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

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

Reference number
ISO 4363:1993(E)

Foreword

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

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

International Standard ISO 4363 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, Sub-Committee SC 6, *Sediment transport*.

This second edition cancels and replaces the first edition (ISO 4363:1977), of which it constitutes a technical revision.

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Introduction

Sediment has been defined generally as solid particles which are moved, or might be moved, by flow in a channel. It creates numerous problems for the engineer, the agriculturist and the forester along the length of the channel. It raises the stream bed, which increases the highwater level and the risk of flood; it piles up in large quantities behind dams, thereby reducing their capacities and hindering their functions; it causes rivers to meander and often to leave their original courses and flow along a new course, devastating vast areas of land; it silts up irrigation and navigation channels, making them less efficient. The forester is confronted with soil erosion and has to devise measures for effective soil conservation.

Erosion is caused by water, wind, ice and human activities such as cultivation, 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 the sediment transport.

Therefore, for thorough understanding of a particular problem, comprehensive knowledge of sediment movement and the methods of determination of sediment load is absolutely essential.

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

1 Scope

This International Standard specifies methods for detailed measurement of sediment concentration and also methods for routine sampling. Because sediment load is highly variable with stage and is also highly variable at the same stage in different floods, and because the bulk of sediment is carried in flood periods, accurate computation of total sediment flow in a period entails routine sampling at normal flows combined with frequent routine sampling on rise, peak and fall in floods.

Details regarding the instruments used in the determination of suspended sediment load are covered in ISO 3716.

2 Normative references

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

ISO 748:—[1)], *Measurement of liquid flow in open channels — Velocity-area methods.*

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

ISO 3716:1977, *Liquid flow measurement in open channels — Functional requirements and characteristics of suspended sediment load samplers.*

3 Definitions

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

3.1 sediment transport: Movement of solids transported in any way by a flowing liquid. From the aspect of transport, the sum of the suspended load transported and bed load transported. From the aspect of origin, the sum of the bed material load and the wash load.

3.2 total load: From the aspect of transport of sediment, the total load comprises bed load and suspended load, the latter including wash load. From the aspect of origin of the sediment, the total load comprises the bed material load (including the suspended portion) and the wash load (see figure 1).

3.3 bed material: Material, the particles of which are found in appreciable quantities in that part of the bed affected by transport.

3.4 bed material load: Part of the total sediment transport which consists of the bed material and whose rate of movement is governed by the transporting capacity of the channel.

3.5 suspended load: That part of the total sediment transported which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water. It is generally expressed in mass or volume per unit of time.

3.6 bed load: Sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

3.7 wash load: That part of the suspended load which is composed of particle sizes smaller than

1) To be published. (Revision of ISO 748:1979)

those found in appreciable quantities in the bed material.

It is in near permanent suspension and, therefore, is transported through the 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 and not on the transport capacity of flow. It is generally expressed in mass or volume per unit of time.

3.8 sediment concentration: Ratio of the mass or volume of dry sediment in a water—sediment mixture to the total mass or volume of the suspension.

4 Units of measurement

The units of measurement used in this International Standard are SI units. The concentration of suspended sediment is preferably expressed in parts per million (by mass or volume). For convenience, it is sometimes expressed in grams or milligrams per litre.

5 General

To help understand sediment transport and related terms, the flow of water over an artificially flattened bed of sediment may be considered. No movement of bed material is observed at very low velocities; with increasing velocity some particles begin to move by sliding, rolling or hopping along the bed (bed load); at still higher velocities particles of the bed are thrown into suspension by turbulence (suspended load). The suspended load also includes finer particles in near permanent suspension brought in from the catchment (wash load).

Bed load and suspended load may occur simultaneously, but the borderline between them is not well defined. From the aspect of sediment transport, the total load comprises bed load and suspended load, the latter including wash load. From the aspect of sediment origin, the total load comprises the bed material load (including the suspended portion) and the wash load.

6 Measurement of suspended sediment load

6.1 Principles of measurement

There are two methods of measuring suspended sediment load, namely:

a) the indirect method, in which the time-averaged concentration of the sediment and the time-averaged current velocity at a point are measured almost simultaneously, with the aid of separate devices, and multiplied to obtain the sediment load, or in which the discharge-weighted average concentration of the sediment in the cross-section of the stream, collected by depth integration, is multiplied by the discharge of the stream to obtain the sediment discharge;

b) the direct method, in which, with the aid of a single device, the time-averaged suspended sediment load at a point is measured directly.

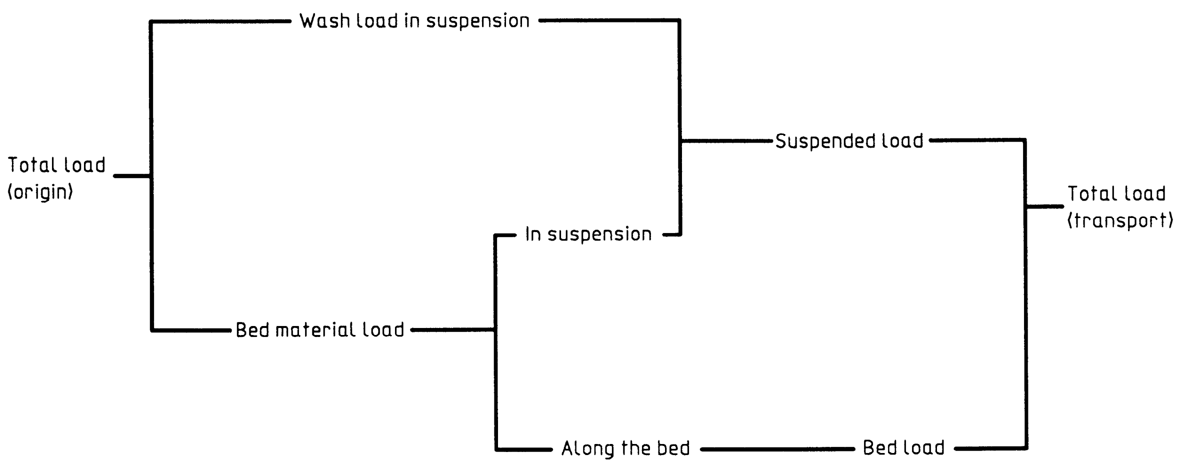

Figure 1 — Diagram of definitions

6.1.1 Indirect method of measurement

The time-averaged concentration of suspended sediment ($\bar{c}_i$) and the time-averaged current velocity ($\bar{v}_i$) are measured almost simultaneously at a large number of points (m) in the sampling area of a cross-section. Each concentration and velocity is representative over a small area (Δa_i) of a sampling cross-section. The sum of all the areas Δa_i is the sampling area (A).

The suspended sediment load (Q_s) is determined using the formula

$$Q_s = \sum_{i=0}^{m} \bar{c}_i \bar{v}_i \, \Delta a_i \qquad \ldots (1)$$

The right-hand side of the above equation shall be multiplied by C when Q_s is expressed as mass per unit of time, where C is a coefficient having the dimension of mass of sediment per unit volume of flow.

The discharge-weighted concentration of suspended sediment is collected with a depth-integrating sampler at verticals in the cross-section of the stream (see 6.4.3.2). The average concentration determined from these samples is multiplied by the stream discharge to determine the suspended-sediment discharge.

NOTE 1 Since a suspended-sediment sampler cannot take samples near the channel bed where concentration is quite high, the suspended sediment load is determined for, and applicable only to, the "sampled zone" of the channel.

6.1.2 Direct method measurement

The water—sediment mixture flows through a sampler in such a way that the mixture enters the nozzle of the sampler with almost the same velocity as that of the undisturbed flow. Because of the decrease in velocity, the sediment material settles in the settling chambers of the instrument.

At the measuring point, the time-averaged suspended sediment load per unit area $\bar{q}_{si}$ is determined directly from the relation:

$$\bar{q}_{si} = \frac{1}{t} \int_0^t v q_{si} \, dt \qquad \ldots (2)$$

where

v is a dimensionless coefficient, which may vary with grain size, current velocity and the type of nozzle (see note 5 under 6.5.3.1);

t is the measuring time.

The value ($\bar{q}_{si}$) is representative of an area (Δa_i). Therefore, the suspended load transport through the sampling area (A) can be determined by using the formula:

$$Q_s = \sum_{i=0}^{m} \bar{q}_{si} \, \Delta a_i \qquad \ldots (3)$$

NOTE 2 Since a suspended-sediment sampler cannot take samples near the channel bed where concentration is quite high, the suspended sediment load is determined for, and applicable only to, the "sampled zone" of the channel.

6.2 Site selection

Since the requirements for the selection of a site for measurement of suspended load are usually similar to those for discharge measurement, the site should normally be selected in accordance with ISO 748.

6.3 Requirements for measuring concentration of suspended sediment

The concentration of suspended sediment not only changes from point to point in a cross-section, but also fluctuates from moment to moment at a fixed point. The kind of sampler and the technique of sampling used will depend on a large number of factors. The average suspended-sediment concentration at a vertical in a cross-section can be determined either by averaging over the depth, at each of a number of points on the vertical, or by using a depth-integrating sampler which automatically takes a sample in which the concentration of suspended sediment is the average concentration on the vertical (see 6.4.3).

The suspended-sediment concentration in a flowing stream, as well as the sediment particle size, generally increases from top to bottom and also varies across the section. The variation depends upon the size and shape of the cross-section, the stage of flow and other channel characteristics. Hence, a preliminary investigation shall be made to select the sampling points on a vertical and also the number and location of the sampling verticals, taking into consideration the accuracy desired and the resources available.

A comparative summary of the sampling methods and their reliability is given in table 1, and the methods are described in 6.4.3.

For the determination of both the magnitude and the location of the point of mean concentration of sediment, sediment concentration shall be determined at several points on a vertical.

6.4 Procedure for the computation of sediment load from measurements obtained by the indirect method

6.4.1 General

The procedure for indirectly computing sediment discharge from samples collected by depth integration is given in 6.1.1.

The procedure for obtaining the mean sediment discharge per unit width is as follows.

6.4.1.1 Draw the velocity distribution and sediment concentration curves as in figure 2 a) and 2 b). The curves shall be extended to the sampled zone.

6.4.1.2 Determine the product of mean concentration ($\bar{c}_i$) and mean velocity ($\bar{v}_i$) at corresponding points and plot the curve of the rate of sediment discharge as in figure 2 c).

6.4.1.3 The suspended sediment load per unit width can be obtained numerically by a rule such as the trapezoïdal rule, or after having drawn a curve as in figure 2 c) by measuring the area under the curve with a planimeter.

NOTES

3 Since both concentration and velocity fluctuate with respect to time in turbulent flow, from $c_i = \bar{c}_i + c'_i$ and $v_i = \bar{v}_i + v'_i$ it follows that $(\overline{cv})_i = (\bar{c}\bar{v})_i + (\overline{c'v'})_i$. The indirect method, therefore, assumes implicitly that the time-averaged sediment transport, $(\overline{cv})_i$, is equal to $(\bar{c}\bar{v})_i$.

4 The procedure outlined from 6.4.1.1 to 6.4.1.3 is more laborious in many cases than would be justified for routine sediment load measurement. Therefore, it is sometimes assumed that the suspended load transport through a vertical is equal to the product of the time-averaged mean flow velocity ($\bar{v}_m$) and the mean concentration ($\bar{c}_m$) in the vertical. The fine sediment (below 0,075 mm sieve diameter) is generally found to be sufficiently uniformly distributed throughout the vertical so that a single sample taken at any depth is adequate for determining the mean concentration.

6.4.2 Selection of verticals

For determination of the suspended sediment transport in a stream, the section should be divided into as large a number of equally spaced segments as is practicable to observe in one period.

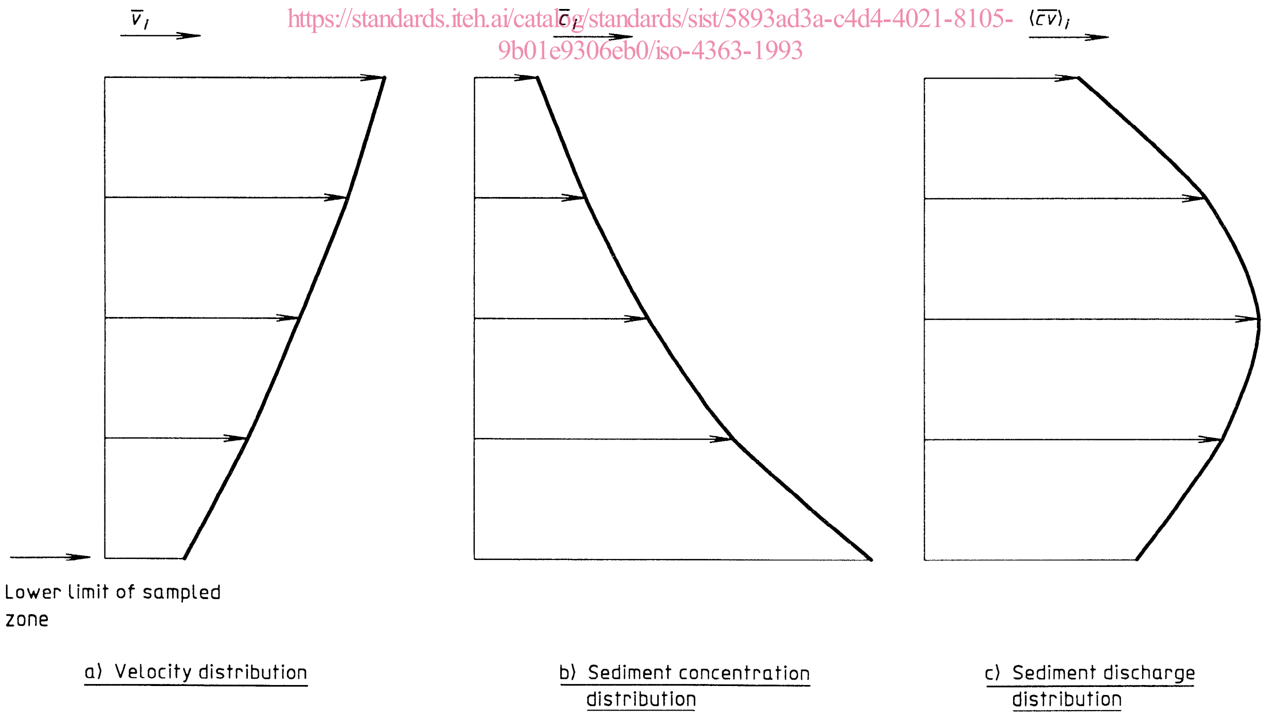

Figure 2 — Sediment discharge computation curve

During a flood, when the stage and sediment transport are changing rapidly, the observation period is governed by the shapes of the discharge and the sediment concentration hydrographs. Therefore, the observation period shall be adjusted to define the suspended load concentration and the discharge hydrographs. In order to do this, it may be necessary to reduce the number of verticals measured during each observation period.

6.4.3 Methods of routine sampling

6.4.3.1 Selected points method

In this method, the sampler shall be immersed at selected points which have a proportional relation to the mean sediment concentration in the vertical as determined by the preliminary experiments in 6.4.1.

The time-averaged suspended sediment load through the vertical, $\bar{q}_s$, is determined from the formula:

$$\bar{q}_s = \frac{1}{n} \sum_{i=1}^{n} \frac{\bar{c}_i \bar{v}_i}{\alpha_i} \qquad \ldots (4)$$

where

$\bar{c}_i$ is the time-averaged sediment concentration;

$\bar{v}_i$ is the time-averaged velocity at the sampling point;

α_i is the ratio $\bar{c}_i \bar{v}_i / \bar{q}_s$;

n is the number of sampling points on the vertical.

The values of n and α_i are determined from preliminary measurements carried out during various stages. Information about various selected point methods in use, together with their limitations, is given in table 1.

6.4.3.2 Depth-integration method

This method of sampling is based on the premise that the sampler, designed specifically for the purpose, fills at a rate proportional to the velocity of the approaching flow. By traversing the depth of the stream at a uniform speed, the sampler will receive at every point on the vertical a sample of the water—sediment mixture at a rate which will be proportional to the instantaneous velocity. The sampler shall be lowered to the bottom of the stream at a uniform rate and shall be raised again, without pausing, to the surface at a uniform rate, but not necessarily at the same rate. Sampling may occur continuously during both periods of transit, or the sampler may be designed to sample at a uniform rate in one direction only.

Two different depth-integration methods are commonly used to obtain a mean discharge-weighted concentration for a cross-section. Both methods weight the concentration with discharge laterally as well as vertically. They are the equal-discharge increment (EDI) method and the equal-width increment (EWI) method.

6.4.3.2.1 EDI method

In the EDI method, the cross-sectional area is divided laterally into a series of subsections, each of which has the same water discharge. Depth integration is then carried out on each of the verticals dividing each subsection discharge in half. In each individual subsection, a vertical transit rate is used that will provide a sample volume for the vertical that is equal to the sample volumes for every other vertical. The procedures provide a group of subsamples that are the same size and that represent the same proportion of the total water discharge through the sampled zone. Such subsamples can be combined to provide a single composite sample. Alternatively, if subsample volumes are different, the concentrations of all subsamples can be averaged to give the sample concentration. Generally, an accurate mean discharge-weighted concentration will be obtained if more than five verticals (subsections) are sampled.

6.4.3.2.2 EWI method

In the EWI method, depth integration is carried out on a series of verticals in the cross-section that are equally spaced across the transection to obtain a series of subsamples. Unlike the EDI method, the vertical transit rate used at each vertical is exactly the same as that used at every other vertical, and the subsamples are composited even though they are of different volumes. Because the transection sample is a composite, subsamples from more than one vertical can be collected in a single sample container. Generally, 10 to 20 verticals will provide an accurate mean discharge-weighted concentration.

6.5 Procedure for the computation of sediment load from measurements obtained by the direct method

6.5.1 General

The procedure for obtaining the mean suspended sediment load per unit width on a vertical is as follows.

The suspended sediment load per unit area is measured at a number of points on the vertical. The suspended load transported per unit width can be obtained numerically, by a rule such as the trapezoidal rule, or, after having drawn a curve as in figure 2 c), by measuring the area under the curve with a planimeter.