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Hydrometry — Position fixing equipment for hydrometric boats

Hydrométrie — Système de positionnement pour embarcation hydrométriques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html .

The committee responsible for this document is Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*.

This second edition of ISO 6420 cancels and replaces ISO 6420:1984, which has been technically revised. The following major changes have been made:

— information on the use of global navigation satellite systems has been added;

— the former Annexes A and B have been removed;

— the treatment of uncertainty has been expanded and aligned with ISO/TS 25377.

Introduction

The necessity of positioning hydrometric boats arises in several types of measurements on open channels or lakes, reservoirs and estuaries. First, it is necessary to position a boat on a measuring section in order to conduct the appropriate observations of velocity and depth for a discharge measurement. Position fixing also is required for collecting suspended sediment and bedload samples at appropriate verticals on a river cross section. Similarly, positioning of a boat is needed for morphological surveys and sediment sampling of lakes, reservoirs and estuaries.

This document provides information for positioning hydrometric boats with various methods ranging from standard surveying equipment to navigation systems employing signals from the constellation of satellites.

Hydrometry — Position fixing equipment for hydrometric boats

1 Scope

This document specifies methods of determining the position of hydrometric boats based on satellite navigation systems and/or with respect to known points on the banks of rivers, estuaries or lakes. It applies to electronic positioning equipment and conventional surveying techniques.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 748, *Hydrometry — Measurement of liquid flow in open channels using current-meters or floats*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 772 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Requirements for position fixing

The necessity of using position fixing equipment arises in two types of measurements on open channels or lakes, reservoirs and estuaries.

First, it is necessary to position a boat on a measuring section in order to conduct the appropriate observations of velocity and depth for a discharge measurement (as specified in ISO 748). The use of acoustic Doppler current profilers for making discharge measurements (see ISO/TR 24578) has largely diminished the need for position fixing equipment for hydrometric boats when making discharge measurements. However, there are still some types of measurements when verticals on a cross section have to be positioned for velocity and depth determinations. Position fixing also is required for collecting suspended sediment and bedload samples at appropriate verticals.

The second type of measurements requiring position fixing are morphological surveys of lakes, reservoirs and estuaries. Position fixing is required to determine the positions at which depth observations and bottom samples are obtained.

5 Position fixing equipment for streamgauging and sediment sampling

5.1 General

There are different types of position-fixing equipment. This clause describes the following: measuring tapes, tag lines, global navigation satellite systems (GNSS), a combination of targets and electronic distance measuring equipment, electronic surveying equipment, and theodolites and stadia rods.

5.2 Tapes and tag lines

Tapes and tag lines are the most frequently used means for width measurements when measuring rivers by boat or wading. Steel measuring tapes with markings at metres and 10^{ths} of metres (or 100^{ths} of meters) are used in streams and rivers less than 50 m wide. A typical tag line consists of a marked corrosion-resistant steel cable that is 2 mm to 3 mm in diameter. The diameter of the tag line depends on the width of the channel, the velocity of the water and whether or not the same tag line is used for holding the boat and for determining its position. Larger diameter tag lines may be needed if used for dual purposes. Tag lines are typically marked at intervals of 5 m to 10 m with double markings at 50 m and 100 m. Tag lines are commonly used on channels up to 300 m wide, however, the accuracy of the distance measurements depends on cable tension. Long tag lines are usually wound on a drum having a diameter of at least 0,3 m and equipped with a cranking and braking mechanism.

Caution should be used when tapes and tag lines are used to position hydrometric boats on navigable rivers. An observer on the river bank should be available to alert the hydrographers of approaching boats and also alert boat operators of the tape or tag line. Other operators may be required to temporarily remove the tape or tag line to allow boat passage through the measuring section.

5.3 Global navigation satellite systems

5.3.1 General

Navigation systems that use GNSS technology are used on larger rivers that are too wide for stringing a tagline. These systems provide reliable location and time information, in all weather conditions and at all times, anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more satellites in the constellation of satellites.

There are two operational GNSS.

— The NAVSTAR Global Positioning System (GPS) was developed by the U. S. Department of Defense; it is composed of 24 satellites.

— GLONASS was developed by the Soviet Union and is operated by the Russian Aerospace Defense Forces; it also is composed of 24 satellites.

Other global or regional systems under development include Galileo being developed by the European Union, Compass being developed by China, and IRNSS, a regional system being developed by India.

There are two general operating methods by which satellite-derived positions can be obtained; either absolute point positioning or relative (differential) positioning.

a) With absolute point positioning, measurements of the distance to each individual satellite are made by analysing the time it takes for a signal to travel from a satellite to the antenna of the navigation system. Trilateration is then used to establish the receiver's position. The accuracy of the position is about 3 m or less.[6]

b) Differential positioning is the technique or method used to position one point relative to another. Differential positioning requires a ground station within line of sight distance of 20 km or less. Differential positioning can provide a relative accuracy of a few centimetres..[5] Receivers with real-time kinematic (RTK) technology can provide a relative accuracy of 1 cm to 2 cm. RTK uses a similar set-up to differential positioning, but with two significant differences: the RTK signal is evaluated for timing error (not just the information contained within the signal), and the error correction is transmitted immediately to the GNSS units resulting in real time accuracy. Some RTK-enabled receivers are able to use satellite-broadcasted corrections and provide very accurate positioning over much longer distances. There is an added cost of using broadcasted corrections from private satellites.

GNSS technology uses the World Geodetic System 1984 (WGS84) as the default datum. Other earth models or coordinate reference systems may be desired for specialized applications, such as for high-resolution mapping and navigation in specific regions of the Earth.[7] The use of any preferred local coordinate reference systems in such applications requires a suitable coordinate transformation from WGS84.[7]

5.3.2 Hydrometric application

Satellite navigation systems allow operators to preselect transects and verticals for making depth and velocity determinations. The systems consist of a receiver, navigation software, and a digital display that shows the position of the boat on the cross section. Navigation systems facilitate the measurement of depth and velocity or the collection of samples at verticals with only a boat operator and one hydrographer.

5.3.3 System specifications

There are a wide range of navigation systems that can be used for hydrometric applications. Systems should have the following minimum capabilities for positioning boats on river cross sections:

— ability to receive signals from more than one global or regional satellite navigation system and ground reference stations;

— sufficient channels to receive signals for up to 12 satellites;

— water proof or resistant so electronics will not be damaged during rain or spray from waves;

— a digital display that shows the boat position, cross section and waypoints (verticals);

— a sunlight mode so the system can be operated in direct sunlight;

— ability to store 100 or more waypoints (verticals);

— an alarm system to indicate when the boat drifts from the cross section or designated waypoint (vertical);

— output function for transferring position information to a discharge measurement application.

5.4 Targets and electronic distance measuring equipment

5.4.1 General

Targets are used to align the boat on the cross section, and range finders or other distance measuring equipment are used to position the boat on the correct vertical. This approach usually requires a boat operator to align the boat on the cross section between the targets, a hydrographer to make the depth and velocity measurements, and another individual on the river bank or on the boat to read and record the distance measuring equipment. Communication between the shore personnel and the boat operator is done using hand signals or radios.

5.4.2 Targets

The target technique requires that two targets be positioned on each bank to give the line of the cross section. The size and type of the targets will depend on the channel width. To ensure sufficient accuracy of the line, the spacing between the targets on each bank should not be less than 10 % of the channel width.

5.4.3 Electronic distance measuring devices

Electronic distance measuring devices use visible or infrared electromagnetic waves. Laser rangefinders can be used to measure horizontal distances ranging from 20 m to 4 000 m. The optimum setup consists of a single lens or binocular rangefinder and a reflector or multiple reflectors. The rangefinder can be used on the boat with reflectors mounted on the near-shore targets on each bank, or the rangefinder can be used on one bank with a reflector mounted on the boat. The accuracy of rangefinders is a function of beam divergence. Units used for measuring distances greater than 500 m should have good optics with tightly collimated beams to hold focus.

Distance measuring instruments using radio waves operate on the principle that if a carrier is frequency modulated, it will exhibit a phase shift that is proportional to the distance travelled and to the modulating frequency. By using a number of modulating frequencies and comparing the phase shifts of a signal that has travelled between a master unit and a remote unit to a reference signal, it is possible to determine distance within 1 mm to 2 mm over a distance of 1 500 m. For streamgauging applications, the master unit is set up on one streambank and the remote unit or prism reflector is mounted on the hydrometric boat.

The accuracy of the distance measurement is affected by the angle of the line-of-sight from horizontal. The master unit should be levelled, and the prism reflector should be mounted at the same height above an arbitrary datum as the master unit.

5.5 Electronic survey instruments

A total station is an electronic/optical instrument used in modern surveying. The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point. For hydrometric applications, the total station is positioned and levelled on the cross section on one bank of the river and a prism reflector is mounted on the hydrometric boat. A typical total station can measure distances with an accuracy of about 1 mm to 2 mm + 1,5 ppm[1)] over a distance of up to 1 500 m [4].

This method requires a boat operator, a hydrographer, and an instrument operator on the river bank. The boat is maintained on the cross section at the appropriate vertical by radio communication or hand signals between the instrument operator and the boat operator.

5.6 Theodolites

5.6.1 Theodolites and stadia

A combination of theodolite or transit and a stadia rod can be used for positioning hydrometric boats; however, this is the least accurate method. The approach is similar to the total station method. The theodolite or transit is positioned on the cross section on one bank of the river, and the distance from the instrument to the boat is determined by the intersection of the stadia lines on a surveying rod. This method requires at least three experienced personnel: an instrument operator, a boat operator, and a hydrographer. An assistant on the boat may be required to set an anchor and adjust the line so the boat remains stable on the cross section while stadia readings are made.

5.6.2 Angular technique

Another use of theodolites for positioning hydrometric boats is the angular technique. A baseline is established on one bank perpendicular to the cross section being measured. The length of the baseline, which should be approximately the width of the measuring section, is measured with a surveying tape or stadia readings. The theodolite is then positioned on the end of the baseline that is not on the cross section as shown in Figure 1. The angle measured determines the position on the cross section from the initial measuring point by the following formula:

$$L_{AB} = \tan\beta \cdot L_{AC} \quad (1)$$

1) ppm = parts per million

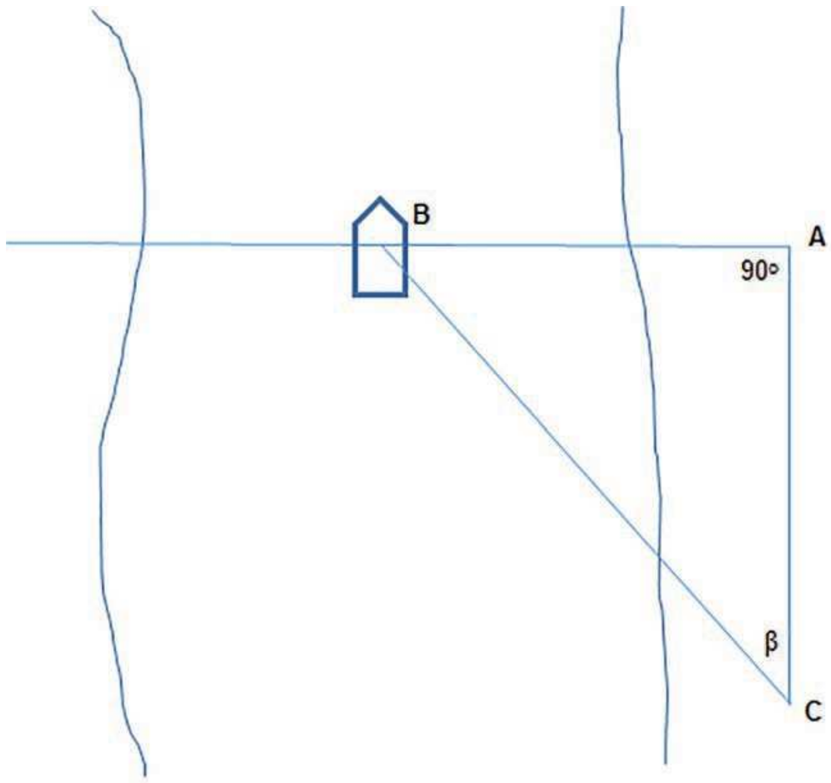

Figure 1 — Position fixing on a cross section by angular techniques

6 Position fixing equipment for morphological surveys

6.1 General

The same type of position fixing equipment that is used for streamgauging applications can be used for morphological surveys, however, some of them have limited applications. For example, tag lines could only be used for narrow estuaries and reservoirs not greater than 300 m wide. Also, targets and electronic distance measuring equipment probably would only be used if pre-surveyed cross sections were established on the banks of the lake, reservoir or estuary. The three types of equipment discussed in this clause are GNSS, electronic surveying instruments, and theodolites and stadia rods.

6.2 Global navigation satellite systems

Navigation systems using GNSS, as discussed in 5.3, provide a cost-effective and efficient method for positioning boats for morphological surveys. Surveys and sampling can be accomplished with a boat operator and a hydrographer. Modern navigation systems allow operators to preset a large number of transects and verticals for making depth measurements and/or collecting water or bottom-material samples.

6.3 Electronic surveying instruments

A total station, as discussed in 5.5, is an effective, but more costly method for positioning hydrometric boats for morphological surveys. The method requires the establishment of one or multiple baselines on the bank of the body of water being surveyed as shown in Figure 2. The total station is set up on one end of the baseline, and the position of the boat is determined by the angle from the baseline and the distance from the total station to the boat. Surveys can be accomplished with an instrument operator, boat operator and hydrographer.

6.4 Theodolites and stadia rods

Positioning of hydrometric boats for morphological surveys also can be accomplished by using a theodolite and stadia rod. Using one theodolite and a stadia rod is the same process as described in 6.3. The angle from the baseline to the boat is determined with the theodolite, and the distance from one end of the baseline to the boat is determined by reading the intersection of the stadia lines on the surveying rod. This method has limited application because of the difficulty in reading the markings on the surveying rod while the hydrometric boat is in the water. Another limitation is the length of the distance that can be measured. The maximum distance that can be measured with a typical surveying rod is 400 m, but the difficulty in reading the rod increases dramatically beyond 100 m.

Triangulating the position of the hydrometric boat using two theodolites is the preferred and more accurate method. The two theodolites are set up on each end of the baseline, and the angles (α and β; Figure 2) from the baseline to the boat are determined. The intersection of the two lines determines the position.

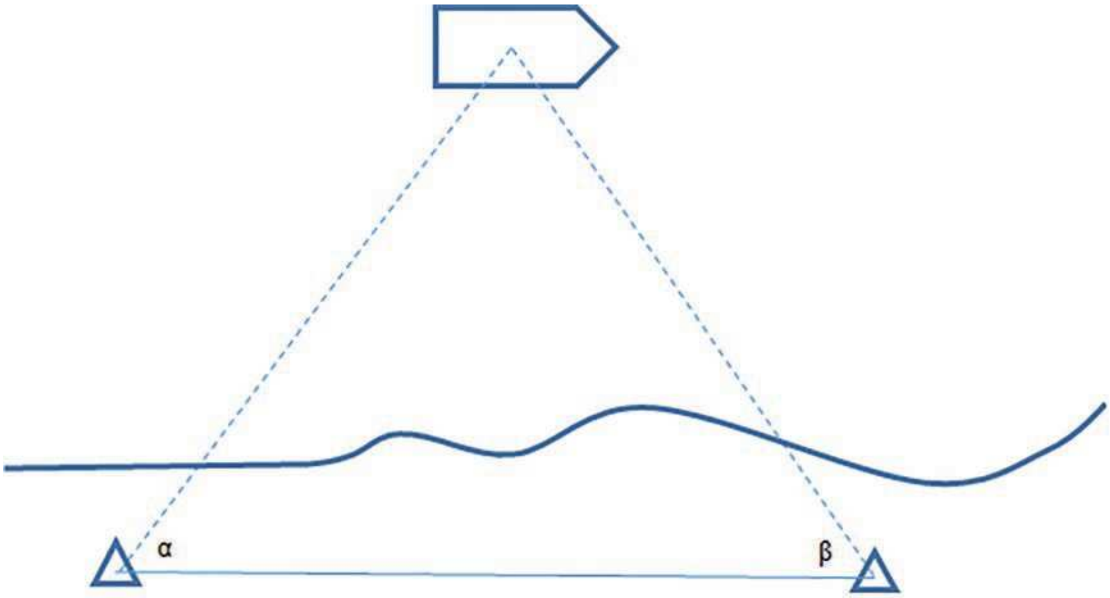

Figure 2 — Position-fixing of hydrometric boat for morphological surveys

7 Uncertainty

7.1 Definition of uncertainty

All measurements of a physical quantity are subject to uncertainties. These may be due to systematic errors (biases) in the equipment used for measurement, or to random scatter caused by a lack of sensitivity of the equipment used for the measurement. A measurement thus is only an estimate of the true value of the measured quantity and is complete only when accompanied by a statement of its uncertainty.

The discrepancy between the true and measured values is the measurement error. The measurement error is a combination of component errors that arise during the performance of various elementary operations during the measurement process. For measurements of composite quantities that depend on several component quantities, the total error of the measurement is a combination of the errors in all component quantities. Determination of measurement uncertainty involves identification and characterization of all components of error, quantification of the corresponding uncertainties, and combination of the component uncertainties. The uncertainties are combined using the statistical rules for combining standard deviations, giving proper consideration to correlations among all of the various sources of measurement error in order to account for both systematic and random errors. The resulting uncertainty values are termed standard uncertainties; they correspond to one standard deviation of the probability distribution of measurement errors.

For further information on the evaluation of uncertainty, see Annex A.

7.2 Uncertainty of position fixing for streamgauging and sediment sampling

7.2.1 General

The uncertainty of the relative position of a hydrometric boat on a river cross section includes errors caused by the accuracy of the positioning equipment, the accuracy of the distance or width measuring instruments, the accuracy of angle measuring instruments if the angular technique is used, the cross section not being perpendicular to the flow, and the drift of the boat upstream and downstream or laterally along the cross section.

7.2.2 Tag lines

A tag line is an accurate method of positioning a boat on a cross section for streamgauging and sediment sampling. The uncertainty associated with this method is interpreting the distance between markings on the tag line and the tag line not being perpendicular to the cross section. This is expressed as:

$$U = \left[u_s^2 + u_i^2 + u_\alpha^2 \right]^{\frac{1}{2}} \quad (2)$$

where

u_s is the uncertainty in the distance from the left bank resulting from the sag in the tag line and the unknown tension on the tag line;

u_i is the uncertainty in the distance from the left bank caused by interpolating the distance between beads on the tag line;

u_α is the uncertainty in distance from the left bank resulting from the tag line not being perpendicular to the flow.

7.2.3 Global navigation satellite systems

A navigation system that uses GNSS is the most accurate method for positioning hydrometric boats on rivers wider than 300 m. The uncertainty is limited to three factors: the section not being perpendicular to the flow, the relative position on the cross section, and boat drift. This is expressed as:

$$U = \left[u_\alpha^2 + u_{\text{pos}}^2 + u_{\text{dr}}^2 \right]^{\frac{1}{2}} \quad (3)$$

where

u_α is the uncertainty in distance from the left bank resulting from the cross section not being perpendicular to the flow;

u_{pos} is the uncertainty of the position from the left bank or station 0 based on GNSS signals;

u_{dr} is the uncertainty resulting from boat drift upstream, downstream or horizontally on the section.

7.2.4 Targets and distance measuring devices

Targets and distance measuring devices are a relatively accurate method of positioning hydrometric boats. The uncertainties associated with this method are the distance measured from the left bank or station 0 by the distance measuring device, the target line not being perpendicular to the river banks, and boat drift. This is expressed as:

$$U = \left[u_d^2 + u_\alpha^2 + u_{\mathrm{dr}}^2 \right]^{\frac{1}{2}} \quad (4)$$

where

u_d is the uncertainty of the distance measuring device;

u_α is the uncertainty in distance from the left bank resulting from the target line not being perpendicular to the flow;

u_{dr} is the uncertainty resulting from boat drift upstream, downstream or horizontally on the section.

7.2.5 Electronic surveying instruments

Electronic surveying instruments or total stations are a very accurate method of positioning hydrometric boats. The uncertainty factors are the same as the method that uses targets and distance measuring devices, and Formula (4) applies.

7.2.6 Theodolites

The use of theodolites and stadia are the least accurate method for positioning hydrometric boats. The uncertainty factors are the same as the two previous methods (see 7.2.4 and 7.2.5), and Formula (4) applies.

The angular method (see Figure 1) that also uses a theodolite has slightly different uncertainty factors. They include the uncertainty of the distance measuring device to establish the baseline, the uncertainty of the baseline not being parallel to the flow, the uncertainty of the angle measured from the baseline to the hydrometric boat, and the drift of the boat. The uncertainty is expressed as:

$$U = \left[u_d^2 + u_\alpha^2 + u_\beta^2 + u_{\mathrm{dr}}^2 \right]^{\frac{1}{2}} \quad (5)$$

where

u_d is the uncertainty of the distance measuring device;

u_α is the uncertainty of the baseline not being parallel to the flow;

u_β is the uncertainty of the angle measured from the baseline to the hydrometric boat;

u_{dr} is the uncertainty resulting from boat drift upstream, downstream or horizontally on the section.

7.3 Uncertainty of position fixing for morphological surveys

7.3.1 General

The uncertainty of positioning a hydrometric boat for a hydrometric survey is similar to that for positioning a boat on a river cross section. The uncertainty includes errors caused by the accuracy of the positioning equipment, the accuracy of the distance measuring instruments, the accuracy of angle measuring instruments, and the drift of the boat during the survey or sampling period.

7.3.2 Global navigation satellite systems

Navigation systems that use GNSS are the most accurate method for positioning hydrometric boats for morphological surveys. The uncertainty is limited to absolute positioning based on GNSS signals and the drift of the hydrometric boat during depth measurements and bottom sampling. Formula (3) applies where u_{pos} is the uncertainty of the absolute position based on GNSS signals.

7.3.3 Electronic surveying instruments

The uncertainty of positioning hydrometric boats using electronic surveying instruments or total stations includes the uncertainty of the length of the baseline, the uncertainty of the distance from one end of the baseline to the hydrometric boat, the uncertainty of the angle from the baseline to the hydrometric boat, and the drift of the boat. This is expressed as:

$$U = \left[u_{d1}^2 + u_{d2}^2 + u_{\beta}^2 + u_{\text{dr}}^2 \right]^{\frac{1}{2}} \tag{6}$$

where

u_{d1} is the uncertainty of the length of the baseline;

u_{d2} is the uncertainty of the distance between one end of the baseline and the hydrometric boat;

u_{β} is the uncertainty of the angle measured from the baseline to the hydrometric boat;

u_{dr} is the uncertainty resulting from boat drift.

7.3.4 Triangulation method using theodolites

The uncertainty of positioning hydrometric boats using a baseline and two theodolites is affected by the uncertainty of the length of the baseline, the uncertainty of angles, α and β, and the drift of the boat. This is expressed as:

$$U = \left[u_{d}^2 + u_{\alpha}^2 + u_{\beta}^2 + u_{\text{dr}}^2 \right]^{\frac{1}{2}} \tag{7}$$

where

u_{d} is the uncertainty of the length of the baseline;

u_{α} is the uncertainty of the angle, α;

u_{β} is the uncertainty of the angle, β;

u_{dr} is the uncertainty resulting from boat drift.

Annex A
(informative)

Evaluation of uncertainty components

A.1 General

The uncertainty components described in Clause 7 are evaluated by a Type B evaluation of uncertainty, which is a method of evaluating uncertainty by means other than a statistical analysis of a series of observations (see ISO/TS 25377). The uncertainty is estimated by determining the upper and lower limits of a measurement such as the length of a cross section, and then applying a probability distribution. Rectangular and triangular probability distributions are the natural forms for human estimation of readings from devices such as tapes, rulers, and verniers. The choice between using a rectangular or triangular distribution is based on what seems most probable to the user, but a rectangular distribution should be used if the choice is not obvious.

The uncertainty based on a rectangular distribution is defined as:

$$U\left(d_{\text{mean}}\right) = \frac{1}{\sqrt{3}} \cdot \frac{\left(d_{\text{max}} - d_{\text{min}}\right)}{2} \tag{A.1}$$

The uncertainty based on a triangular distribution is defined as:

$$U\left(d_{\text{mean}}\right) = \frac{1}{\sqrt{6}} \cdot \frac{\left(d_{\text{max}} - d_{\text{min}}\right)}{2} \tag{A.2}$$

where

d_{max} is the discernible upper limit of the measurement;

d_{min} is the discernible lower limit of the measurement.

A.2 Uncertainty about the length of a tag line and interpolating the distance between markings

Tag lines are typically marked with beads at 5 m or 10 m intervals. If the discernible lower and upper limits of a point midway between beads at 300 m and 305 m are 302,3 and 302,7 m, respectively; applying a rectangular distribution yields an uncertainty of 0,115 m or 0,04 %.

If the discernible upper and lower limits of a point midway between beads at 10 m intervals at 300 m probably are 304,7 and 305,3 m, the uncertainty would be 0,173 m or 0,06 %.

A.3 Uncertainty resulting from cross section not being normal to the flow

An experienced hydrographer and instrument operator should be able to align a cross section within ± 5 degrees of normal. The error in a 300 m wide cross section that is 5 degrees from normal is

$$E_d = \frac{300\ \text{m}}{\cos 5^\circ} - 300\ \text{m} = 1{,}146\ \text{m} \qquad \text{(A.3)}$$

Applying a rectangular distribution with a lower discernible limit of 300 m and an upper discernible limit of 301,146 m yields an uncertainty of 0,331 m or 0,11 %.

A.4 Uncertainty of GNSS positioning

Positioning through triangulation with four or more GNSS signals is usually within 3 m [3]. The upper and lower discernible limits at 300 m would be 297 m and 303 m, respectively. Applying a rectangular distribution yields an uncertainty of 1,732 m or 0,58 %.

Positioning through triangulation with four or more GNSS signals and a line of sight reference station is accurate to within 15 cm [2]. The upper and lower discernible limits at 300 m would be 299,85 m and 300,15 m, respectively. Applying a rectangular distribution yields an uncertainty of 0,087 m or 0,029 %.

A.5 Uncertainty of EDMs

EDMs can measure distances very accurately, within 1,5 mm + 1,5 ppm at distances up to 1 500 m [4]. At 300 m, the uncertainty would be 0,001 m or 0,000 4 %.

A.6 Uncertainty of position because of boat drift

The hydrometric boat drifting off the cross section probably is the greatest source of uncertainty associated with positioning a boat for a depth and velocity measurement or a sediment sample. The drift will vary with wind conditions and macro-turbulence associated with water velocity and discharge. For measurements with low velocities and no wind, the boat may drift 1 m or 2 m. At 300 m, the lower and upper limits of the positioning would be 298,5 m and 301,5 m. The uncertainty would be 0,867 m or 0,29 %.

During windy conditions and high surface turbulence, the boat may drift off position by 10 m or more. At 300 m, the lower and upper limits of positioning would be 290 m and 310 m. The uncertainty would be 5,8 m or 1,9 %.

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