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***भारतीय मानक***

***Indian Standard*** *Superseding IS 2501 : 2009 IS 2502 : 2009 & IS 2503 : 2009)*

***खुले चैंनलों में निलंबित तलछट की***

***माप के लिए पद्धति***

*(* पहला पुनरीक्षण *)*

**Methods for Measurement of Suspended**

**Sediments in Open Channels**

*( First Revision )*

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भारतीय मानक ब्यूरो

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Hydrometry Sectional Committee, WRD 01

NATIONAL FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydrometry Sectional Committee had been approved by the Water Resources Division Council.

Sediment is generally defined as solid particles that are, or could have been, transported by flow in a channel. The presence of sediment poses significant challenges for engineers, agriculturists, and foresters along the channel. It elevates the streambed, leading to increased flood levels and inundation. Sediment accumulation behind dams reduces their storage capacity and functionality. Furthermore, it alters river courses, causing rivers to meander or shift, which can lead to the devastation of large tracts of land. Siltation of irrigation and navigation channels also decreases their efficiency. Foresters are faced with the issue of soil erosion and must implement effective soil conservation measures.

When considering a river system in its entirety, the sediment issue originates from the very source of sediment supply in the uppermost drainage area and extends to the river’s outlet into the sea. However, in certain cases—such as when the sea is shallow and the currents are insufficient to transport the sediment discharged by the river—the sediment problem persists even after reaching the sea.

Thus, for a comprehensive understanding of specific issues, it is essential to have thorough knowledge of sediment movements and methods for estimating sediment load.

In the formulation of this standard, due consideration has been given to international coordination with standards and practices prevailing in different countries, while also aligning it with the practices in this field within India.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

**IS 4890 : 2024**

*India Standard*

Methods for Measurement of Suspended Sediments in Open Channels

*( First Revision )*

## 1 SCOPE

This 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 REFERENCES

The standards listed below contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

|  |  |
| --- | --- |
| *IS No./ISO* | *Title* |
| ISO 31 (all parts), | *Quantities and units* |
| IS 1192 : 2024  ISO 748 : 2021 | *Measurement of liquid flow in open channels — Velocity-area methods using point Velocity Measurements (Third Revision)* |
| 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

**3.2.1** *Bed load* — The sediment in almost continuous contact with the bed while carried by rolling, sliding or hopping along the bed of the stream. Bed load is also divided into contact load and saltation load.

**3.2.1.1** *Contact load* — The sediment that is rolling or sliding along the bed of the stream in substantially continuous contact with the bed.

**3.2.1.2** *Saltation load* —the sediment bouncing and hopping along the bed of the stream or moved directly or indirectly by the impact of the bouncing particles.

**3.2.2** *Bed material load* —The coarser part of the sediment load which consists of particle sizes represented in the bed (that is bed material) and which is limited in its rate of movement by the transporting capacity of the channel, is called the bed material load.

**3.2.3** *Suspended load* —That part of the sediment load of a stream which remains in suspension in the flowing water for considerable periods of time without contact with the stream bed, being kept up by the upward component of the turbulence or by colloidal suspension.

**3.2.4** *Wash load* —That part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of the stream bed. It is in near permanent suspension and is transported through a reach of stream without deposition. The discharge of the wash load through a reach depends only on the rate with which these particles become available in the catchment.

**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 (*QA*,s) to the cross-sectional flow discharge ().

**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.

1. **Mass concentration of the water-sediment mixture** , generally expressed in milligrams per litre /ppm, grams per litre (g/l) or kilograms per cubic metre (kg/m3)/ parts per million, is dry sediment per unit volume of the water- sediment mixture. This is the expression used in this International Standard; and
2. **Volume fraction** , expressed as a percentage is the ratio of the volume of sediment to the volume of the water-
3. sediment mixture and is given by Equation:

(1)

where

is the volume of sediment

is the volume of the)

(c) **Mass fraction**, 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):

(2)

where is defined in a) and;

and are the mass concentrations of water and sediment, respectively, expressed in mg/l, or kg/m3.

If no measured data are available, may be adopted between 1400 kg/m3 to 2650 kg/m3 based on the river basin and location.

## 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 shall be measured at a number of points in the cross- section, with each point representing a small area of . From the

(3)

Cross-sectional flow discharge and sediment discharge can be calculated. From the definition given in 3.4, the cross-sectional mean sediment mass concentration is given by:

(4)

where

= are the width and depth of the small area represented by the point, respectively; and

= are the surface width and vertical depth of flow, respectively; and

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 can be expressed by Equation:

(5)

where

average percentage of the mass of sediment finer than the given diameter in the total sediment mass of sample for segment *i*;

sediment discharge of segment

= diameter;

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.

#### 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.

* + 1. *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 totaled 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 determined by the sediment discharge method can be

expressed by Equation:

(6)

where

and are the sediment discharge and flow discharge passing through segment , respectively;

and are the mean sediment mass concentration and mean velocity of segment , respectively;

and are the mean flow depth and surface width of segment

is the number of segments.

Two methods, namely the mid-section method and mean-section method, are used to calculate the segment sediment discharge and segmental flow discharge (*see* ISO 748). In using the mid-section method, and are the vertical mean values, is the vertical depth. In using the mean-section method and are the average values of two neighboring 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.

1. Method for selecting verticals at turning points of sediment discharge per unit width; and

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.

1. Method for selecting verticals at centre lines 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 analyzing 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.

Note — When the investigation is not important enough to merit preliminary experiments, Table 2 may be used as a guide for locating the number of verticals and their approximate location across the section. It is not always correct unless a considerable amount of preliminary work has been done at a given sampling cross-section which justifies it to assume a relationship between distribution of concentration in motion and velocity.

**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.

1. 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.

1. Selected-point method:

It includes the two-point method (and from water surface, where is total vertical depth of the water), the three-point method (, , and from water surface), the five-point method [near water surface, , and from water surface, and near bottom (to )]. The one-point method (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.

1. 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 3.

**Table 3 — Sampling Points and Duration for the Method of Combining Samples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl No.** | **Method** | **Relative depth of points (from water surface)** a | **Sampling durations**b |
| (1) | **(2)** | **(3)** | **(4)** |
| i) | Two-point |  | 0,5*t*; 0,5*t* |
| ii) | Three-point |  |  |
| iii) | Five-point | Near surface, 0,8*h* near riverbed |  |

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).

1. h is total vertical depth of the water; and
2. t is the total sampling duration in a vertical; and

**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 centre lines 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 centre lines. 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 vertical**

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 to

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 percent 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:

1. river (name);
2. river width and maximum depth;
3. site (name of hydrological station);
4. operator’s name;
5. date;
6. weather conditions;
7. wind direction and speed;
8. air temperature;
9. water temperature;
10. time of sampling, i.e. form …to…;
11. gauge reading and discharge (at the beginning of measurement);
12. gauge reading and discharge (at the end of measurement);
13. water surface slope; and
14. 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 30o 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:

where

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

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

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, , can be calculated by one of the following equations.

For the two-point method:

(7)

For the three-point method:

(8)

For the five-point method:

(9)

where

,...

are the velocities, expressed in metres per second (m/s), at the points , , ...from the water surface, respectively;

are the sediment mass concentration (mg/l, g/l or kg/m3) at the points of 0,0*h*, 0,2*h*, ...1,0*h* from the water surface, respectively.

+ ] is the mean velocity in a vertical.

NOTE — 1,0 is the sediment mass concentration at the level closest to the river bed.

**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 *QA*,s is:

(10)

where and *qi* 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, is the mean sediment mass concentration of vertical *i*.

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

**8.1.3.1** The cross-sectional mean sediment mass concentration,

Equation:

(11)

where

is the cross-sectional flow discharge;

is the cross-sectional sediment discharge.

#### 8.2 Calculation of particle size distribution

**8.2.1** *Vertical mean particle size distribution*

can be calculated in accordance with

**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, 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:

(12)

For the three-point method:

(13)

For the five-point method:

(14)

where..., are the percentages (%) of the masses of sediment finer than the given diameter at the points of 0,0*h*, 0,2*h*, ..., 1,0*h* 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.

1. 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.
2. 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).

#### Estimation of component errors

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

1. 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 and systematic error ;
2. 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 and systematic error ;
3. 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 ;
4. 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 and systematic error ; and

**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 and systematic error.

#### 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, can be calculated by the following equation:

(+++]

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

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

where

is the random uncertainty due to limited verticals and calculation principles;

is the random uncertainty due to fluctuation;

is the random uncertainty due to sampler;

is the random uncertainty due to sample treatment;

is the random uncertainty due to limited measurement points and calculation principles;

is the number of segments in a cross-section;

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 ( *ρ 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 the relative average error (i.e. systematic error), and the relative standard deviation of sediment mass concentration comparing with the standard values are calculated by the following equations:

The relative error is calculated as follow

### Where and are the sediment mass concentrations of the *i*th measurement by the sampler to be checked and the standard sampler, respectively.

(A.1)

### The relative average error is calculated as follows:

### The relative standard deviation is calculated as follows:

(A.2)

(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:

### where

(A.4)

is the relative standard deviation of *C*I-type error;

is the sediment mass concentration of sample *i*;

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

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:

is the *C*I-type vertical relative standard deviation;

is the number of points in a vertical;

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:

1. the depth-integration method,
2. the selected-point method, and
3. 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, , , , 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 and 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.

where

is the approximate true value of vertical mean sediment mass concentration;

, is the approximate true value of vertical mean sediment mass concentration;

are the velocity and sediment mass concentration at the river surface, respectively; are the velocity and sediment mass concentration at the riverbed, respectively;

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, relative average error and relative standard deviation can be calculated by the following equations, respectively.

(A.7)

(A.8)

### (A.9)

### where

is the *C*II-type error in vertical *i* in taking samples by the *n*-point method;

is the vertical mean sediment mass concentration in vertical *i* in taking samples by the *n*-point method;

is the approximate true value of the vertical mean sediment mass concentration in vertical

is the average value of *C*II-type error (i.e. systematic error) in taking samples by the *n*-point method;

is the number of the verticals;

*σ*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.

(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 , relative average error, and relative standard deviation can be calculated by the following equations, respectively.

(A.11)

(A.12)

(A.13)

### where

is the *C*III-type error of the cross-sectional mean sediment mass concentration by selecting *n*

verticals in the *i*th set of measurements;

is the mean value of *C*III-type error (i.e. systematic error) of the cross-sectional mean sediment mass concentration of *n* verticals;

is the number of the sets of measurements;

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, is related to the minimum graduation of the cylinder. This random error, is  0,5 percent.

**A.6.2.2** The relative error due to weighing sediment, , is related to accuracy of the scale and amount of the sediment. Generally, the random error due to weighing sediment, is  1 percent.

**A.6.2.3** The error due to settling loss, , 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 percent.

**A.6.2.4** In river water, errors occurs due to dissoluble materials in river water, (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, shall not be larger than 1,0 percent in general, and 2,0 percent 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 papers often contains dissoluble materials which can cause errors, 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 24h, dry and weigh them to obtain the mass difference () between the paper masses before filtration and after filtration The ratio of 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

**A.6.3.3** Errors can occur due to sediment leaking through filter paper,. 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 percent in general, and -2.0 percent in lower requirement of accuracy.

**A.6.3.4** Errors can occur due to moisture absorption fo the sediment bag,. In weighing the dry filter paper and their 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 test. The relative error due to the moisture absorption of sediment bag. shall not be more than 1.0 percent in general, and 2.0 percent 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.

1. For 7 verticals, the relative standard deviation of *C*III-type error *σ*III is 3,0 percent, then = 6,0 %;
2. For sampling duration of 30 s, the relative standard deviation of *C*I-type error is 8,0 percent, then

= 16,0 percent.

1. The relative standard deviation of the error due to sampler *σ*c is 8,0 percent, then = 16,0 percent;
2. In sample treatment by the dry method, the relative standard deviation *σ*s is 1,5 percent, then = 3,0 percent;
3. In taking sample by the depth-integration method, the relative standard deviation of *C*II-type error is 8,0 percent, then = 16,0 percent;

f)

### The total random uncertainty is

### **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.

### 2,0%

### The total systematic uncertainty

### The total uncertainty

# 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.

1. Locate the sampling verticals at the centreline of each segment of equal width;
2. Take samples using the depth-integration method;
3. In taking samples, move the sampler at a uniform transit rate for all verticals;
4. Keep the same nozzle diameter of the sampler for all verticals;
5. Combine samples collected in all verticals into one sample; and
6. 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;

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

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

* is the water surface width of each segment;

### are the vertical sediment discharges per unit width, respectively;

* , , ..., are the vertical flow discharges per unit width, respectively;

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

* , are the total sediment mass and volume, respectively;

### 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.

(B.1)

### where *η* is the relative depth.

As the sampling volume of the sampler is

### (B.2)

### The sediment mass collected by the sampler is

(B.3)

Substituting (*h* is the depth of vertical) into Equation (B.1), then

(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.

(B.5)

## B.2 EAI method

**B2.1 Procedure**

Perform the EAI method according to the following procedure.

1. Locate the sampling verticals at area centreline of each segment with equal area.
2. Take samples using the same method for combining samples collected in a vertical for all verticals (*see* 7.3.2.2).
3. Use the same sampling duration for all verticals.
4. Use the same nozzle diameter of the sampler for all verticals.
5. Combine samples collected in all verticals into one sample.
6. 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.

(B.6)

where

is the segmental area;

is the sampling duration in verticals;

, ,*......*, *m*s*n* are sediment masses of samples in verticals, respectively;

,*......*, 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

1. Locate the sampling verticals at discharge centrelines of each segment with equal discharge;
2. Take samples with equal volume for all verticals;
3. Combine samples collected in all verticals into one sample; and
4. 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.

(B.7)

where

is the segmental discharge;

are the vertical mean sediment mass concentration at discharge centrelines of each segment, respectively;

is the sampled volume in each vertical;

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 percent), 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.

(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

### (B.9)

where

is the cross-sectional mean mass fraction of sediment finer than a given diameter in the total sediment mass of sample percent;

is the mean mass fraction of sediment finer than a given diameter in the total sediment mass of sample for segment;

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

(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.

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

==

Assuming the cross-sectional area of the nozzle A and the transit rate of the sampler to be constant, and , Equation (B, 10) can be derviced 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.

1. In taking samples using the EAI method and using Equation (B.9) it can be shown
2. Similarly, from the basic principle Equation (B,10) is derived. It includes 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:

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.

**Table 1 Method of Selecting Sampling Points in A Vertical**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sl No | METHOD AND DESCRIPTION | | DISCUSSION | | RELIABILITY AND ACCURACY FOR DETERMINING | | | | PRACTICAL CONSIDERATION | NUMBER OF SAMPLES AND ANALYSIS PER VERTICAL | |
|  |  | |  | | Concentration Only\* | | Concentration and Particle Size | |  |  | |
| (1) | (2) | | (3) | | (4) | | (5) | | (6) | (7) | |
| i) | Single-point A single sample secured at the surface | | Arbitrary method unless coefficients have been determined from previous, more complete sampling,  and then it is somewhat empirical | | Not reliable or necessarily accurate even when a coefficient has been determined | | Not at all reliable or accurate | | Simplest of all present methods, rapid and easy to use. Readily adapted for use by unskilled observers.  Requires previous, more exact sampling for justification | One sample and one laboratory analysis | |
| ii) | *Single-point*  A single sample secured at any point in the vertical other than the surface | | Arbitrary method unless coefficients have been determined from previous, more complete sampling, and then it is somewhat empirical. A common arbitrary point has been 0.6 depth | | Generally not reliable or accurate even when a coefficient has been determined, but more so than a single surface sample.  Thoroughness of preliminary investigations will determine,  somewhat, the reliability and accuracy | | Not reliable or accurate | | Simple, rapid, and easy to use, but fractional depth measurements make it less adaptable to use by unskilled observers than single surface method. Requires previous, more exact sampling for justification | One sample and one laboratory analysis | |
| iii) | *Two-point*  Two points selected arbitrarily for convenience and adaptability to the skill  of the Observor | | Arbitrary method with no rational justification | | Generally not reliable or accurate for all conditions of a given stream | | Generally not reliable or accurate | | Fairly simple, rapid, and easy to use. May be used by dependable observers even though inexperienced | Two samples may be combined if of equal volume for a single analysis | |
| iv) | *Three-point*  Arbitrary selection of points at surface, mid depth and bottom with equal weights | | Points located arbitrarily | | Not necessarily reliable or accurate for all stream conditions | | Not necessarily reliable or accurate | | Sampling at surface, mid- depth, and bottom is the most simple and easiest to use of all methods requiring more than two samples may be used by dependable observers even  though inexperienced | Three samples may be combined if of equal volume for a single analysis | |
| v) | *Three-point*  Arbitrary selection of points at surface, mid-depth, and bottom with weights of 1, 2, and 1 applied, respectively | | Basis of method is the assumption that the averages of surface and mid-depth sample represent upper-half of discharge and average of mid-depth and  bottom represents lower-half | | Not necessarily reliable or accurate for all stream condition | | Not necessarily reliable or accurate, but more so than three points, surface mid-depth, and bottom with equal weights | | Sampling at surface, mid- depth, and bottom is the simplest and the easiest to use of all methods requiring more than two samples. May be  used by dependable observers even though inexperienced | Three samples. If of equal volume, surface and bottom samples may be combined for single analysis | |
| vi) | *Precise*  A relatively large number of point samples at known locations in each vertical, simultaneous with velocity measurements | | Rational method for use primarily in special investigations. Number of sampling points depends upon depth of stream, the velocity and sediment  distribution, and the degree of accuracy desired. | | Reliable and accurate. Accuracy depends upon the curvature of the velocity and sediment distribution curves and number of samples. The most accurate method in use at present | | Reliable and accurate. Accuracy depends upon curvature of particle distribution. curves, and number of samples. The most  accurate method in use at present | | Not adapted to routine sampling because of the excessive work required. Its use is limited to research or preliminary investigations. Laboratory work excessive as  all samples must be analysed separately | Minimum of four or five samples all to be analysed separately | |
| *\*For methods where coefficients are used, comments apply only to individual observations or short period investigations, as over long periods, totals may have a fair degree of accuracy.* | | | | | | | | | | | |
| Contd.. | | | | | | | | | | | |
|  | | | | | | | | | | | |
| **TABLE 1 METHOD OF SELECTING SAMPLING POINTS IN A VERTICAL……contd**…. | | | | | | | | | | |  |
| SL NO | | METHOD AND DESCRIPTION | | DISCUSSION | | RELIABILITY AND ACCURACY FOR | | | PRACTICAL | NUMBER OF SAMPLES AND ANALYSIS PER  VERTICAL |
|  | |  | |  | | DETERMINING | | | CONSIDERATION |  | |
|  | |  | |  | | Concentration Only\* | | Concentration and Particle Size |  |  | |
| (1) | | (2) | | (3) | | (4) | | (5) | (6) | (7) | |
| vii) | | *Straub*  Sampling at 0.2 and 0.8 depth, applying coefficient obtained by mathematical derivation for both linear and curvilinear sediment distribution for linear distribution values weighted 5/8 and 3/8 for 0.2 and 0.8 depth,  respectively | | Rational method, best adapted for use where the vertical sediment distribution curve approximates a straight line and the velocity distribution is fairly  constant | | Accuracy and reliability depends almost entirely upon the agreement of the actual to the assumed sediment and velocity. In most cases quite reliable | | Theoretically not sound if sediment distribution is curvilinear, but, practically, one of the most reliable methods | Field work relatively simple for skilled observer but adaptable also to dependable observers, even though inexperienced | Two samples and two analyses | |
| Viii) | | *Luby*  Sampling points selected at the middle of increments of depth representing equal portions of stream discharge | | Rational method if a sufficient number of samples are collected. The samples if of equal volume, may be combined and the composite is representative of the mean concentration and composition in the vertical. Number of points with respect to depth depends primarily upon curvature of sediment distribution curve; to a lesser extent, generally, upon  curvature of vertical velocity curve | | Reliable and accurate if a sufficient number of samples are collected. One of the most reliable and accurate, of the present methods except the precise | | Fairly reliable and accurate if a sufficient number of samples are collected. One of the most reliable and accurate of the present methods except the precise. Enough samples should be taken so that one will be close to the stream bed | Requires either an assumed velocity distribution or previous velocity measurements. Too complicated for use except by trained hydrographers. Because of sampling more points a better representation of the actual sediment distribution will probably be obtained than with the Straub method | Minimum of five samples. May be combined if of equal volume for a single analysis | |
| ix) | | *Depth-integration*  Single sample collected from all points in the vertical usually obtained by lowering and raising a slow filling sampler at constant rate. These usually consist of ordinary milk bottle types or specially designed slow-filling samplers | | Rational method only it sample is collected proportional to velocity | | Relatively reliable under usual conditions but its accuracy varies as most of the present equipment does not sample proportional to the velocity and many samplers do not approach close enough to the bottom. As used, accuracy depends upon depth of stream and  type of sampler | | Relatively reliable under usual conditions but its accuracy varies as most of the present equipment does not sample proportional to the velocity and many samplers do not approach close enough to the bottom. As used, accuracy depends upon depth of stream and  type of sampler | As commonly used with simple slow-filling samplers this method is simple, rapid, easy to use, and well adapted to dependable observers, even though inexperienced. No previous measurements necessary | One sample and one analysis | |
| *\*For methods where coefficients are used, comments apply only to individual observations or short period investigations, as over long periods, totals may have a fair degree of accuracy.* | | | | | | | | | | | |
|  | | | | | | | | | | | |

**Table 2 Selection of Verticals**

(*Clause* 7.3.2.3, Note 1)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sl No.** | **WIDTH OF THE RIVER** | **NUMBER OF VERTICALS** | **LOCATION OF VERTICALS IN NORMAL SECTION WITH**  **SLOPING SIDES** | **LOCATION OF VERTICALS IN STREAMS OF UNIFORM DEPTH**  **AND VELOCITY** |
| (1) | (2) | (3) | (4) | (5) |
| i) | Less than  30 m | 3 | 25, 50 and 75 percent of the  width | 17, 50 and 83 percent of the  width |
| ii) | 30 – 300 m | 5 | 20, 35, 50, 65 and 80 percent of the width | 10, 30, 50, 70 and 90 percent of  the width |
| iii) | Over 300 m | 7 | 15, 30, 40, 50, 60, 70 and 85  percent of the width | 7, 21, 36, 50, 64, 79 and 93  percent of the width |
| *NOTE — These are suggested for tentative adoption in natural and artificial channels until by experimentation more suitable location and spacing of verticals are determined.* | | | | |