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Measurement of liquid flow in open channels — Methods for measurement of characteristics of suspended sediment

Mesure de débit des liquides dans les canaux découverts — Méthodes de mesurage des caractéristiques des sédiments en suspension

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4363 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 6, *Sediment transport*.

This third edition cancels and replaces the second edition (ISO 4363:1993), which has been technically revised.

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

Introduction

Sediment has been defined generally as solid particles that are moved or might be moved, by stream flow in a channel. Sediment transportation creates numerous problems such as soil erosion, local scour, degradation and aggradation of streams, siltation in irrigation canals and navigation channels, loss of capacity of reservoirs, meandering of streams, damages to hydraulic machinery, etc. For solving varied sediment related issues arising out of human endeavours for development and management of water resources, a comprehensive knowledge of the mechanism of sediment transport and methods of determination of sediment load is highly essential.

Erosion is caused by water, wind, ice and human activities such as cultivation urbanization, mining, etc. Clods and aggregates of soil in the catchment area are broken down into small particles which are thrown into suspension and carried away as sediment. Not all the eroded material enters the stream channel. The total amount of eroded material which travels from a source to a downstream measuring point is termed as sediment yield.

The purpose for making measurements on suspended sediment is to determine the variation of the cross-sectional mean mass concentration and mean particle size distribution of suspended sediment in sediment transport processes using appropriate methods at a suitable frequency; then to determine the characteristic values of suspended sediment transport such as sediment load, mean particle size distribution, and sediment load of various particle sizes in various periods by jointly using the data of water stage, discharge, and suspended sediment.

Measurement of liquid flow in open channels — Methods for measurement of characteristics of suspended sediment

1 Scope

This International Standard specifies conventional and simplified methods for the measurement of cross-sectional mean suspended sediment mass concentration and mean particle size distribution. The conventional method is used for routine measurements in periods of stable or slowly varied flow. The simplified method is mainly used for sediment measurements for the purpose of observing the variation process of sediment transport and can be performed under difficult conditions. Empirical relationships are established between the cross-sectional mean suspended sediment mass concentrations and mean particle size distributions measured by conventional and simplified methods.

The methods specified in this International Standard are applicable to suspended sediment measurements at hydrological stations.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 31 (all parts), *Quantities and units*

ISO 748, *Measurement of liquid flow in open channels — Velocity-area methods*

ISO 772, *Hydrometric determinations — Vocabulary and symbols*

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 3716, *Liquid flow measurement in open channels — Functional requirements and characteristics of suspended sediment load samplers*

ISO 4365, *Liquid flow in open channels — Sediment in streams and canals — Determination of concentration, particle size distribution and relative density*

3 Terms and definitions

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

3.1
suspended sediment discharge
mass of suspended sediment passing through a specific cross-section of streams or canals per unit time

3.2
suspended sediment load
total mass of suspended sediment, generally expressed in mass or volume of dry sediment, passing through a specific cross-section of streams or canals in a given period of time

3.3
vertical average sediment mass concentration
ratio of the suspended sediment discharge per unit width (q_s) to the flow discharge per unit width (q) in a vertical

3.4
cross-sectional mean sediment mass concentration
ratio of the cross-sectional suspended sediment discharge ($Q_{A,s}$) to the cross-sectional flow discharge (Q_A)

3.5
method for combining samples collected in a cross-section
method for measurement of cross-sectional mean sediment mass concentration in accordance with the segmental discharge-weighted principle

NOTE The method involves dividing a cross-section by verticals into several segments with equal water surface width, or equal flow area or equal discharge. Samples are taken by a specific method in each vertical passing through each segment centre. (The flow velocity at a sediment sampling point should be measured simultaneously with the taking of the sediment sample or as soon as practicable after the collection of the sediment sample. In rivers subjected to rapidly changing stage, it is strongly recommended that the sediment sample be taken at the same time as the measurement of flow velocity.) Then the sediment mass concentration of the combined samples is determined as the cross-sectional mean sediment mass concentration.

3.6
particle size analysis
entire technological operation for determining the ratio of sediment mass of each size group to the total sediment mass of a sample as specified in ISO 4365

3.7
particle size distribution
distribution in ratios of sediment mass of each size group to the total sediment mass of a sample

NOTE It is generally expressed in ratios of mass of sediment coarser or finer than a given diameter to the total sediment mass of the sample.

3.8
cross-sectional mean size distribution of suspended sediment
conceptual characteristic value representing the ratios of sediment mass of each size group to the total suspended sediment mass in the cross-section

4 Units of measurement

4.1 The International System of Units (SI Units) is used in this International Standard in accordance with ISO 31 (all parts) and ISO 1000.

4.2 The suspended sediment concentration is expressed in one of the following three ways.

a) **Mass concentration of the water-sediment mixture** ρ_{ws}, generally expressed in milligrams per litre (mg/l), grams per litre (g/l) or kilograms per cubic metre (kg/m^3), is dry sediment per unit volume of the water-sediment mixture. This is the expression used in this International Standard.

b) **Volume fraction** φ, expressed as a percentage (%), is the ratio of the volume of sediment to the volume of the water-sediment mixture and is given by Equation (1):

$$\varphi = \frac{V_s}{V_{ws}} \tag{1}$$

where

V_s is the volume of sediment;

V_{ws} is the volume of the water-sediment mixture.

c) **Mass fraction**, w_w, expressed as a percentage (%), is the ratio of the mass of dry sediment to the mass of water-sediment mixture and is given by Equation (2):

$$w_\mathrm{w} = \frac{\rho_\mathrm{ws}}{\rho_\mathrm{w} + \left(1 - \frac{\rho_\mathrm{w}}{\rho_\mathrm{s}}\right)\rho_\mathrm{ws}} \qquad (2)$$

where ρ_ws is defined in a) and ρ_w and ρ_s are the mass concentrations of water and sediment, respectively, expressed in mg/l, g/l, or kg/m^3. If no measured data are available, ρ_s may be adopted as 2 650 kg/m^3.

5 Selection of site

The cross-section for measurement of suspended sediment shall preferably coincide with that for measurement of velocity and shall meet the requirements specified in ISO 748.

6 Selection of samplers

Samplers shall conform to the requirements specified in ISO 3716.

In measurement of suspended sediment, a time-integration type sampler and an *in-situ* velocity measurement device with good performance shall be used to eliminate or mitigate the influence of fluctuation of sediment concentration.

7 Measurement methods and frequencies

7.1 Principle for measurement of cross-sectional mean sediment mass concentration

As the distributions of velocity and sediment mass concentration in a cross-section of a stream vary spatially, the time-mean velocity v and sediment mass concentration ρ shall be measured at a number of points in the cross-section, with each point representing a small area of $\mathrm{d}A = \mathrm{d}h\mathrm{d}b$. From

$$Q_A = \int_0^B \int_0^H v\mathrm{d}h\mathrm{d}b \text{ and } Q_{A,\mathrm{s}} = \int_0^B \int_0^H \rho v\mathrm{d}h\mathrm{d}b .$$

the cross-sectional flow discharge and sediment discharge can be calculated. From the definition given in 3.4, the cross-sectional mean sediment mass concentration $\overline{\rho_A}$ is given by:

$$\overline{\rho_A} = \frac{Q_{A,\mathrm{s}}}{Q_A} = \frac{\int_0^B \int_0^H \rho v\mathrm{d}h\mathrm{d}b}{\int_0^B \int_0^H v\mathrm{d}h\mathrm{d}b} = \frac{\int_0^Q \rho \mathrm{d}q_A}{\int_0^Q \mathrm{d}q_A} \qquad (3)$$

where

$\mathrm{d}b$ and $\mathrm{d}h$	are the width and depth of the small area represented by the point, respectively;
B and H	are the surface width and vertical depth of flow, respectively;
$\mathrm{d}q_A$	(= $v\mathrm{d}h\mathrm{d}b$) is the discharge passing through the small area.

The cross-sectional mean sediment mass concentration is determined by weighting the mass concentration for the discharge of each section. This is the basic principle for measurement of cross-sectional mean sediment mass concentration. In practice, it is normally simplified into the sediment discharge method and the method for combining samples collected in a cross-section.

7.2 Principle for measurement and calculation of cross-sectional mean particle size distribution

The product of the cross-sectional mean particle size distribution and the cross-sectional sediment discharge shall be equal to the sum of the products of segmental particle size distribution and the corresponding sediment discharges. The cross-sectional mean particle size distribution conforms to the principle of weighting sediment mass concentration based on water discharge. The particle size distribution determined by the method for combining samples collected in a cross-section specified in this International Standard also conforms to the cross-sectional mean particle size distribution.

The cross-sectional mean mass fraction of sediment finer than a given diameter in the total sediment mass of sample $\overline{w_{d,A}}$ can be expressed by Equation (4):

$$\overline{w_{d,A}} = \frac{\sum_{i=1}^{n} w_{di} \cdot q_{\mathrm{s}i}}{\sum_{i=1}^{n} q_{\mathrm{s}i}} \tag{4}$$

where

w_{di} is the average percentage of the mass of sediment finer than the given diameter in the total sediment mass of sample for segment i;

$q_{\mathrm{s}i}$ is the sediment discharge of segment i;

d is the given diameter;

n is the number of segments.

In practice, some simplified sampling methods may be designed based on the above principle. Normally, the same sampling method for both measurements of cross-sectional mean sediment mass concentration and cross-sectional particle size analysis may be used.

7.3 Conventional method

7.3.1 General

The conventional method is designed for measurement of cross-sectional mean sediment mass concentration in accordance with the discharge-weighted principle. In this International Standard, the sediment discharge method and the method for combining samples collected in a cross-section are specified with respect to their characteristics.

7.3.2 Sediment discharge method (for measurement of sediment mass concentration)

7.3.2.1 Cross-sectional mean sediment mass concentration

In this method the cross-section is divided into several segments by verticals along the cross-section and the velocity and sediment mass concentration are measured by the selected point method or depth integration method in each vertical. The flow discharge and sediment discharge of each segment are calculated and totalled respectively as the total cross-sectional flow discharge and sediment discharge. The ratio of the cross-sectional sediment discharge to the cross-sectional flow discharge is taken as the cross-sectional mean sediment mass concentration.

The cross-sectional mean sediment mass concentration $\overline{\rho_A}$ determined by the sediment discharge method can be expressed by Equation (5).

$$\overline{\rho_A} = \frac{\sum_{i=1}^{n} q_{si}}{\sum_{i=1}^{n} q_i} = \frac{\sum_{i=1}^{n} \overline{\rho_i}\,\overline{v_i}\,\overline{h_i} b_i}{\sum_{i=1}^{n} \overline{v_i}\,\overline{h_i} b_i} \tag{5}$$

where

q_{si} and q_i are the sediment discharge and flow discharge passing through segment i, respectively;

$\overline{\rho_i}$ and $\overline{v_i}$ are the mean sediment mass concentration and mean velocity of segment i, respectively;

$\overline{h_i}$ and b_i are the mean flow depth and surface width of segment i;

n is the number of segments.

Two methods, namely the mid-section method and mean-section method, are used to calculate the segmental sediment discharge and segmental flow discharge (see ISO 748). In using the mid-section method, $\overline{\rho_i}$ and $\overline{v_i}$ are the vertical mean values, $\overline{h_i}$ is the vertical depth. In using the mean-section method, $\overline{\rho_i}$, $\overline{v_i}$, and $\overline{h_i}$ are the average values of two neighbouring verticals.

7.3.2.2 Methods for selecting verticals

Factors such as the shape and stability of the cross-section, characteristics of lateral distribution of sediment, sampling devices and methods, and requirement for accuracy shall be considered comprehensively for the method for selecting verticals. The following two methods are available.

a) Method for selecting verticals at turning points of sediment discharge per unit width:

   This method is applicable to the cross-sections with stable shape and lateral distributions of velocity and sediment, and clear turning points of sediment discharge per unit width. Its main advantage is that of obtaining relatively high accuracy using fewer verticals.

b) Method for selecting verticals at centrelines of segments with equal discharge:

   This method is applicable to stable cross-sections. If it meets the requirements of equal discharge increment (EDI) method (see 7.3.2.4), the EDI method can be used directly.

7.3.2.3 Number of verticals

The number of verticals shall be determined by analysing experimental data so as to meet the requirements for accuracy. Generally, it shall not be less than seven verticals for a water surface width larger than 300 m or it shall not be less than five verticals for a water surface width smaller than 300 m.

In measuring both sediment and velocity simultaneously, the number of verticals should be determined by the requirements for discharge measurement, as this is generally more than is required for the measurement of suspended sediment load.

7.3.2.4 Methods for sediment sampling in a vertical

In using the sediment discharge method to measure sediment, the point velocity or mean velocity in a vertical shall be measured simultaneously. The following three methods are available.

a) Depth-integration method:

In the depth-integration method, the time-integration type sampler is moved at a uniform transit rate along the vertical. In sampling, the moving rate of the sampler, volume of the sample should match the water depth and flow velocity. The method is highly accurate when the water is deep, the sampler is moved slowly and the effect of unmeasured layer near the bed is negligible.

b) Selected-point method:

It includes the two-point method (0,2h and 0,8h from water surface, where h is total vertical depth of the water), the three-point method (0,2h, 0,6h, and 0,8h from water surface), the five-point method [near water surface, 0,2h, 0,6h, and 0,8h from water surface, and near bottom (0,95h to 0,98h)]. The one-point method (0,6h from water surface) can be used for either low water depth or lower accuracy requirements.

NOTE The accuracy of the method for sediment sampling in a vertical can be improved by increasing the number of sampling points in a vertical. In this case, the seven-point method (see annex A) is usually used.

c) Method for combining samples collected in a vertical:

All the samples collected in a vertical are put together as one sample and its mass concentration is taken as the vertical mean sediment mass concentration.

The sampling points and duration for the method for combining samples collected in a vertical often used are listed in Table 1.

Table 1 — Sampling points and duration for the method of combining samples

Method	Relative depth of points (from water surface) [a]	Sampling durations [b]
Two-point	0,2h; 0,8h	0,5t; 0,5t
Three-point	0,2h; 0,6h; 0,8h	t/3, t/3; t/3
Five-point	Near surface; 0,2h; 0,6h; 0,8h near riverbed	0,1t; 0,3t; 0,3t; 0,2t; 0,1t

NOTE Generally, the accuracy of the vertical mean sediment increases as the number of sampling points in the vertical increases. An accurate measurement of the vertical mean sediment concentration also can be obtained using the depth-integration method when the water depth does not exceed 4,5 m.

In using the selected-point method, a relatively long duration of sampling can eliminate the effect of fluctuation between measured points. The depth-integration method takes samples over the whole vertical, so that a good spatial representative sampling can be obtained. However the sampling is instantaneous and fluctuation effects are eliminated by random compensation of all sampling points. Both the selected-point method and depth-integration method have their own advantages and disadvantages.

In accuracy tests, the seven-point method is commonly used as a standard method to evaluate the accuracy of other vertical sampling methods (see A.4).

[a] h is total vertical depth of the water.

[b] t is the total sampling duration in a vertical.

7.3.3 Methods for combining samples collected in a cross-section

7.3.3.1 General

There are three principal methods for combining samples collected in a cross-section. These methods are given in 7.3.3.2 to 7.3.3.4. Details for technical requirements and examples of methods for combining samples collected in a cross-section are given in annex B.

7.3.3.2 Equal-width-increment (EWI) method

In this method, the cross-section is divided into several segments of equal width. Select the verticals at the centrelines of segments. In each vertical, determine the mean sediment mass concentration using the depth-