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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):

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

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 dA = dhdb. From

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

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:

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

where

db and dh 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;

dq_A (= vdhdb) 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):

$$\overline{w_{d,A}} = \frac{\sum_{i=1}^{n} w_{di} \cdot q_{\text{s}i}}{\sum_{i=1}^{n} q_{\text{s}i}} \quad (4)$$

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;

$q_{\text{s}i}$ 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-integration method and/or the point sampling technique. Measure the velocity. Keep the nozzle diameter of the sampler constant. Combine samples collected in all verticals in the cross-section into one sample and take the sediment mass concentration as the cross-sectional mean sediment mass concentration.

7.3.3.3 Equal-area-increment (EAI) method

In this method, the cross-section is divided into several segments of equal area. Select the verticals at the centre of segments. In each vertical, determine the mean sediment mass concentration using the depth-integration method and/or point sampling technique. Keep the same sampling duration for all verticals. Keep the nozzle diameter of the sampler constant. Measure the velocity. Combine samples collected in all verticals into one sample and take the sediment mass concentration as the cross-sectional mean sediment mass concentration.

7.3.3.4 Equal-discharge-increment (EDI) method

In this method, a curve is obtained by plotting the percentage of cumulative discharge against the distance from the left side or right side of the water surface using the discharge data. Using the curve, divide the cross-section into several segments with equal discharge. Select the verticals at the segment centrelines. In each vertical, determine the mean sediment mass concentration using the depth-integration method and/or the point sampling technique. Collect the same volume from each vertical. Measure the velocity. Then combine all samples collected in the cross-section into one sample and take the sediment mass concentration as the cross-sectional mean sediment mass concentration.

If the volumes collected in verticals are not equal, treat each sample separately. Take the average value of sediment mass concentrations from all verticals as the cross-sectional sediment mass concentration.

7.3.4 Sampling methods for particle size analysis

Another set of samples may be collected in all or a part of verticals for measurement of sediment mass concentration using the same or different methods specifically for particle size analysis.

7.4 Simplified method

7.4.1 General

This method is a method for measurement of sediment mass concentration and particle size distribution in one or a few verticals which are representative of the cross-sectional mean sediment mass concentration and the mean particle size distribution.

7.4.2 Measurement of sediment mass concentration

7.4.2.1 Selection of sampling verticals

In the simplified method, it is necessary to statistically analyse the measured data and then to select verticals in a cross-section. The ratio of the sediment mass concentration, obtained by the simplified method, to the cross-sectional mean sediment mass concentration, obtained by the conventional method, shall be in the range of 0,90 to 1,10.

Sampling only in a fixed vertical is permissible if it has been established beforehand that the lateral sediment mass concentration is stable. Otherwise, two to three verticals shall be selected based on data analysis. For composite cross-sections where the lateral sediment mass concentration distribution varies largely with water levels, the position of the verticals shall be selected with respect to the water levels and the data analysis.

7.4.2.2 Sampling method in verticals

The depth-integration method and method for combining samples collected in a vertical are normally to be used.

In depth-integration sampling for either a round trip of lifting and lowering or for a repeated single trip from the bottom to the surface, use the sampler in the suspension mode.

7.4.3 Sampling method for particle size analysis

In sampling by the simplified method, the particle size distribution of sample shall be representative or have a stable relationship with the cross-sectional mean particle size distribution. Consequently, the sampling method and the location of verticals have to be selected using a statistical analysis of the data. Generally, the method can be the same as that used for the measurement of sediment mass concentration. The sample used for the measurement of the sediment mass concentration using the simplified method can also be used for particle size analysis. If the lateral sediment particle size distribution is uneven and the particle size distribution of one vertical has a systematic error, samples from three verticals at the thalweg, on the left side and the right side of the thalweg shall be collected respectively, then mixed for particle size analysis to give a more representative sample.

7.4.4 Conditions for using the simplified method

If the results of the conventional and simplified methods agree well in comparing tests and the conversion coefficient between them meets the requirements for cross-sections having a stable channel bed, lateral discharge and sediment mass concentration distributions, then the simplified method may be used fully for later measurements of the suspended sediment.

7.5 Distribution and requirements of measurements

7.5.1 General

The distribution of measurements is comprised of two aspects, their frequency and time intervals between measurements. Inadequate and irregular measurements affect the accuracy of long-term sediment discharge, particle size distribution and their characteristic values.

7.5.2 Distribution of measurements for sediment mass concentration

The distribution of suspended sediment mass concentration and sediment load generally varies over a period of a year. Therefore, to cover the range in water discharge and sediment mass concentration, it is preferable to make regular measurements of sediment mass concentration throughout the year.

In the dry season, if the sediment load over three consecutive months is less than 3,0 % of the annual average sediment load and there is no special need, sediment measurements for this period may be stopped. The sediment load during this period can be estimated to be zero.

7.5.3 Distribution of measurements for particle size analysis

The suspended sediment particle size distribution varies with the season and is also related to the sediment source. Most of the measurements of particle size distribution should be carried out in the flood season to represent the temporal variation of the particle size distribution. For hydrological stations where the particle size distribution for different periods is not required, several samples per year may be collected for measurement of particle size distribution.

Generally, long-term measurement of sediment particle size distribution need not be carried out as the particle size distribution is unlikely to change significantly between years. After the data of wet, dry, and normal years have been obtained, the measurement of sediment particle size distribution can be stopped.

Depending upon requirements, the measurement of the sediment mass concentration may or may not be performed simultaneously with the measurement of the particle size distribution.

7.6 Additional information

For proper use of sediment measurement data, additional information is required. Therefore, for each suspended sediment measurement, the following information shall be recorded in relation to the purpose of the measurement:

a) river (name);

b) river width and maximum depth;

c) site (name of hydrological station);

d) operator's name;

e) date;

f) weather conditions;

g) wind direction and speed;

h) air temperature;

i) water temperature;

j) sampler used;

k) time of sampling, i.e. from ... to ...;

l) gauge reading and discharge (at the beginning of measurement);

m) gauge reading and discharge (at the end of measurement);

n) water surface slope;

o) any other measurements taken simultaneously with the suspended sediment measurement (for example, discharge measurement, bed load and bed material sampling, ice measurement, etc.).

7.7 Source and control of errors

7.7.1 General

Errors made when making sediment measurements mainly originate from the methods, the devices, the operation technology, the treatment of samples and the technology of size analysis. All of these errors may cause relatively large systematic errors. Therefore, systematic errors, having been confirmed by data analysis, shall be effectively kept under control. Similarly, random errors shall be kept to a minimum.

7.7.2 Conventional method

7.7.2.1 In taking samples by the depth integration method, the water depth shall not be too shallow. The distance between the sampler nozzle and the riverbed shall not be larger than 5 % of the vertical depth; and the sampler shall be moved at a uniform transit rate. The ratio of the flow velocity at the entrance of the intake tube to the local stream velocity shall be close to 1,0. The sampler cannot stay near the riverbed when its intake is open. If the deviation of the cable suspending the sampler from the vertical exceeds 30^{o} in fast flow, the depth integration method is unsuitable.

7.7.2.2 In taking samples by the selected-point method, the sampling points shall be appropriately located. For the five-point method, the lowest sampling point shall be located at a relative depth of 0,95 to 0,98.

7.7.2.3 Verticals for sediment sampling shall be placed at the turning points of lateral distribution of water depth, flow velocity and sediment mass concentration. The number of verticals shall not be less than half of that for the velocity measurement.

7.7.2.4 The accuracy of various methods for combining samples collected in a cross-section shall be checked by the sediment discharge method. The selected method shall meet the requirement of accuracy.

7.7.3 Simplified method

The positions of verticals in the simplified method shall be determined by data analysis. The ratio of the sediment mass concentration by the simplified method to the cross-sectional mean sediment mass concentration by the sediment discharge method shall be in the range of 0,95 to 1,05. If the ratio is outside this range, the positions of the verticals shall be readjusted. Significant systematic deviation shall not exist between the particle size distribution by the simplified method and the cross-sectional mean particle size distribution by the sediment discharge method. Otherwise, the positions of verticals shall be readjusted to meet the requirements of accuracy.

Sampling using the simplified method shall be repeated once.

8 Calculation

8.1 Sediment discharge and mass concentration

8.1.1 Sediment mass concentration

If using the mass of dry sediment in a unit volume of water-sediment mixture to express sediment mass concentration, the sediment mass concentration of the sample can be calculated by the following equation:

$$\rho = \frac{m}{V}$$

where

ρ is the sediment mass concentration, expressed in the unit specified in 4.2 a);

m is the mass, expressed in milligrams, grams or kilograms, of dry sediment in the sample;

V is the volume, expressed in litres or cubic metres, of the sample.

The sediment mass concentration of the sample determined using the depth integration method or the method for combining samples collected in a vertical can be taken as the vertical mean sediment mass concentration. The sediment mass concentration of the sample determined using the method for combining samples collected in a cross-section can be taken as the cross-sectional mean sediment mass concentration.

The readings of an *in-situ* measurement device or its transmitted readings can be taken as the measured sediment mass concentration.

The sediment mass concentration can be expressed in other forms by deriving its definition or converting Equations (1) and (2).

8.1.2 Mean sediment mass concentration in a vertical

8.1.2.1 When sampling using the depth integration method or the method for combining samples collected in a vertical, the sediment mass concentration can be taken as the mean sediment mass concentration in a vertical.

8.1.2.2 When sampling using the selected point method and measuring the velocity, the mean sediment mass concentration in a vertical, $\overline{\rho_{\text{v}}}$, can be calculated by one of the following equations.

For the two-point method:

$$\overline{\rho_{\text{v}}} = \frac{v_{0,2}\rho_{0,2} + v_{0,8}\rho_{0,8}}{v_{0,2} + v_{0,8}} \quad (7)$$

For the three-point method:

$$\overline{\rho_{\text{v}}} = \frac{v_{0,2}\rho_{0,2} + v_{0,6}\rho_{0,6} + v_{0,8}\rho_{0,8}}{v_{0,2} + v_{0,6} + v_{0,8}} \quad (8)$$

For the five-point method:

$$\overline{\rho_\text{v}} = \frac{1}{10\overline{v_\text{v}}}(v_{0,0}\rho_{0,0} + 3v_{0,2}\rho_{0,2} + 3v_{0,6}\rho_{0,6} + 2v_{0,8}\rho_{0,8} + v_{1,0}\rho_{1,0}) \quad (9)$$

where

$v_{0,0}, v_{0,2}, ... v_{1,0}$ are the velocities, expressed in metres per second (m/s), at the points 0,0h, 0,2h, ...1,0h from the water surface, respectively;

$\rho_{0,0}, \rho_{0,2}, ... \rho_{1,0}$ are the sediment mass concentration (mg/l, g/l or kg/m^3) at the points of 0,0h, 0,2h, ...1,0h from the water surface, respectively.

$\overline{v_\text{v}}$ $\left[= \frac{1}{10}(v_{0,0} + 3v_{0,2} + 3v_{0,6} + 2v_{0,8} + v_{1,0}) \right]$ is the mean velocity in a vertical.

NOTE $\rho_{1,0}$ is the sediment mass concentration at the level closest to the riverbed.

8.1.3 Cross-sectional sediment discharge and mean sediment mass concentration

8.1.3.1 The universal equation for the calculation of the cross-sectional sediment discharge $Q_{A,\text{s}}$ is:

$$Q_{A,\text{s}} = \sum_{i=1}^{n} q_{\text{s}i} = \sum_{i=1}^{n} \rho_i q_i \quad (10)$$

where $q_{\text{s}i}$, ρ_i and q_i are the sediment discharge, sediment mass concentration, and flow discharge of segment i, respectively.

In calculating the segmental sediment discharge by the mid-section method, ρ_i is the mean sediment mass concentration of vertical i.

In calculating the segmental sediment discharge by the mean-section method, ρ_i, is the average sediment mass concentration of two neighbouring verticals of segment i.

8.1.3.2 The cross-sectional mean sediment mass concentration, $\overline{\rho_A}$ can be calculated in accordance with Equation (11):

$$\overline{\rho_A} = \frac{Q_{A,\text{s}}}{Q_A} \quad (11)$$

where

Q_A is the cross-sectional flow discharge;

$Q_{A,\text{s}}$ is the cross-sectional sediment discharge.

8.2 Calculation of particle size distribution

8.2.1 Vertical mean particle size distribution

8.2.1.1 The particle size distribution resulting from using the depth integration method or using the method for combining samples collected in a vertical can be taken as the vertical mean particle size distribution.

8.2.1.2 In taking samples and measuring velocity by the selected point method, the vertical mean particle size distribution $\overline{w_{d,\mathrm{v}}}$, i.e. the percentage (%) of the mass of sediment finer than a given diameter accounting for the total sediment mass of the sample, can be calculated by the following equations:

For the two-point method:

$$\overline{w_{d,\mathrm{v}}} = \frac{w_{d0,2} v_{0,2} \rho_{0,2} + w_{d0,8} v_{0,8} \rho_{0,8}}{v_{0,2} \rho_{0,2} + v_{0,8} \rho_{0,8}} \quad (12)$$

For the three-point method:

$$\overline{w_{d,\mathrm{v}}} = \frac{w_{d0,2} v_{0,2} \rho_{0,2} + w_{d0,6} v_{0,6} \rho_{0,6} + w_{d0,8} v_{0,8} \rho_{0,8}}{v_{0,2} \rho_{0,2} + v_{0,6} \rho_{0,6} + v_{0,8} \rho_{0,8}} \quad (13)$$

For the five-point method:

$$\overline{w_{d,\mathrm{v}}} = \frac{w_{d0,0} v_{0,0} \rho_{0,0} + 3 w_{d0,2} v_{0,2} \rho_{0,2} + 3 w_{d0,6} v_{0,6} \rho_{0,6} + 2 w_{d0,8} v_{0,8} \rho_{0,8} + w_{d1,0} v_{1,0} \rho_{1,0}}{v_{0,0} \rho_{0,0} + 3 v_{0,2} \rho_{0,2} + 3 v_{0,6} \rho_{0,6} + 2 v_{0,8} \rho_{0,8} + v_{1,0} \rho_{1,0}} \quad (14)$$

where $w_{d0,0}$, $w_{d0,2}$, ..., $w_{d1,0}$ are the percentages (%) of the masses of sediment finer than the given diameter at the points of 0,0h, 0,2h, ..., 1,0h from the water surface accounting for the total sediment mass of the sample, respectively.

8.2.2 Cross-sectional mean particle size distribution

The cross-sectional mean particle size distribution can be determined by the following.

a) Particle size distribution resulting from the sample combined to obtain cross-sectional mean sediment mass concentration may be taken as the cross-sectional mean particle size distribution.

b) In the case where data from individual samples are to be used, the cross-sectional mean particle size distribution can be calculated from Equation (4).

9 Estimation of random uncertainty and systematic error for measurement of suspended sediment

9.1 General

The mass concentration and the particle size distribution of suspended sediment are dynamic variables without repeatability. It is impossible to measure them directly, without error at a point, or indirectly as the cross-sectional mean values. The aims of setting up this International Standard are to keep systematic error strictly under control, to minimize random error and to eliminate any false error so as to ensure the necessary accuracy of measurement and to check and evaluate the quality of measurements.

Error and uncertainty are two different but relevant variables. Error is defined as the difference between the observed and the true values. Uncertainty is defined as a range in which the true value of the measured variable is expected to fall at a specified probability. In this International Standard, the probability is specified as 95 %, the corresponding uncertainty is 1,96 times the standard error.

As relatively large systematic error easily occurs in the measurement of suspended sediment, it is the main factor affecting measurement quality but it can be identified and kept under control. Therefore in this International Standard, random error and systematic error are treated individually.

9.2 Sources of error

Measurements of different sediment characteristics have different sources of error. Errors in the measurement of cross-sectional sediment discharge include all the component errors for the measurement of flow discharge specified in ISO 748. Errors in the measurement of cross-sectional mean sediment mass concentration mainly depend on the samplers, the sampling duration, the sampling methods in verticals, the methods of sample treatment and the selection of verticals. Errors in the measurement of flow discharge having only a weighted function can be neglected. In this International Standard, only errors in the measurement of the cross-sectional mean sediment mass concentration are considered.

Errors in the measurement of cross-sectional mean particle size distribution originate mainly from sampling, sample preparation and size analysis. Therefore, only errors made from sampling are considered in this International Standard.

The estimation of the uncertainty of cross-sectional sediment discharge requires the analysis of errors associated with the cross-sectional flow discharge and the mean sediment mass concentration. The estimation of the uncertainty of flow discharge can be conducted in accordance with ISO 748.

According to the principles of measurement, the random uncertainty and systematic errors of the cross-sectional mean sediment mass concentration are composed of two component errors, i.e. the error of the vertical mean sediment mass concentration and the error due to limited verticals (calculation principles).

9.3 Estimation of component errors

9.3.1 The errors of vertical mean sediment mass concentration consist of the following:

a) the error due to sampler, defined as the deviation of measurement by a sampler under normal working conditions from that by a standard sampler and includes random uncertainty $e_{\mathrm{r,c}}$ and systematic error $e_{\mathrm{s,c}}$;

b) the error due to sample treatment, defined as the error due to the methods or operations for the measurement of sediment mass concentration and includes random uncertainty $e_{\mathrm{r,s}}$ and systematic error $e_{\mathrm{s,s}}$;

c) the C_{I}-type error, defined as the fluctuation error due to limited sampling duration at a point in a vertical and its random uncertainty is $e_{\mathrm{r,e}}$;

d) the C_{II}-type error, defined as the error of the vertical mean sediment mass concentration due to limited sampling points and calculation principle and includes random uncertainty $e_{\mathrm{r,p}}$ and systematic error $e_{\mathrm{s,p}}$.

9.3.2 The C_{III}-type error is defined as the error of the cross-sectional mean sediment mass concentration due to limited verticals and calculation principles and includes random uncertainty $e_{\mathrm{r},n}$ and systematic error $e_{\mathrm{s},n}$.

9.4 Total random uncertainty for measurement of cross-sectional mean sediment mass concentration

If the error of flow discharge is not considered, the total random uncertainty of one measurement of cross-sectional mean sediment mass concentration, $e_{\overline{\rho_A}}$, can be calculated by the following equation:

$$e_{\overline{\rho_A}} = \left[e_{\mathrm{r},n}^2 + \frac{\sum_{i=1}^{n} (q_i \rho_{\mathrm{s}i})^2}{\left(\sum_{i=1}^{n} q_i \rho_{\mathrm{s}i}\right)^2} \left(e_{\mathrm{r,e}}^2 + e_{\mathrm{r,c}}^2 + e_{\mathrm{r,s}}^2 + e_{\mathrm{r,p}}^2 \right) \right]^{\frac{1}{2}} \tag{15}$$

If the segmental sediment discharges in a cross-section are roughly equal, Equation (15) can be simplified as

$$e_{\overline{\rho_A}} = \sqrt{e_{\mathrm{r},n}^2 + \frac{1}{n}(e_{\mathrm{r,e}}^2 + e_{\mathrm{r,c}}^2 + e_{\mathrm{r,s}}^2 + e_{\mathrm{r,p}}^2)} \qquad (16)$$

If the segmental sediment discharges in a cross-section are not equal, Equation (15) can be simplified as

$$e_{\overline{\rho_A}} = \sqrt{e_{\mathrm{r},n}^2 + \frac{k}{n}(e_{\mathrm{r,e}}^2 + e_{\mathrm{r,c}}^2 + e_{\mathrm{r,s}}^2 + e_{\mathrm{r,p}}^2)} \qquad (17)$$

where

$e_{\mathrm{r},n}$ is the random uncertainty due to limited verticals and calculation principles;

$e_{\mathrm{r,e}}$ is the random uncertainty due to fluctuation;

$e_{\mathrm{r,c}}$ is the random uncertainty due to sampler;

$e_{\mathrm{r,s}}$ is the random uncertainty due to sample treatment;

$e_{\mathrm{r,p}}$ is the random uncertainty due to limited measurement points and calculation principles;

n is the number of segments in a cross-section;

k is a coefficient to modify the effect of uneven distribution of the segmental sediment discharge. k can be determined by analysing data and is generally in the range of 1,0 to 1,3. The more uneven the distribution, the larger the value.

9.5 Total systematic error for one measurement of cross-sectional mean sediment mass concentration

If the signs and values of each component systematic error are known in the sediment measurement, the total systematic error is their algebraic sum. If their signs are unknown, the total systematic uncertainty can be calculated by the root-sum-of-square rule.

Annex A
(informative)

Data collection for determining the error in measurement of cross-sectional mean sediment mass concentration and estimation of errors

A.1 General considerations

To determine the component errors in the measurement of cross-sectional mean sediment mass concentration, appropriate methods are to be adopted for data collection with respect to the sources of error. Then, calculation is carried out to determine each component error as the basis for estimating the total random uncertainty and systematic errors.

From the universal Equation (5) for the calculation of the cross-sectional mean sediment mass concentration, it can be seen that the errors in measurement of cross-sectional mean sediment mass concentration are mainly composed of the errors in the measurement of vertical mean sediment mass concentration ($\overline{\rho_i}$) and the errors due to limited verticals (n) and calculation principles. The errors in measurement of vertical mean sediment mass concentration include the errors due to sampler, the limited points in a vertical, the calculation principle, the sediment fluctuation error due to insufficient sampling duration and the error from sample treatment. Each of these is to be experimentally studied.

A.2 Data collection for analysing error due to sampler

A.2.1 Methods and requirements

The error due to the sampler can be determined by making comparative tests with a standard sampler[1]. The comparative tests should include the measurement of the sediment mass concentration, the hydraulic efficiency (i.e. velocity coefficient of intake) and the particle size distribution. Carry out the tests in a stable flow. First check the sampler. Then operate the standard sampler simultaneously with the sampler to be tested under the same flow conditions making sure there is no disturbance from the other sampler. In a set of comparative tests, it is necessary to collect between 20 to 30 samples by each of the two samplers at the same place and to simultaneously measure the flow velocity. When half of samples have been collected, exchange the suspension positions of the two samplers and then take the second half of samples. Carry out these tests at different sediment mass concentrations.

A.2.2 Calculation of errors

The results measured by the standard sampler are taken to be the standard values. The relative error E_i, the relative average error e_s (i.e. systematic error), and the relative standard deviation σ_ρ of sediment mass concentration comparing with the standard values are calculated by the following equations:

The relative error is calculated as follows:

$$E_i = \frac{\rho_i}{\rho_{0i}} - 1 \qquad \text{(A.1)}$$

where ρ_i and ρ_{0i} are the sediment mass concentrations of the ith measurement by the sampler to be checked and the standard sampler, respectively.

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1) The USP61 (or P63) sampler recommended by the WMO can be used as the standard sampler.

The relative average error is calculated as follows:

$$e_{s,\rho} = \frac{1}{n}\sum_{i=1}^{n} E_i \tag{A.2}$$

The relative standard deviation is calculated as follows:

$$\sigma_\rho = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(E_i - e_{s,\rho}\right)^2} \tag{A.3}$$

A.3 Data collection for analysing C_I-type error (fluctuation error of sediment mass concentration)

A.3.1 Methods and requirements

In determining the fluctuation error of sediment mass concentration, if possible, use an *in-situ* automatic recorder (for example, an *in-situ* nuclear gauge) at a fixed point and record the fluctuation of sediment mass concentration every 30 s for a period of 3 min to 5 min. The fluctuation cycle varies in the range of 10 s to 10 min. The mass concentration fluctuates more or less around the time-averaged value without a given rule. The fluctuation error of sediment mass concentration decreases with the increase in sediment mass concentration.

If it is impossible to perform the method above, the fluctuation error of sediment mass concentration can be determined by placing a sampler at a fixed point and continuously collecting between 20 to 30 samples for the same sampling duration so as to obtain the fluctuation in sediment mass concentrations and to analyse its fluctuation error. Carry out the sampling under stable flow conditions. Select several representative verticals based on the lateral distribution of sediment mass concentration. Collect and make measurements on samples and velocities at points 0,2, 0,6 and 0,8 of the relative water depth.

A.3.2 Calculation of errors

The fluctuation of sediment mass concentration is a random process and follows the normal distribution law. Consequently, only the error due to randomly sampling is estimated.

The relative standard deviation of C_I-type error can be calculated by the following equation:

$$\sigma_I = \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{\rho_i}{\rho_t} - 1\right)^2}{n-1}} \tag{A.4}$$

where

σ_I is the relative standard deviation of C_I-type error;

ρ_i is the sediment mass concentration of sample i;

ρ_t is the approximate true value of sediment mass concentration by averaging each set of measurements;

n is the number of samples of each set.

In taking samples by the selected point method, the C_I-type error of the vertical mean sediment mass concentration can be estimated by the following equation:

$$\sigma_{\mathrm{I,v}}^2 = \sum_{l=1}^{L} K_{\mathrm{w},l}^2 \sigma_{\mathrm{I}}^2 \tag{A.5}$$

where

$\sigma_{\mathrm{I,v}}$ is the C_{I}-type vertical relative standard deviation;

L is the number of points in a vertical;

$K_{\mathrm{w},l}$ is the weighted coefficient of sediment mass concentration at a point. For n verticals, it is the arithmetic average value of errors of each vertical.

A.4 Data collection for analysing C_{II}-type error

A.4.1 Methods and requirements

There are three categories of sampling methods for measuring the vertical mean sediment mass concentration:

a) the depth-integration method,

b) the selected-point method, and

c) the method for combining samples collected in a vertical.

It is common to take a multi-point method for the measurement of the vertical mean sediment mass concentration as the standard to check the accuracy of other methods. In this International Standard, a particular sampling method, i.e. seven-point method (near water surface, 0,2h, 0,4h, 0,6h, 0,8h, 0,9h and near riverbed), is taken as the standard one.

Data from various water levels and sediment mass concentrations in more than 30 verticals is collected for the test of C_{II}-type error. The verticals are placed at the thalweg and the points where the water depths are 0,6 and 0,3 of the maximum water depth in the wider subsection from the thalweg to riverbank. In the verticals, the seven-point method is used for sampling and the velocity is measured simultaneously. At each point, sampling is conducted twice and the average value is adopted. The samples collected at each point may be used for the particle size analysis. The water temperature is measured. If it is necessary to check the accuracy of the depth-integration method, the data of comparative tests shall be collected simultaneously.

A.4.2 Calculation of error

A.4.2.1 The vertical mean sediment mass concentration from the seven-point method can be calculated by Equation (A.6) and taken as the approximate true value.

$$\overline{\rho_{\mathrm{v,t}}} = \frac{v_{0,0}\rho_{0,0} + 2v_{0,2}\rho_{0,2} + 2v_{0,4}\rho_{0,4} + 2v_{0,6}\rho_{0,6} + 1{,}5v_{0,8}\rho_{0,8} + (1 - 5\eta_{1,0})v_{0,9}\rho_{0,9} + (0{,}5 + 5\eta_{1,0})v_{1,0}\rho_{1,0}}{v_{0,0} + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 1{,}5v_{0,8} + (1 - 5\eta_{1,0})v_{0,9} + (0{,}5 + 5\eta_{1,0})v_{1,0}} \tag{A.6}$$

where

ρ_{t} is the approximate true value of vertical mean sediment mass concentration;

$v_{0,0}$, $\rho_{0,0}$ are the velocity and sediment mass concentration at the river surface, respectively;

$v_{1,0}$, $\rho_{1,0}$ are the velocity and sediment mass concentration at the riverbed, respectively;

$\eta_{1,0}$ is the relative water depth (from the riverbed) of the point near the bed.

A.4.2.2 In measurement of vertical mean sediment mass concentration by using the n-point method to take samples, the relative error $E_{\mathrm{II},n}$, relative average error $e_{\mathrm{II,s},n}$ and relative standard deviation $\sigma_{\mathrm{II},\rho,n}$ can be calculated by the following equations, respectively.

$$E_{\mathrm{II},n} = \frac{\rho_{i,n}}{\rho_{\mathrm{t},i}} - 1 \quad \text{(A.7)}$$

$$e_{\mathrm{II,s},n} = \frac{1}{I}\sum_{i=1}^{I} E_{\mathrm{II},n} \quad \text{(A.8)}$$

$$\sigma_{\mathrm{II},n} = \sqrt{\frac{1}{L-1}\sum_{i=1}^{L}(E_{\mathrm{II},n} - e_{\mathrm{II,s},n})^2} \quad \text{(A.9)}$$

where

$E_{\mathrm{II},n}$ is the C_{II}-type error in vertical i in taking samples by the n-point method;

$\rho_{i,n}$ is the vertical mean sediment mass concentration in vertical i in taking samples by the n-point method;

$\rho_{\mathrm{t},i,n}$ is the approximate true value of the vertical mean sediment mass concentration in vertical i;

$e_{\mathrm{II,s},n}$ is the average value of C_{II}-type error (i.e. systematic error) in taking samples by the n-point method;

L is the number of the verticals;

$\sigma_{\mathrm{II},n}$ is the relative standard deviation of C_{II}-type error in taking samples by the n-point method.

A.5 Data collection for analysing C_{III}-type error

A.5.1 Methods and requirements

To analyse the errors of cross-sectional mean sediment mass concentration due to various number of verticals and calculation principles, it is common to select as many as possible verticals. The measured cross-sectional mean sediment mass concentration is taken as the approximate true value. Then, the C_{III}-type errors for various numbers of verticals are calculated.

The test of C_{III}-type error shall collect data from various water levels and sediment mass concentrations by the depth-integration method or two-point method in more than 30 sets of measurements. The number of verticals can be determined using Table A.1.

Table A.1 — Determination of number of verticals

River width, m	< 100	100 to 300	300 to 1 000	> 1 000
Number of verticals	15 to 20	20 to 25	25 to 30	30 to 40

The two-point or one-point method is used to measure velocity simultaneously in each vertical. The samples collected in each vertical may be used for particle size analysis respectively if it is necessary. The water temperature is measured.

A.5.2 Calculation of error

A.5.2.1 From data measured in verticals the approximate true value of the cross-sectional mean sediment mass concentration can be calculated by the following equation.

$$\overline{\rho_A} = \frac{\sum_{i=1}^{n} q_{A,\mathrm{s}i}}{\sum_{i=1}^{n} {}_{A,i}} = \frac{\sum_{i=1}^{n} \overline{\rho_i v_i d_i} b_i}{\sum_{i=1}^{n} \overline{v_i d_i} b_i} \quad \text{(A.10)}$$

A.5.2.2 In using the method for selecting verticals, the errors are calculated based on the principles of EWI, EAI or EDI methods.

In selecting n verticals to calculate the cross-sectional mean sediment mass concentration, the relative error $E_{\mathrm{III},n}$, relative average error $e_{\mathrm{III},n}$, and relative standard deviation $\sigma_{\mathrm{III},n}$ can be calculated by the following equations, respectively.

$$E_{\mathrm{III},n} = \frac{\bar{\rho}_{i,n}}{\bar{\rho}_{\mathrm{t}i}} - 1 \quad \text{(A.11)}$$

$$e_{\mathrm{III},n} = \frac{1}{I}\sum_{i=1}^{I}\left(\frac{\bar{\rho}_{i,n}}{\bar{\rho}_{\mathrm{t},i}} - 1\right) \quad \text{(A.12)}$$

$$\sigma_{\mathrm{III},n} = \sqrt{\frac{1}{I-1}\sum_{i=1}^{I}(E_{\mathrm{III},n} - e_{\mathrm{III},n})^2} \quad \text{(A.13)}$$

where

$E_{\mathrm{III},n}$ is the C_{III}-type error of the cross-sectional mean sediment mass concentration by selecting n verticals in the ith set of measurements;

$e_{\mathrm{III},n}$ is the mean value of C_{III}-type error (i.e. systematic error) of the cross-sectional mean sediment mass concentration of n verticals;

I is the number of the sets of measurements;

$\sigma_{\mathrm{III},n}$ is the relative standard deviation of C_{III}-type error of the cross-sectional mean sediment mass concentration in selecting n verticals.

A.6 Data collection for analysing sample treatment error

A.6.1 General

In using drying or filtration methods to determine the sediment mass concentration, the error sources are different. In the component errors by the drying and filtration methods, systematic errors are the main ones and shall be tested and analysed respectively.

A.6.2 Data collection for analysing errors of drying method

A.6.2.1 The relative error due to volume measurement of sample, E_V is related to the minimum graduation of the cylinder. This random error, E_V is ± 0,5 %.

A.6.2.2 The relative error due to weighing sediment, E_w, is related to accuracy of the scale and amount of the sediment. Generally, the random error due to weighing sediment, E_w is ± 1 %.

A.6.2.3 The error due to settling loss, E_s, is defined as the loss of sediment due to insufficient duration of settling. It is a negative systematic error and related to settling duration and the percentage of fine sediment in the total sediment of the sample. The settling duration shall be determined by tests. The relative error due to settling loss E_s shall be generally within − 1,0 %.

A.6.2.4 In river water, errors occurs due to dissoluble materials in river water, E_d, (for instance salt). Some river water containing dissoluble materials still remains in the sediment sample to be dried, making the sediment heavier than the real mass. The contents of dissoluble materials can be determined by field investigation or measurement. In an estuarine environment, it is strongly recommended to flush the salt out of the filter paper after the filtration of the sample using distilled water.

The relative error due to dissoluble materials E_d shall not be larger than 1,0 % in general, and 2,0 % in lower requirement of accuracy.

A.6.3 Data collection for analysing error of filtration method

A.6.3.1 The analysis of component errors due to volume measurement, weighing sediment, and settling loss of the filtration method is the same as that in the drying method.

A.6.3.2 Filter paper often contains dissoluble materials which can cause errors, E_f. In filtration, the dissoluble materials in the filter paper is lost with clean water which makes the paper lighter than its original mass and produces a negative systematic error of sediment mass. The loss of dissoluble materials in the filter paper is related to the filtering duration and type of the filter paper. It can be determined by tests. The test method is to dry and weigh several pieces of filter papers, then put them into clean water for 24 h, dry and weigh them to obtain the mass difference ($\Delta m = m_0 - m_f$) between the paper masses before filtration, m_0, and after filtration, m_f. The ratio of Δm to the sediment mass is the relative error of sediment mass due to dissoluble materials in the filter paper. To eliminate the systematic error, the mass of filter paper can be modified by multiplying a mean correction coefficient, the average value of m_f/m_0.

A.6.3.3 Errors can occur due to sediment leaking through filter paper, E_e. The pore size of filter paper is normally in the range of 0,001 mm to 0,002 mm. During filtration, fine sediment might leak through the paper, making a negative systematic error due to the loss of sediment. The error due to sediment leaking through the filter paper is related to the pore size of the filter paper, dry sediment mass, and content of fine sediment in the total sediment and should be determined by tests. The test method consists in allowing filtered water to sit for a long time. The clean water is then decanted, and the settled sediment dried and weighed. The relative error due to sediment leaking through the filter paper is within − 1,0 % in general, and − 2,0 % in lower requirement of accuracy.

A.6.3.4 Errors can occur due to moisture absorption of the sediment bag, E_a. In weighing the dry filter paper and the sediment bag (filter paper and dry sediment) after filtration, they often absorb air moisture, and the moisture absorbed by the latter is more than that by the former which produces a positive systematic error. The error due to the moisture absorption of the sediment bag mainly depends on the ability of the moisture to be absorbed by the filter paper. The amount of moisture absorbed is mainly related to the duration in air and the relative air moisture and can be determined by tests. The relative error due to the moisture absorption of sediment bag, E_a, shall not be more than 1,0 % in general, and 2,0 % in lower requirement of accuracy.

A.7 Control indexes of errors for measurement of suspended sediment

The control indexes of errors for measurement of suspended sediment are listed in the Table A.2.

Table A.2 — Control indexes of errors

Types	C_{I}	C_{II}	C_{III}	Error due to device	Error due to sample treatment
Random error (%)	8,0	8,0	3,0	8,0	1,5
Systematic error (%)		2,0	1,5		2,0
NOTE The random error is the standard deviation, and the systematic error is the relative average error.					

A.8 Example of error calculation of cross-sectional mean sediment mass concentration in a measurement

A.8.1 The equation for calculation of the total random uncertainty is Equation (17) in this International Standard.

$$e_{\text{r},\overline{\rho_A}} = \sqrt{e_{\text{r},n}^2 + \frac{k}{n}(e_{\text{r,e}}^2 + e_{\text{r,c}}^2 + e_{\text{r,s}}^2 + e_{\text{r,p}}^2)}$$

a) For 7 verticals, the relative standard deviation of C_{III}-type error σ_{III} is 3,0 %, then $e_{\text{r},n}$ = 6,0 %;

b) For sampling duration of 30 s, the relative standard deviation of C_{I}-type error σ_{I} is 8,0 %, then $e_{\text{r,e}}$ = 16,0 %.

c) The relative standard deviation of the error due to sampler σ_{c} is 8,0 %, then $e_{\text{r,c}}$ = 16,0 %;

d) In sample treatment by the dry method, the relative standard deviation σ_{s} is 1,5 %, then $e_{\text{r,s}}$ = 3,0 %;

e) In taking sample by the depth-integration method, the relative standard deviation of C_{II}-type error σ_{II} is 8,0 %, then $e_{\text{r,p}}$ = 16,0 %;

f) $k = 1{,}15$.

The total random uncertainty is

$$e_{\text{r},\overline{\rho_A}} = \sqrt{6^2 + \frac{1{,}15}{7}(16^2 + 16^2 + 3^2 + 16^2)} = 12{,}8\ \%$$

A.8.2 If the signs and values of all component systematic errors are known, the total systematic error is their algebraic sum. If their signs are unknown, it can be calculated by the root-sum-square rule.

Based on the existing measurement data, the following are taken as the component systematic errors if without new data.

$e_{\text{s},n}$ = 1,5 %; $e_{\text{s,c}}$ = 1,5 %; $e_{\text{s,s}}$ = 2,0 %; $e_{\text{s,p}}$ = 2,0 %

The total systematic uncertainty

$$e_{\text{s},\overline{\rho_A}} = \sqrt{1{,}5^2 + 1{,}5^2 + 2{,}0^2 + 2{,}0^2} = 3{,}5\ \%$$

The total uncertainty

$$e_{\overline{\rho_A}} = \sqrt{{e_{\text{r},\overline{\rho_A}}}^2 + {e_{\text{s},\overline{\rho_A}}}^2} = \sqrt{12{,}8^2 + 3{,}5^2} = 13{,}3\ \%$$

Annex B
(informative)

Procedures and examples of methods for combining samples collected in a cross-section

B.1 EWI method

B.1.1 Procedure

Perform the EWI method according to the following procedure.

a) Locate the sampling verticals at the centreline of each segment of equal width.

b) Take samples using the depth-integration method.

c) In taking samples, move the sampler at a uniform transit rate for all verticals.

d) Keep the same nozzle diameter of the sampler for all verticals.

e) Combine samples collected in all verticals into one sample.

f) Ensure the water and sediment of the samples is not lost when combining the samples and measuring their volumes in field.

B.1.2 Example

B.1.2.1 Make the following assumptions:

— the cross-sectional area of the nozzle is to be constant, denoted as A in the measurement;

— k_v is the intake velocity coefficient of the sampler (the ratio of the flow velocity at the sampler intake to the local stream velocity);

— u is the transit rate of the sampler and kept the same for all verticals;

— b is the water surface width of each segment;

— q_{s1}, q_{s2}, ..., q_{sn} are the vertical sediment discharges per unit width, respectively;

— q_1, q_2, ..., q_n are the vertical flow discharges per unit width, respectively;

— ρ_v, v_v are the sediment mass concentration and velocity of any point in a vertical, respectively;

— m_s, V_{tot} are the total sediment mass and volume, respectively;

— $\overline{\rho_v}$, $\overline{\rho_A}$ are the vertical and cross-sectional mean sediment mass concentrations, respectively.

B.1.2.2 For samples taken using the depth-integration method, the sediment mass concentration of the sample is the vertical mean sediment mass concentration after addressing sediment discharge distribution.

$$\overline{\rho_v} = \frac{q_s}{q} = \frac{\int_0^1 \rho v \mathrm{d}\eta}{\int_0^1 v \mathrm{d}\eta} \tag{B.1}$$

where η is the relative depth.

As the sampling volume of the sampler is

$$V_{tot} = \int_0^t A k_v v \mathrm{d}t = A k_v \int_0^t v \mathrm{d}t \tag{B.2}$$

The sediment mass collected by the sampler is

$$m_s = A k_v \int_0^t \rho v \mathrm{d}t \tag{B.3}$$

substituting $\mathrm{d}\eta = \frac{u}{h}\mathrm{d}t$ (h is the depth of vertical) into Equation (B.1), then

$$\overline{\rho_v} = \frac{u\int_0^t \rho v \mathrm{d}t}{u\int_0^t v \mathrm{d}t} = \frac{m_s}{V_{tot}} \tag{B.4}$$

B.1.2.3 The sediment mass concentration measured from the combined sample collected in a cross-section following the technical requirements specified in B.1.1, is the cross-sectional mean sediment mass concentration, after addressing sediment discharge distribution.

$$\overline{\rho_A} = \frac{Q_{A,s}}{Q_A} = \frac{\sum q_s}{\sum q} = \frac{b(q_{s1} + q_{s2} + \cdots + q_{sn})}{b(q_1 + q_2 + \cdots + q_n)} = \frac{buAk_v \sum \int_0^t \rho v \mathrm{d}t}{buAk_v \sum \int_0^t v \mathrm{d}t} = \frac{m_s}{V_{tot}} \tag{B.5}$$

B.2 EAI method

B.2.1 Procedure

Perform the EAI method according to the following procedure.

a) Locate the sampling verticals at area centreline of each segment with equal area.

b) Take samples using the same method for combining samples collected in a vertical for all verticals (see 7.3.2.2).

c) Use the same sampling duration for all verticals.

d) Use the same nozzle diameter of the sampler for all verticals.

e) Combine samples collected in all verticals into one sample.

f) Ensure the water and sediment of the samples is not lost when combining the samples and measuring their volumes in field.

B.2.2 Example

The sediment mass concentration measured from the combined sample collected in a cross-section following the technical requirements specified in B.2.1 is the cross-sectional mean sediment mass concentration in coincidence with the discharge-weighted principle.

$$\overline{\rho_A} = \frac{Q_{A,\mathrm{s}}}{Q_A} = \frac{\sum q_s}{\sum q} = \frac{A_{\mathrm{seg}}\sum \rho v}{A_{\mathrm{seg}}\sum v} = \frac{\frac{V_1}{At}\frac{m_{\mathrm{s1}}}{V_1} + \frac{V_2}{At}\frac{m_{\mathrm{s2}}}{V_2} + \cdots + \frac{V_n}{At}\frac{m_{\mathrm{s}n}}{V_n}}{\frac{V_1}{At} + \frac{V_2}{At} + \cdots + \frac{V_n}{At}} = \frac{m_{\mathrm{s1}} + m_{\mathrm{s2}} + \cdots + m_{\mathrm{s}n}}{V_1 + V_2 + \cdots + V_n} = \frac{m_{\mathrm{s}}}{V_{\mathrm{tot}}} \tag{B.6}$$

where

A_{seg} is the segmental area;

t is the sampling duration in verticals;

$m_{\mathrm{s1}}, m_{\mathrm{s2}},\ldots\ldots, m_{\mathrm{s}n}$ are sediment masses of samples in verticals, respectively;

$V_1, V_2,\ldots\ldots, V_n$ are sample volumes in verticals, respectively.

The other symbols are the same as in B.1.2 and B.2.2.

B.3 EDI method

B.3.1 Procedure

Perform the EDI method according to the following procedure.

a) Locate the sampling verticals at discharge centrelines of each segment with equal discharge.

b) Take samples with equal volume for all verticals.

c) Combine samples collected in all verticals into one sample.

d) Ensure the water and sediment of the samples is not lost when combining the samples and measuring their volumes in field.

B.3.2 Example

B.3.2.1 The sediment mass concentration measured from the combined sample collected in a cross-section following the procedure specified in B.3.1 is the cross-sectional mean sediment mass concentration in agreement with the discharge-weighted principle.

$$\overline{\rho_A} = \frac{Q_{A,\mathrm{s}}}{Q_A} = \frac{q\overline{\rho_{\mathrm{v}1}} + q\overline{\rho_{\mathrm{v}2}} + \cdots + q\overline{\rho_{\mathrm{v}n}}}{nq} = \frac{\overline{\rho_{\mathrm{v}1}} + \overline{\rho_{\mathrm{v}2}} + \cdots + \overline{\rho_{\mathrm{v}n}}}{n}$$

$$= \frac{\frac{m_{\mathrm{s}1}}{V} + \frac{m_{\mathrm{s}2}}{V} + \cdots + \frac{m_{\mathrm{s}n}}{V}}{n} = \frac{m_{\mathrm{s}1} + m_{\mathrm{s}2} + \cdots + m_{\mathrm{s}n}}{nV} = \frac{m_\mathrm{s}}{V_\mathrm{tot}} \tag{B.7}$$

where

q	is the segmental discharge;
$\overline{\rho_{\mathrm{v}1}}, \overline{\rho_{\mathrm{v}1}}, \ldots, \overline{\rho_{\mathrm{v}n}}$	are the vertical mean sediment mass concentration at discharge centrelines of each segment, respectively;
V	is the sampled volume in each vertical;
V_tot	is the total sampled volume.

The other symbols are the same as in B.1.2.

B.3.2.2 If the sampled volumes in all verticals are not equal (the difference between the sampled volumes in verticals can be larger than 10 %), the sample of each vertical is to be treated separately. The average value of vertical sediment mass concentration is taken as the cross-sectional mean sediment mass concentration.

$$\bar{\rho} = \frac{Q_\mathrm{s}}{Q} = \frac{\sum q_\mathrm{s}}{\sum q} = \frac{q(\frac{m_{\mathrm{s}1}}{V_1} + \frac{m_{\mathrm{s}2}}{V_2} + \cdots + \frac{m_{\mathrm{s}n}}{V_n})}{nq}$$
$$= \frac{1}{n}(\rho_{\mathrm{m}1} + \rho_{\mathrm{m}2} + \cdots + \rho_{\mathrm{m}n}) \tag{B.8}$$

B.4 Example of the method for combining samples collected in a cross-section into one sample to measure cross-sectional mean particle size distribution

The basic equation, applicable to the three methods listed in a), b) and c) of this subclause, for calculation of the cross-sectional mean particle size distribution is

$$\overline{w_{d,A}} = \frac{\sum_{i=1}^{n} q_{\mathrm{s}i}\overline{w_{d,i}}}{\sum_{i=1}^{n} q_{\mathrm{s}i}} = \frac{q_{\mathrm{s}1}\overline{w_{d,1}} + q_{\mathrm{s}2}\overline{w_{d,2}} + \cdots + q_{\mathrm{s}n}\overline{w_{d,n}}}{q_{\mathrm{s}1} + q_{\mathrm{s}2} + \cdots + q_{\mathrm{s}n}} \tag{B.9}$$

where

$\overline{w_{d,A}}$	is the cross-sectional mean mass fraction of sediment finer than a given diameter in the total sediment mass of sample (%);
$\overline{w_{d,i}}$	is the mean mass fraction of sediment finer than a given diameter in the total sediment mass of sample for segment i;
$q_{\mathrm{s}i}$	is the sediment discharge of segment i.

The sample obtained by the method for combining samples in a cross-section is used for the particle size analysis. During such analysis, the particle size distribution is actually obtained by weighing sediment mass in each vertical and can be expressed as

$$\overline{w_{d,A}} = \frac{m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}}}{m_{s1} + m_{s2} + \cdots + m_{sn}} \tag{B.10}$$

Equation (B.10), which can be derived from Equation (B.9), is applicable to the method of combining samples collected in a cross-section. In particle size analysis using the combined sample, if it meets Equation (B.10), it also meets the basic principle of Equation (B.9). This can be proven as follows, respectively.

a) In taking samples by the EWI method, from Equation (B.9) it can be shown:

$$\overline{w_{d,A}} = \frac{\sum_{i=1}^{n} q_{si}\overline{w_{d,i}}}{\sum_{i=1}^{n} q_{si}} = \frac{\sum_{i=1}^{n} q_i \overline{\rho_i}\,\overline{w_{d,i}}}{\sum_{i=1}^{n} q_i \overline{\rho_i}}$$

$$= \frac{b\left(d_1\overline{v_1}\frac{m_{s1}}{V_1}\overline{w_{d,1}} + d_2\overline{v_2}\frac{m_{s2}}{V_2}\overline{w_{d,2}} + \cdots + d_n\overline{v_n}\frac{m_{sn}}{V_n}\overline{w_{d,n}}\right)}{b\left(d_1\overline{v_1}\frac{m_{s1}}{V_1} + d_2\overline{v_2}\frac{m_{s2}}{V_2} + \cdots + d_n\overline{v_n}\frac{m_{sn}}{V_n}\right)}$$

$$= \frac{d_1\overline{v_1}\frac{m_{s1}}{At_1\overline{v_1}}\overline{w_{d,1}} + d_2\overline{v_2}\frac{m_{s2}}{At_2\overline{v_2}}\overline{w_{d,2}} + \cdots + d_n\overline{v_n}\frac{m_{sn}}{At_n\overline{v_n}}\overline{w_{d,n}}}{d_1\overline{v_1}\frac{m_{s1}}{At_1\overline{v_1}} + d_2\overline{v_2}\frac{m_{s2}}{At_2\overline{v_2}} + \cdots + d_n\overline{v_n}\frac{m_{sn}}{At_n\overline{v_n}}}$$

$$= \frac{\frac{d_i}{At_i}\left(m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}}\right)}{\frac{d_i}{At_i}\left(m_{s1} + m_{s2} + \cdots + m_{sn}\right)} = \frac{m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}}}{m_{s1} + m_{s2} + \cdots + m_{sn}}$$

Assuming the cross-sectional area of the nozzle A and the transit rate of the sampler d_i/t_i to be constant, and $V_i = At\overline{v_i}$, Equation (B.10) can be derived for the particle size distribution of the combined sample. It indicates that the use of the EWI method for particle size analysis is in good agreement with the basic principle.

b) In taking samples using the EAI method and using Equation (B.9) it can be shown:

$$\overline{w_{d,A}} = \frac{A_{seg}\left(\overline{v_1}\frac{m_{s1}}{V_1}\overline{w_{d,1}} + \overline{v_2}\frac{m_{s2}}{V_2}\overline{w_{d,2}} + \cdots + \overline{v_n}\frac{m_{sn}}{V_n}\overline{w_{d,n}}\right)}{A_{seg}\left(\overline{v_1}\frac{m_{s1}}{V_1} + \overline{v_2}\frac{m_{s2}}{V_2} + \cdots + \overline{v_n}\frac{m_{sn}}{V_n}\right)}$$

$$= \frac{\overline{v_1}\frac{m_{s1}}{Atv_{m1}}\overline{w_{d,1}} + \overline{v_2}\frac{m_{s2}}{At\overline{v_2}}\overline{w_{d,2}} + \cdots + \overline{v_n}\frac{m_{sn}}{At\overline{v_n}}\overline{w_{d,n}}}{\overline{v_1}\frac{m_{s1}}{Atv_{m1}} + \overline{v_2}\frac{m_{s2}}{At\overline{v_2}} + \cdots + \overline{v_n}\frac{m_{sn}}{At\overline{v_n}}}$$

$$= \frac{\frac{1}{At}(m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots m_{sn}\overline{w_{d,n}})}{\frac{1}{At}(m_{s1} + m_{s2} + \cdots + m_{sn})} = \frac{m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}}}{m_{s1} + m_{s2} + \cdots + m_{sn}}$$

c) Similarly, from the basic principle Equation (B.10) is derived. It indicates that the EAI method for particle size analysis is in good agreement with the basic principle.

In taking sample using the EDI method and using Equation (B.9) it can be shown:

$$\overline{w_{d,A}} = \frac{q(\overline{\rho_1} \times \overline{w_{d,1}} + \overline{\rho_2} \times \overline{w_{d,2}} + \cdots + \overline{\rho_n} \times \overline{w_{d,n}})}{q(\overline{\rho_1} + \overline{\rho_2} + \cdots + \overline{\rho_n})}$$

$$= \frac{\frac{1}{V_{tot}}(m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}})}{\frac{1}{V_{tot}}(m_{s1} + m_{s2} + \cdots + m_{sn})}$$

$$= \frac{m_{s1}\overline{w_{d,1}} + m_{s2}\overline{w_{d,2}} + \cdots + m_{sn}\overline{w_{d,n}}}{m_{s1} + m_{s2} + \cdots + m_{sn}}$$

Similarly, from the basic principle Equation (B.10) is derived. It indicates that the EDI method for particle size analysis is in good agreement with the basic principle.

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