in the flow regime from subcritical to supercritical or from supercritical to subcritical.

While a uniform reach is ideal, a converging reach should be selected in preference to an expanding reach. The energy losses induced by large expansions over the entire reach cannot be properly accounted for, thus reaches with large or rapid expansions should not be selected (see 9.3.3).

5.3 Demarcation of site

If the site is used for periodic slope–area measurements or continuous measurement of high flows, permanent cross sections normal to the direction of flow shall be chosen and markers (clearly visible and identifiable) shall be placed on both banks.

The site should be monitored to identify and assess any physical changes to the cross sections or reach that occur over time.

6 Measurement of slope

6.1 High-water marks

The slope–area method is most often used to document a flood or very high flow event. The friction slope defined in the flow resistance formulae is approximated by surveying high-water marks on both banks within the measuring reach to determine the change in water surface elevation, determining the velocity heads at each section, and evaluating the loss due to contraction or expansion. The high-water marks should extend upstream of the most upstream cross section and downstream of the most downstream cross section. The high-water marks may consist of 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, which will help with interpreting the high-water profile and slope. Mud lines and seed lines on tree trunks or structures typically are excellent high-water marks. Drift and wash lines are usually good, fair or poor depending on the tendency of the stream bank vegetation to bounce back from the forces exerted on it by the flowing water. Care should be exercised in using high-water marks on trees and other obstacles in high-velocity areas because they may be more representative of the total energy than the water level, which will reduce the accuracy of the computed discharge.

The high-water marks should be surveyed as soon as possible after the flood. If this is not practical, the marks should be preserved with paint, nails, flagging or labels until the survey can be done.

6.2 Crest-stage gauges

If the site is to be used for periodic measurement of high flows, a series of crest-stage gauges installed on each side of the reach can be used to determine the high-water profile and slope. There should be at least one crest-stage gauge at the left and right bank of each cross section; cross-section locations should reflect known hydraulic changes in the measurement reach (observed slope breaks in the high-water profile, for example). The crest-stage gauges should conform to ISO 4373.

6.3 Pressure transmitters

If the site is to be used for periodic measurement of high flow or continuous measurement of flood hydrographs, a series of recording gauges installed on each side of the reach can be used to determine the high-water profile and slope; as noted in 6.2, cross-section locations should reflect any known hydraulic changes in the measurement reach. The recording devices can be individual water-level recording gauges, or a series of pressure transmitters connected to a single data logger or recorder.

6.4 Reference gauge

The water levels determined by surveying high-water marks or from crest-stage or recording gauges should be referenced to national or local datum by precise levelling to the nearest benchmark. If the site is maintained as a stage–discharge gauging station, the water levels should be surveyed to the reference gauge whether it is a vertical staff gauge or inclined gauge. The reference gauge shall conform to ISO 4373 and be securely fixed to an immovable, rigid support in the stream or river.

7 Determination of slope

The high-water profile or surface slope is usually determined from a plot of high-water marks from both river banks. The average of the intersections of the lines of best fit of the high-water marks on both banks with the cross sections represent the water levels at each cross section. Each high-water mark will be defined by its position and quality rating on a graphical plot of water level versus distance, as measured along the stream thalweg or centre line of conveyance through the reach.

Alternatively, the water levels can be the difference in the average of the left and right bank crest-stage gauge measurements at the upstream and downstream cross sections of the measuring reach.

A large number of high mark levels, even if apparently redundant and not located in the considered cross sections, will help to identify and discount inconsistent flood marks and confirm uniformity of the flow regime along the reach.

8 Cross sections of a stream

8.1 Number and location of cross sections

A minimum of three cross sections in the selected measuring reach generally is desirable; five or more cross sections can provide insight into and reduce the uncertainty of the computed discharge. Cross sections 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.

Cross-section locations should be determined based on plotted high-water profiles (see Clause 7), with cross sections located at any major slope breaks in the high-water profiles. This approach ensures conveyance varies uniformly between cross sections, which is an assumption of the slope–area method. In addition to this criterion, cross-section spacing should be consistent with the length of the measurement reach and number of cross sections used. Each cross section should be oriented perpendicular to the direction of flow[4].

8.2 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 (by sounding) the cross section during flood and therefore an error may be introduced in the flow determination owing to an unobserved and temporary change in a cross section. If the section is stable, however, it will be sufficient to measure the cross sections before and after a flood.

9 Computation of discharge

9.1 General

Discharge calculations are presented for three types of stream reaches. The first case is for reaches with uniform cross-section geometry and roughness. In this case, the water surface slope (S_w) is virtually equivalent to the friction slope (S) because the velocity head throughout the reach is constant. The more complex cases are reaches that have converging or slightly diverging cross-sectional areas, and reaches that have composite cross sections consisting of a main channel section and one or two floodplain sections.

9.2 Uniform cross sections

9.2.1 General

The discharge of a stream for which the cross sections are uniform (both for geometry and roughness) is the product of the mean cross-sectional area and the mean velocity of flow in the reach, as shown by Formula (5):

$$Q = \bar{v}_{1-m} \bar{A} \tag{5}$$

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

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

In natural streams, it is very difficult to find a reach that has a uniform cross section throughout its length. However, if the reach is uniform with only small differences in the cross-sectional areas A_1, A_2, ..., A_m, the mean cross-sectional area of the reach may be taken as shown by Formula (6):

$$\bar{A} = \frac{A_1 + 2A_2 + ... + 2A_{m-1} + A_m}{2(m-1)} \tag{6}$$

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 shown by Formula (7):

$$\bar{P} = \frac{P_1 + 2P_2 + ... + 2P_{m-1} + P_m}{2(m-1)} \tag{7}$$

9.2.3 Determination of hydraulic radius

The hydraulic radius, R, at any section is the ratio of the area of flow A to the wetted perimeter P, as shown by Formula (8):

$$R_\text{h} = \frac{A}{P} \tag{8}$$

The area of flow, i.e. the area of the cross section, and the wetted perimeter are computed as follows (also see Figure 1).

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, ..., $d_{\text{m}-1}$ and $d_0 = d_\text{m} = 0$ (see Figure 1), the area of the cross section may be computed as shown by Formula (9):

$$A = \frac{1}{2} \sum_{i=1}^{m} b_i (d_{i-1} + d_i) \tag{9}$$

and the wetted perimeter may be computed as shown by Formula (10):

$$P = \sum_{i=1}^{m} \sqrt{b_i^2 + (d_i - d_{i-1})^2} \tag{10}$$

