INTERNATIONAL STANDARD ISO 4363

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Liquid flow measurement 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

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FOREWORD

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 4363 was developed by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, and was circulated to the member bodies in February 1976.

It has been approved by the member bodies of the following countries :

Australia	Germany	Switzerland
Belgium	India	Turkey
Canada	Mexico	United Kingdom
Chile	Netherlands	U.S.A.
Czechoslovakia	Norway	U.S.S.R.
Finland	Romania	Yugoslavia
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No member body expressed disapproval of the document.

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INTERNATIONAL STANDARD ISO 4363-1978 (E)/ERRATUM

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Liquid flow measurement in open channels — Methods for measurement of suspended sediment

ERRATUM

Page 3

Sub-clause 5.1.2. Replace equation (2) by the following :

$$\bar{q}_{si} = \frac{1}{t}\int_0^t v\, q_{si}\, \mathrm{d}t$$

Page 4

Sub-clause 5.4.1.3, Note 1. Replace the first equation in line 2 by the following :

$$c_i = \bar{c}_i + c'_i$$

Liquid flow measurement in open channels – Methods for measurement of suspended sediment

0 INTRODUCTION

Sediment has been defined generally as solid particles which are moved or might have been moved by flow in a channel. It creates numerous problems for the engineer, the agriculturist and the forester all along the channel. It raises the stream bed which increases the flood heights and inundation; 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 the 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 materials get into the stream channel. The total amount of eroded material which travels from source to a downstream measuring point is termed the sediment transport.

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

1 SCOPE AND FIELD OF APPLICATION

This International Standard gives 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 floods, accurate computation of total sediment flow in a period entails routine sampling at normal flows combined with frequent routine sampling on rise, fall and peak in floods.

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

2 REFERENCES

ISO 748, *Liquid flow measurement in open channels – Velocity-area methods.*

ISO 772, *Liquid flow measurement in open channels – Vocabulary and symbols.*

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

3 TERMINOLOGY

3.1 For a proper comprehension of sediment movement and related terms, the flow of water over an artificially flattened bed of sediment may be considered. From no movement of bed material at very low velocities, some particles begin to move with the increase of velocity by sliding, rolling or hopping along the bed ("bed load"); at still higher velocities particles of 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 point of transport of sediment the "total load" comprises bed load and suspended load, the latter including "wash load". From the point of origin of the sediment, the "total load" comprise the "bed material load" (including the suspended portion) and the "wash loads".

3.2 For the purpose of this International Standard, the following definitions shall apply, in addition to those given in ISO 772.

3.2.1 sediment transport : The movement of solids transported in any way by a flowing liquid. From the point of transport, the sum of the suspended load transported and bed load transported. From the point of origin the sum of the bed material load and the wash load.

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

3.2.3 bed material : The material, the particle sizes of which are found in appreciable quantities in that part of the bed affected by transport.

3.2.4 bed material load : The 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.

3.2.5 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.

3.2.6 bed load : The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

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

3.2.8 sediment concentration : The ratio of the mass or volume of the 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 metres, kilograms and seconds. 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.

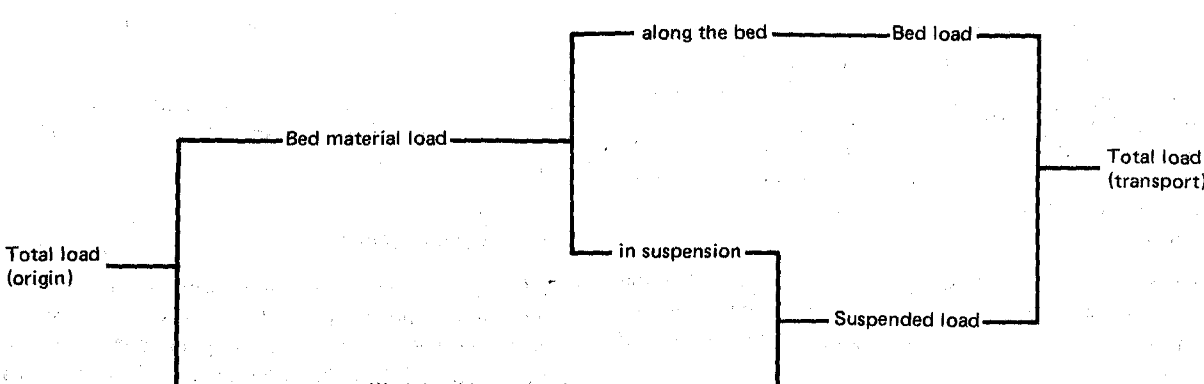


FIGURE 1 — **Definition sketch**

5 MEASUREMENT OF SUSPENDED SEDIMENT LOAD

5.1 Principles of measurement

There are two methods, namely :

a) INDIRECT METHOD, in which the time-averaged concentration of the sediment and the time-averaged current velocity at a point are measured practically simultaneously with the aid of separate devices and multiplied to obtain the sediment load.

b) DIRECT METHOD, in which with the aid of one device the time-averaged suspended sediment load at a point is measured directly.

5.1.1 *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 practically 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 by using the formula

$$Q_s = \sum_0^m \bar{c}_i \, \bar{v}_i \, \Delta a_i \qquad \ldots (1)$$

The right-hand side of the above equation should 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.

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

5.1.2 *Direct method of 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 the undisturbed flow. Due to decrease of velocity, the sediment material settles in 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 relationship :

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

where

ν is a dimensionless coefficient, which may vary with grain size, current velocity and the type of nozzle — see note under 5.5.3.1;

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 :

$$Q_s = \sum_0^m \bar{q}_{si} \, \Delta a_i \qquad \ldots (3)$$

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

5.2 Selection of site

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

5.3 Requirements for measurement of 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 in the vertical, or by using an integrating depth sampler which automatically takes a sample in which the concentration of suspended sediment is the average concentration in the vertical (see 5.4.3).

The suspended sediment concentration, as well as the particle size of sediment, in a flowing stream generally increases from top to bottom and it also varies transversely 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 must 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 the table and the methods are described in 5.4.3.

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 in a vertical.

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

5.4.1 *General*

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

5.4.1.1 Draw the velocity distribution and sediment concentration curves as in figures 2 a) and 2 b). The curves shall be drawn up to the sampled zone.

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

5.4.1.3 The suspended sediment load 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.

NOTES

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

2 The procedure outlined in 5.4.1.1, 5.4.1.2 and 5.4.1.3 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 $(\overline{v}_m)$ and the mean concentration $(\overline{c}_m)$ 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 at any depth is likely to be sufficient for determining the mean concentration.

5.4.2 *Selection of verticals*

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

During a flood, when the stage and sediment transport are changing rapidly, the observational period is governed by the shapes of the discharge and the sediment concentration hydrographs. Therefore, the observational period must 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 observational period.

5.4.3 *Methods of routine sampling*

5.4.3.1 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 5.4.1.

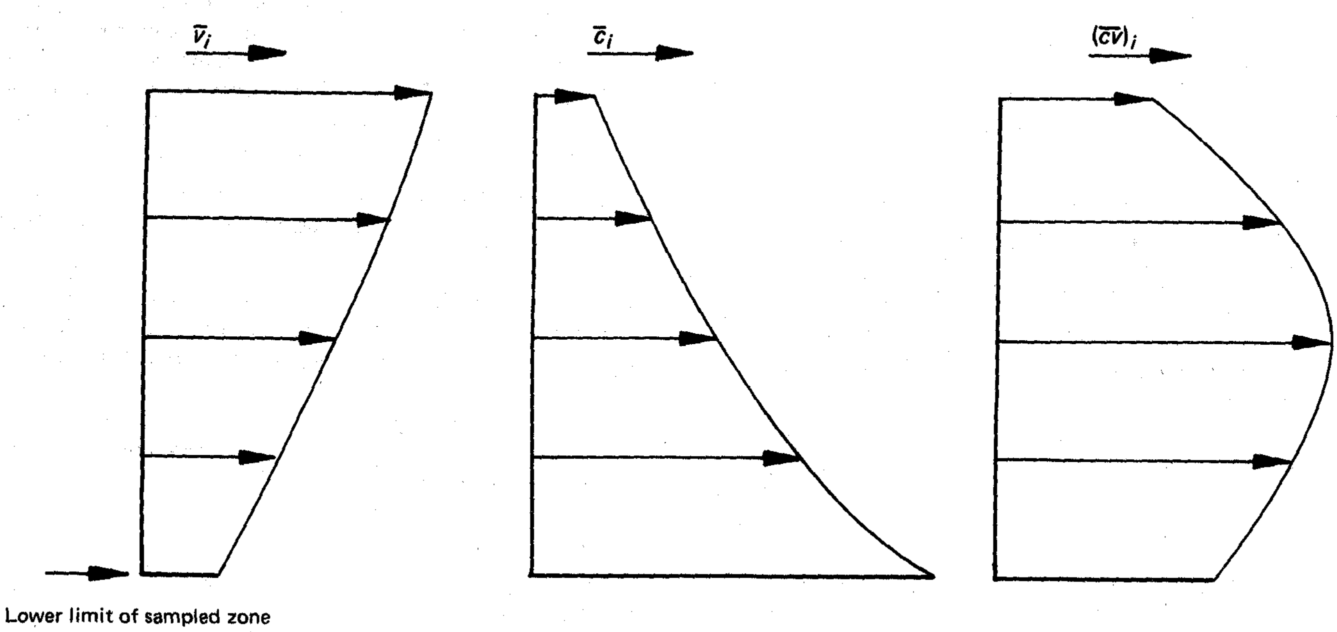
If $\overline{c}_i$, $\overline{v}_i$ are the time-averaged sediment concentration and velocity at the sampling point, α_i is the ratio of $\overline{c}_i\, \overline{v}_i / q_s$, q_s is the time-averaged suspended sediment load through the vertical, and n is the number of sampling points in the vertical, then

$$\overline{q}_s = \frac{1}{n} \sum_{1}^{n} \frac{c_i v_i}{\alpha_i} \qquad \ldots (4)$$

The preliminary measurements carried out during various stages will determine the value of n, the number of the sampling points and α_i. Information about various selected-point methods in use, together with their limitations, is given in the table (page 6).

5.4.3.2 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



2 a) Velocity distribution

2 b) Sediment concentration distribution

2 c) Sediment discharge distribution

FIGURE 2 — **Sediment discharge computation curves**

traversing the depth of the stream at a uniform speed, the sampler will receive at every point in 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 continuously during both periods of transit, or it may be designed to sample at a uniform rate in one direction only.

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

5.5.1 *General*

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

The suspended sediment load per unit area is measured at a number of points in 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.

5.5.2 *Selection of verticals*

The selection of verticals for the direct method is governed by the same considerations as for the indirect method (see 5.4.2).

5.5.3 *Methods of routine sampling*

5.5.3.1 Since the type of instrument applied in the direct measurement method determines directly the suspended load transport, depth integration is possible if the instrument is lowered and raised at a uniform speed from the surface to the bottom.

NOTE — Because the coefficient ν (see 5.1.2) depends upon the grain size, the current velocity and the characteristics of the nozzle, an error is introduced as the velocity and the size distribution of the particles depend upon the elevation. The more uniform the velocity and the size distribution of the particles, the less the error is likely to be.

5.5.3.2 SELECTED POINTS METHOD

In this method, the sampler shall be immersed at selected points which have a proportional relation to the mean sediment discharge in the vertical as determined by the preliminary experiments in 5.4.1.

If $\bar{q}_{si}$ is the sediment discharge per unit area at the sampling point, α_i is the ratio of $\bar{q}_{si}$ to $\bar{q}_s$, $\bar{q}_s$ is the time-averaged suspended sediment load through the vertical, n is the number of sampling points in the vertical and D is the depth, then

$$\bar{q}_s = \frac{1}{n} \sum_{1}^{n} \frac{\bar{q}_{si}}{\alpha_i} D \qquad \dots (5)$$

The preliminary measurements carried out during various stages will determine the value n of the sampling points and α_i.

5.6 Additional information

In order to allow proper use of sediment measurement results, additional information is required. Therefore, for each suspended sediment measurement, the following items should be recorded in relation to the purpose of the measurement :

a) river;

b) site;

c) date;

d) general weather conditions;

e) wind direction and strength;

f) sampler used;

g) time of sampling — from . . . . . . to . . . . . .;

h) gauge reading and/or discharge at the beginning of measurement;

i) gauge reading and/or discharge at the end of measurement;

j) water level slope;

k) temperature of air;

l) temperature of water;

m) any other measurements taken simultaneously with suspended sediment measurement (for example, bed load and/or bed material sampling, ice measurement etc.).

6 ERRORS

The error in the sediment transport measured in a stream is caused by a great many factors. Besides the error due to the instrument, errors are generated owing to the fact that the cross-section is sampled only at a restricted number of points.

As yet, little systematic work has been carried out on the errors due to sampling. As in the case of measurement of discharges in open channels, it can be expected that the number of verticals is important for the reduction of errors in the sediment transport measured.

For fine sediment, the concentration is fairly constant over the vertical. For coarse sediment in suspension, rather large concentration gradients exist in a vertical. The terms "fine" and "coarse" refer here not only to the grain size [or "fall velocity" (W)] but also to the character of flow, usually expressed in terms of the "shear velocity" (v^*). The ratio W/v^* is an important parameter for sediment transport in suspension. The larger the ratio W/v^*, the larger is the concentration gradient in a vertical.