DRAFT INTERNATIONAL STANDARD ISO/DIS 11657

ISO/TC **113**/SC **6** Secretariat: **BIS**

Voting begins on **2012-12-03** Voting terminates on **2013-03-03**

Sediment in streams and canals — Determination of concentration by surrogate techniques

Sédiments dans les cours d'eau et dans les canaux — Détermination de la concentration par des techniques de substitution

ICS 17.120.20

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Foreword

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ISO 11657 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 6, Sediment Transport.

Introduction

Sedimentation and sediment transport in rivers, streams and reservoirs is a world-wide environmental, engineering, and agricultural issue. Success in managing and solving sedimentation problems requires comprehensive knowledge of sediment movement, reliable methods of estimation of sediment load, and improvement in data quality. The amount of sediment-transport data being collected, however, has steadily declined in recent decades largely due to difficulty and costs associated with field methods used for data collection. High temporal resolution data are needed to better understand and more adequately describe many sedimentation processes.

The bed load and suspended load broadly constitute total sediment load. However, the scope of this standard is confined to the measurement of suspended sediment. Conventional methods for measurement of suspended-sediment concentrations and particle-size distributions in streams rely on the principle of collecting samples of water-sediment mixture at various points in time and space using suitable sampling equipment and deployment methods, and analyzing the samples in laboratory for estimating the concentrations and particle-size distributions. These methods of collecting sediment data are labour intensive and expensive and can be hazardous. Moreover, the accuracy of these methods in estimating the sediment concentration of rivers and streams over a period of time may not be dependable due to the large spatial and temporal variability associated with the transport of suspended sediment.

Continuous and accurate estimation of suspended-sediment concentration is essential in certain situations such as:

a) in hydropower projects for the safety of the turbines and other machinery, and

b) water-supply projects for monitoring water quality

c) storm water run-off from urban areas

d) long-term monitoring of sediment transport in rivers and streams, in order to obtain reliable base lines that can be used for decision making

In such situations, automatic and cost-effective techniques are essential to collect high-quality data on suspended-sediment concentrations and particle sizes.

Recent technological advances in the fields of optics and acoustics have provided new sediment-surrogate technologies and methods to determine fluvial suspended-sediment fluxes and characteristics. Some of these methods can be used to measure suspended sediment concentration at higher resolution, with greater automation and potentially lower cost than traditional methods. These methods involve calculating the concentration of suspended sediment from detectable optical backscatter, laser diffraction and acoustic backscatter.

Hydrometry — Suspended Sediment in streams and canals - Determination of concentration by surrogate techniques

1 Scope

1.1 This International Standard specifies methods for determination of the concentrations and particle-size distributions of suspended sediment in streams and canals by surrogate techniques. Methods based on bulk-optical principle of water such as transmission, nephelometry and optical backscatter are the most commonly used surrogates for determining suspended-sediment concentrations (SSC). Instruments and techniques based on acoustic attenuation and/or acoustic backscatter principles are also in use for measurement of suspended-sediment concentration. Instrumentation based on the laser diffraction principle is also used for the measurement of particle size distribution. This Standard covers brief description of the operating principle of each method and details of some of the instruments available.

1.2 The detailed method and principle of Nephelometry, Optical Back Scatter (OBS), Laser Diffraction technique (LD) and Acoustic Back Scatter technique (ABS) with their limitations are described in annexure A, B and C respectively.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry – Vocabulary and symbols.*

ISO 4363, *Measurement of liquid flow in open channels – Methods for measurement of characteristics of suspended sediment.*

ISO 13320-2009, *Particle size analysis – laser diffraction methods*

3 Terms and definitions

For the purpose of this international standard, the definitions given in ISO 772, ISO 4363 and ISO 13320 apply, together with the following:

3.1

surrogate technique

An indirect method in which a surrogate/substitute object or property is used for measurement in place of the original object or property.

NOTE – Optical and acoustic properties of water-sediment mixture such as optical transmission, acoustic scattering, and laser diffraction are some of the surrogates for measurement of suspended sediment concentration.

3.2

nephelometry

Any method for estimating the concentration of particles in suspension by measuring the intensity of scattered light (turbidity), often at right angles to the incident beam.

NOTE Light scattering depends upon number, size distribution, colour, composition (as manifested in the complex index of refraction) and shape characteristics of the particles.

4 Units of measurement

The units of measurement used in this International Standard are SI units in accordance with the appropriate parts of ISO 80000.

5 Measuring principles

Optical and acoustical methods are used for continuous measurement of sediment concentration. The measuring principles for the above surrogate techniques are similar and can be classified in three categories as follows (refer Figure 1):

5.1 Transmission

The source and detector are placed opposite to each other at a distance l as shown in figure 1 A. The sediment particles in the measuring volume reduce the beam intensity resulting in a reduced detector signal. The relationship between the detector signal (l_t) and the sediment concentration (c) is following Beer's Law[23]:

$$l_t = l_o e^{-kcl} \quad (1)$$

where

l_t is the transmitted light through a sample of length l in water of sediment concentration c, and l_o is the incident intensity of the emitter source entering the water sample. The variable k in the exponent depends on the sediment, water, and instrument characteristics.

5.2 Scattering

The source and detector are placed at an angle (φ) relative to each other shown in figure 1 B. The detector receives a part of the radiation scattered by the sediment particles in the measuring volume. The relationship between detector signal (l_s) and sediment concentration (c) is:

$$l_s = k_3 l_o c\, e^{-k_2 c} \quad (2)$$

where

l_o is the incident intensity of the emitter source,

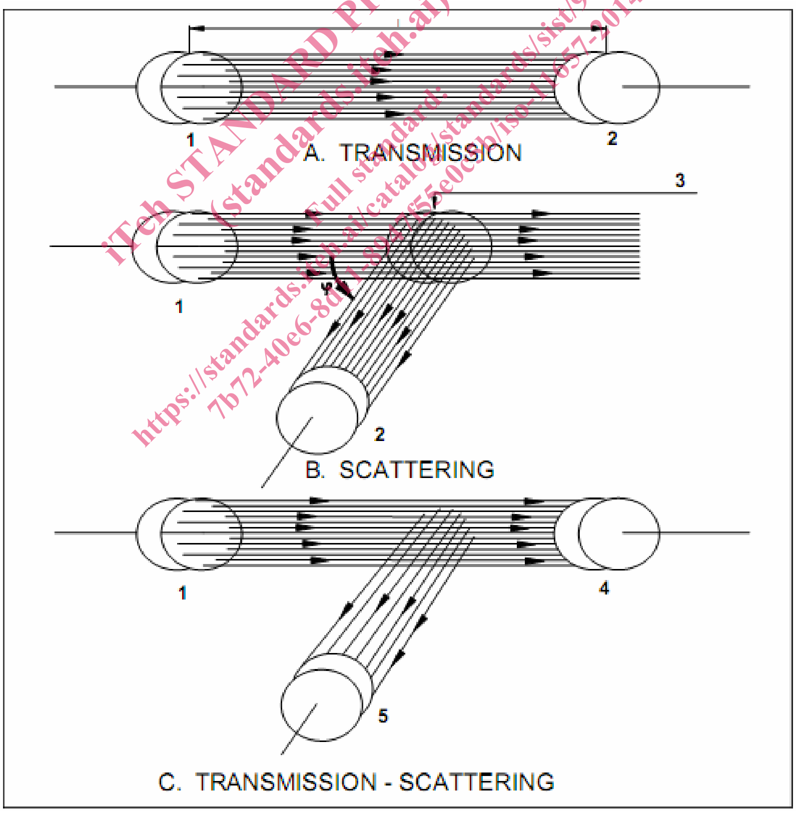
k_2 in the exponent depends on the sediment, water, and instrument characteristics, and

k_3 is calibration coefficient depending on instrument geometry, particle properties (size distribution, shape, index of refraction or composition), optical /acoustic wave length and travel distance (l). Often, the distance l can not be defined in optical backscatter type systems.

An important limitation of the scattering method is the strong nonlinearity of the relation between the detector signal and sediment concentration for large concentrations. Even in low concentrations where the response is linear, the output depends strongly on grain size and colour. For instance, colour alone may change the calibration by a factor of 10 for higher concentration[37]; and the grain size may cause an additional change in calibration. For example, the calibration is shown to change by a factor of 20 between a white 5 micron sediment and a grey 10 micron sediment. As such, changes in sediment properties are not uncommon in nature, which are generally not known during the course of monitoring. Spot calibration from samples is likely to be contaminated by unknown errors when sediment properties change in space/time. The errors can reach several hundred percent and greater. However, the use of laser sensors is able to overcome these errors to great extent.

5.3 Transmission – Scattering

This method is based on the combination of transmission and scattering, as shown in figure 1 C.



Key

1 Source

2 Detector

3 Measuring Volume

4 Detector T

5 Detector V

Figure 1 – Basic principles of optical and acoustic methods

6 Properties of sediment

6.1 General

The transport of sediment is based on hydraulic characteristics and physical properties of the sediment. The properties of sediment are classified by individual particle characteristics and bulk characteristics.

6.2 Properties of individual particles

Suspended-sediment size is the most commonly used parameter to designate the properties of individual particles. The particle size, particle settling velocity and the flow characteristics govern the movement of the suspended sediment. Settling velocity in turn depends upon the relative density, shape and the diameter of the suspended sediment particles.

Since natural sediments are shaped irregularly, a single length or diameter has to be chosen to characterize the size. Four such diameters, i.e. nominal diameter, projected diameter, sedimentation diameter and sieve diameter, are often used for different particle sizes or purposes (for example, sieve diameter for coarse and medium particles, sedimentation diameter for fine particles which are not usually separated by sieves). The nominal diameter has significance in suspended-sediment transport, but is useful in the study of suspended-sediment concentration in rivers, lakes and reservoirs. From the optical/acoustic scattering perspective a property that represents composition is required. In the case of optical scattering, this property is the complex index of refraction. The real part of this complex number represents bending of light (cf. Snell's Law) and is central to light scattering. The imaginary part represents absorption by the particles. Particle colour is manifested as a wavelength-dependent imaginary part of the refractive index. In contrast, for acoustic scattering, the speed of sound in the particle material is important. This is equal to the square root of the ratio of bulk modulus of elasticity, (often denoted by E), and the density, denoted by ρ. Absorption in the particle may be represented by a similar imaginary factor. Both scattering processes depend on the ratio of this property divided by the same for water, i.e. it depends on a mismatch of the key property.

6.3 Bulk characteristics

As sediments typically consist of large numbers of particles differing in size, shape, relative density and settling velocity, it is essential to find some parameters that represent the characteristics of the group of particles as a whole. Therefore, a sample of sediment is usually divided into classes according to their characteristics (size and settling velocity) and the percentage by number, area, volume or mass of the total in each class is determined for the particular characteristic. Frequency distribution curves may be drawn from these data and their parameters (e.g. mean size, median size, standard deviation, median absolute deviation) determined. It is important to realize that the frequency distribution curves for the number, area, volume and mass distribution may be very different from each other for a given sample of sediment. Consequently, the computed parameters, e.g. the mean size will also be different.

7 Methods for determination of suspended-sediment concentration by surrogate techniques

7.1 General

The surrogate methods employ in-situ measurement using sensors that measure the bulk optical properties of the water-sediment mixture, including transmission, nephelometry and

