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Hydrometric determinations — Flow measurements in open channels using structures — Compound gauging structures

Déterminations hydrométriques — Mesure de débit des liquides dans les canaux découverts au moyen de structures — Structures de jaugeage hybrides

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 14139 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 2, *Notches, weirs and flumes*.

Annexes A to C form a normative part of this International Standard.

Hydrometric determinations — Flow measurements in open channels using structures — Compound gauging structures

1 Scope

This International Standard specifies the methods of measurement of flow in rivers and artificial channels, using any combination of standard weirs and/or flumes in a compound structure. For guidance on the selection of weirs and/or flumes, refer to ISO 8368. All structures can be operated in the modular flow range, but only a limited number of structures can be used in the drowned (non-modular) flow range (see clause 4). Compound weirs improve the quality of discharge measurements at low stages.

The characteristics of velocity distribution are described annex A.

Structures standardized for operation in the drowned (non-modular) flow range and the method of computation of flow are described in annex B.

Methods and examples of flow measurement calculations are given in annex C.

Compound flow-measuring structures without divide piers need in situ or model calibrations and are not covered by this International Standard.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 772:1996, *Hydrometric determinations — Vocabulary and symbols.*

ISO 1438-1:1980, *Water flow measurement in open channels using weirs and Venturi flumes — Part 1: Thin-plate weirs.*

ISO 3846:1989, *Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs.*

ISO 4359:1983, *Liquid flow measurement in open channels — Rectangular, trapezoidal and U-shaped flumes.*

ISO 4360:1984, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs.*

ISO 4362:1999, *Hydrometric determinations — Flow measurement in open channels using structures — Trapezoidal broad-crested weirs.*

ISO 4374:1990, *Liquid flow measurement in open channels — Round-nose horizontal broad-crested weirs.*

ISO 4377:1990, *Liquid flow measurement in open channels — Flat-V weirs.*

ISO/TR 5168:1998, *Measurement of fluid flow — Evaluation of uncertainties.*

ISO 8333:1985, *Liquid flow measurement in open channels by weirs and flumes — V-shaped broad-crested weirs.*

ISO 8368:1999, *Hydrometric determinations — Flow measurements in open channels using structures — Guidelines for selection of structure.*

ISO 9826:1992, *Measurement of liquid flow in open channels — Parshall and SANIIRI flumes.*

ISO 9827:1994, *Measurement of liquid flow in open channels by weirs and flumes — Streamlined triangular profile weirs.*

3 Terms, definitions and symbols

For the purposes of this International Standard, the terms and definitions given in ISO 772 apply. A full list of symbols with the corresponding units of measurement is given below.

Symbol		Units of measurement
A	area of cross-section of flow	m^2
b	crest width	m
B	width of approach channel	m
C_D	coefficient of discharge	non-dimensional
C_{dr}	drowned-flow reduction factor	non-dimensional
C_v	coefficient of approach velocity	non-dimensional
e	uncertainty in absolute magnitude	non-dimensional
g	acceleration due to gravity	m/s^2
h	gauged head	m
H	total head	m
h_p	crest-tapping pressure head	m
h_v	velocity approach head	m
L	length of flume throat or weir crest in direction of flow	m
n	number of measurements in a set	non-dimensional
p	height of flume invert or weir crest above mean bed level	m
Q	total discharge	m^3/s
Q_1, Q_2, Q_3	individual section discharges (in general Q_n)	m^3/s
Q_{mod}	total modular discharge	m^3/s
q	discharge per unit width	m^3/s
s_y	standard deviation of a set of measurements of quantity y	m
$s_{\bar{y}}$	estimated standard deviation of the mean of several readings of quantity y	m
$\bar{v}$	mean velocity at cross-section	m/s
$\bar{v}_a$	mean velocity in approach channel	m/s
X_Q	percentage uncertainty in total discharge	non-dimensional

$X_{Q,1}$, $X_{Q,2}$, $X_{Q,3}$ [1)]	percentage uncertainty in individual section discharges	non-dimensional
X_{tu}	percentage uncertainty in estimating upstream water levels or upstream total head levels	non-dimensional
X_{td}	percentage uncertainty in estimating downstream water levels or downstream total head levels	non-dimensional
X_y	percentage uncertainty in quantity y	non-dimensional
α	Coriolis energy coefficient	non-dimensional
Δ	difference in weir-crest levels	m
δ	boundary layer displacement thickness	m

Suffixes

1	denotes upstream value
2	denotes downstream value

Superscripts

G	refers to gauging section
T	refers to crest-tapping section
S	refers to any other section

4 Characteristics of compound gauging structures

A compound gauging structure as covered by this International Standard comprises two or more individual structures, operated in parallel and separated by divide piers.

The individual structures, which can be used in a compound gauging weir, are specified in ISO 1438-1, ISO 3846, ISO 4359, ISO 4360, ISO 4362, ISO 4374, ISO 4377, ISO 8333, ISO 9826 and ISO 9827. The structures described in ISO 4360, ISO 4362, ISO 4377, ISO 8333, ISO 9826 and ISO 9827 may be used in the drowned flow range (see annex B.1).

In the modular flow range, discharges depend solely on upstream water levels, and a single measurement of upstream head is required. In the drowned flow range, discharges depend on both upstream and downstream water levels, and two independent head measurements are required. These are:

a) the upstream head; and either

b) the head measured in the crest-tapping for a triangular profile weir (two dimensional or flat-V forms);

c) the head measured within the throat of a Parshall flume; or

d) the head measured in the tailwater for the other structures.

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1) In cases where the subscript of a symbol also contains a subscript, it is house style to write the second subscript on the same line, after a comma.

Thus X_{Q_1} is written $X_{Q,1}$.

The flow conditions considered are limited to steady or slowly changing flows. The essentially parallel flow through the compound structure is ensured by the use of divide piers. The flow is separated by the divide piers into each individual weir or flume. The discharge can be determined through each individual section by a single upstream head measurement, at one section only, in the case of modular flow or by two independent head measurements, at one section only, as required for drowned flow conditions. The summation of the discharges through each of the sections provides the measurement of total flow within the channel.

5 Installation

5.1 Selection of site

A preliminary survey shall be made of the physical and hydraulic features of the proposed site to check that it conforms (or may be made to conform) to the requirements necessary for measurement using the weir.

Particular attention shall be paid to the following features in selecting the site of the weir:

a) the availability of an adequate length of channel of regular cross-section;

b) the existing velocity distribution;

c) the avoidance of channels having gradients greater than 0,4 %;

d) the effects of any increased upstream water level due to the flow-measuring structure;

e) the conditions downstream, including such influences as tides, confluence with other streams, sluice-gates, mill dams and other controlling features that might cause drowning;

f) the impermeability of the ground on which the structure is to be founded, and the necessity for piling, grouting or other sealing in river installations;

g) the necessity for flood banks to confine the maximum discharge to the channel;

h) the stability of the banks, and the necessity for trimming and/or revetment in natural channels;

i) the clearance of rocks or boulders from the bed of the approach channel;

j) the effects of wind.

NOTE 1 Wind can have a considerable effect on the flow in a river or over a weir, especially if these latter are wide and the head is small and the prevailing wind is in a transverse direction.

If the site does not possess the characteristics required for satisfactory measurements, it shall be rejected unless suitable improvements are practicable.

If a survey of a stream shows that the existing velocity distribution is regular, then it should be assumed that the velocity distribution will remain satisfactory after the weir has been built.

If the existing velocity distribution is irregular and no other site for a gauge is feasible, due consideration shall be given to checking the distribution after the weir has been installed and to improving it, if necessary.

NOTE 2 Several methods are available for obtaining more precise indications of irregular velocity distribution: velocity rods, floats or concentrations of dye can be used in small channels, the latter being useful in checking conditions at the bottom of the channel. A complete and quantitative assessment of velocity distribution may be made by means of a current meter.

NOTE 3 After installation, the velocity profiles will always be improved by the increased depth of water approaching the compound weir.

5.2 Installation conditions

5.2.1 General

The complete measuring installation consists of an approach channel, a flow-measuring structure and a downstream channel. The parameters of each of these three components affect the overall accuracy of the measurements.

Installation requirements include such features as weir finish, the cross-sectional shape of the channel, channel roughness and the influence of control devices upstream or downstream of the gauging structure.

The distribution and direction of velocity have an important influence on the performance of a weir, these factors being determined by the features mentioned in this subclause.

5.2.2 Approach channel

For all installations, the flow in the approach channel shall be smooth, free from disturbance and shall have a velocity distribution as normal as possible over the cross-sectional area (see annex A); this can usually be verified by inspection or measurement. In the case of natural streams or rivers, this flow can only be attained by having a long, straight approach channel free from projections into the flow. Unless otherwise specified in the appropriate clauses of this International Standard, the approach channel shall comply with the general requirements outlined in this subclause.

The altered flow conditions due to the construction of the weir may have the effect of building up shoals of debris upstream of the structure, which in time may affect the flow conditions. The likely consequential changes in the water level should be taken into account in the design of gauging stations.

In an artificial channel, the cross-section shall be uniform and the channel shall be straight for a length equal to at least five times its width, and more if attainable.

In a natural stream or river, the cross-section shall be reasonably uniform and the channel shall be straight for such a length as to ensure regular velocity distribution.

If the entry to the approach channel is through a bend or if the flow is discharged into the channel through a conduit of smaller cross-section or at an angle, then a longer length of straight approach channel is required to achieve a regular velocity distribution.

Baffles shall not be installed closer to the points of measurement than five times the maximum head to be measured.

Under certain conditions, a standing wave may occur upstream of the gauging device, for example if the approach channel is steep. Provided this wave is at a distance of no less than 30 times the maximum head upstream, flow measurement is feasible, subject to confirmation that a regular velocity distribution exists at the gauging station.

If a standing wave occurs within this distance, the approach conditions and/or gauging device shall be modified.

Means of ensuring that the baffles are at all times free of debris both on and below the water surface should be provided.

5.2.3 Flow-measuring structure

The structure shall be rigid, watertight and capable of withstanding flow conditions without distortion or fracture. It shall be at right angles to the direction of flow and shall have the dimensions specified in the relevant International Standard(s) for the type of flow-measuring structure(s) chosen.

For the purposes of this International Standard, a compound flow-measuring structure consists of a series of individual weirs or flumes, which are disposed across the width of an open channel. The individual sections of the compound structure shall be separated by divide piers such that each section can be treated as a simple weir or flume, thus minimizing three-dimensional flow conditions. The computation of discharge for individual sections can therefore be based on established discharge equations (see the references in annex B).

The divide piers that separate individual sections of the compound structure shall be at least 0,3 m thick to avoid sharp curvatures at their upstream noses (cutwaters), which can be semi-circular or semi-elliptical.

To minimize cross flows at the cutwaters of the divide piers and subsequent flow separation, the difference in levels between adjacent crests (weirs) or inverts (flumes) shall not exceed 0,5 m.

NOTE 1 Flow conditions at and near the cutwaters of the divide piers will be improved if the upstream bed levels bear a similar relationship to crest or invert levels at each individual section of the compound structure (see Figure B.1). This minimizes the variations in velocity across the width of the approach channel.

The compound flow-measuring structure shall be capable of withstanding flood flow conditions without damage from outflanking or from downstream erosion. The structure and the immediate approach channel can be constructed of concrete with a smooth cement finish or surfaced with a smooth non-corrodible material.

NOTE 2 In laboratory installations, the finish should be equivalent to rolled sheet metal or planed, sanded and painted timber.

The surface finish is particularly important near the crest or throat invert, but can be relaxed a distance along the profile of 0,5 H_{max} upstream and downstream of the crest or throat. Details of tolerances for the finish and alignment of individual weirs or flumes are given in the appropriate International Standard.

A typical design for a compound flow-measuring structure is shown in Figure B.1.

NOTE 3 The lengths of the divide piers are not crucial but they should extend preferably from the upstream recording section to the downstream limit of individual weirs or flumes.

The height of the divide piers should normally be the same as that of the vertical side walls. If less, then errors will arise in the computation of discharge when water levels exceed the height of the divide piers. These errors will depend on the dimensions of the compound structure and the actual height of the divide piers.

5.2.4 Downstream conditions

Conditions downstream of the structure are important in that they control the tailwater level. This level is one of the factors that determine whether modular or drowned flow conditions will occur at the weir. It is essential, therefore, to calculate or observe stage-discharge relations covering the full discharge range, and to make decisions regarding the type of weir and its required geometry in the light of this evidence.

When making these calculations or observations particular care shall be taken to ensure that influences that may be periodic or seasonal such as tides shall be taken into account.

NOTE Confluences with other streams, sluice-gates, mill dams and other features such as weed growth may also influence tailwater levels.

If the downstream channel is erodible, the extent of protective works necessary to dissipate the additional energy generated by the raised water level upstream of the structure shall be taken into account in the assessment of the site.

6 Maintenance

Maintenance of the flow-measuring structure and the approach channel is important to ensure accurate continuous measurements.

It is essential that the approach channel to weirs be kept clean and free from silt and vegetation as far as practicable, and for at least the distance specified in 5.2.2. The stilling well and the entry from the approach channel shall also be kept clean and free from deposits.

The weir structure shall be kept clean and free from clinging debris and care shall be taken in the process of cleaning to avoid damage to the crest.

NOTE The presence of divide piers between weir sections will inevitably increase maintenance requirements for the structure, particularly if floating debris is prevalent.

7 Measurement of head

7.1 General

The head upstream of the flow-measuring structure may be measured by a hook-gauge, point-gauge or staff-gauge where spot measurements are required, or by a recording-gauge where a continuous record is required; in many cases it is necessary to measure head in a separate stilling well, in particular to measure the crest-tapping head. Stilling wells also eliminate surface turbulence which is necessary for tailwater head measurement.

The discharges given by the working equation in the appropriate standard for the particular structure are volumetric figures, and the liquid density does not affect the volumetric discharge for a given head provided that the operative head is gauged in liquid of identical density. If the gauging is carried out in a separate well, a correction for the difference in density may be necessary if the temperature in the well is significantly different from that of the flowing liquid. However, it is assumed in this International Standard that the densities are equal.

7.2 Stilling well

It is usual to measure the upstream head in a stilling well to reduce the effects of water surface irregularities.

NOTE 1 When this is done, it is also desirable to measure the head in the approach channel periodically.

Where the structure is designed to operate in the drowned flow range a gauge well is required to measure the downstream head as follows:

— for triangular profile weirs the piezometric head developed within the separation pocket immediately downstream of the crest;

— for the other weirs the downstream water level in the downstream channel section according to the appropriate standard.

The gauge well shall be vertical and of sufficient height and depth to cover the full range of water levels and shall have a minimum height of 0,6 m above the maximum water level expected. The gauge well shall be connected to the appropriate head measurement position by means of a pipe or a slot.

Both the well and the connecting pipe shall be watertight and, where the well is provided for the accommodation of the float of a level recorder, it shall be of adequate size and depth to give clearance around and beneath the float at all stages. The float shall be no nearer than 0,075 m to the wall of the well.

The pipe shall have its invert no less than 0,06 m below the lowest level to be gauged.

The pipe connection to the upstream head measurement position shall terminate flush with the boundary of the approach channel and preferably at right angles thereto. The approach channel boundary shall be plain and smooth (equivalent to carefully finished concrete) within a distance of 10 times the diameter of the pipe from the centreline of the connection. A pipe that is oblique to the wall is acceptable only if it is fitted with a removable cap or plate, and set flush with the wall, through which a number of holes are drilled. The edges of these holes shall not be rounded or burred.

Where the individual section of the compound structure is a two-dimensional triangular profile weir the pipe connection to the head measurement position for the separation pocket head shall be as given in ISO 4360.

Where the individual section of the compound structure is a flat-V weir, the pipe connection to the head measurement position for the separation pocket head shall be as given in ISO 4377.

Adequate additional depth shall be provided in the well to avoid the danger of floats grounding either on the bottom or on any accumulation of silt or debris.

The diameter of the connecting pipe or width of slot shall be sufficient to permit the water level in the well to follow the rise and fall of head without appreciable delay, but shall be as small as possible, consistent with ease of maintenance, to damp out oscillations due to short period waves.

NOTE 2 No firm rule can be laid down for determining the size of the connecting pipe, because this is dependent on the circumstances of the particular installation, for example whether the site is exposed and thus subject to waves and whether a large diameter well is required to house the floats of recorders.

It is preferable to make the connection too large rather than too small, because a restriction can easily be added later if short period waves are not adequately damped out. A 100 mm diameter pipe is usually suitable for a flow measurement in the field, as compared with the 3 mm diameter pipe that is appropriate for precision head measurement with steady flows in the laboratory.

7.3 Zero setting

Accurate initial setting of the zeros of the head measuring devices with reference to the level of the crest, or invert, and regular checking of these settings thereafter, is essential if overall accuracy is to be attained.

A means of checking the zero setting of the head-measuring devices shall be provided, consisting of a datum related to the level of the weir.

A zero check based on the level of the water when the flow ceases is liable to serious errors from surface tension effects and shall not be used.

NOTE As the size of the weir and the head on it reduces, small errors in construction and in the zero setting and reading of the head-measuring device become of greater importance.

7.4 Location of head measurement section(s)

The upstream head shall be measured at any one of the individual sections of the compound structure but preferably at the section with the lowest crest or invert. The tapping shall be in the vertical side wall if the individual section is adjacent to the bank, or in the divide pier if the individual section is mid-stream. In this latter case the divide piers shall extend at least H_{max} upstream of the head measurement position.

The distance of the measurement section from crest or invert is usually expressed as a multiple of the maximum total head with a value appropriate to the individual section of three to four. For precise locations for each type of structure, see the appropriate International Standard.

The presence of divide piers is not considered to have a significant influence, and the position of the head measurement section need only satisfy the requirements noted in this subclause.

If a triangular profile or flat-V weir is used as one of the individual sections of the compound structure, and it is designed to operate in the non-modular (drowned) flow range, then a separate crest tapping and associated gauge well shall be provided (see ISO 4360 and ISO 4377).

8 Computation of discharge

8.1 Modular flow conditions

Modular flow calibrations are based on measurements of upstream water levels. Where a single (non-compound) structure is used, the recorded water level is used directly in the computation of discharge. However, it is not usually economical to measure water levels upstream of each individual section of a compound weir, and hence it is necessary to make assumptions about the relationships between flow conditions at the various sections when calculating the total flow.

Research has shown that the total head level can be assumed constant over the full width of a compound flow-measuring structure and that it can be obtained by adding to the observed water level the velocity head appropriate to the individual section at which the water level is observed. Thus the basis of the method of computing the total discharge over a compound structure is to calculate the total head level at the individual section at which the water level is measured, as if it were a simple non-compound structure, and to use the same value of total head level to calculate individual discharges at other sections. Successive approximation or coefficient of velocity techniques are applied at the section of the structure where the water level is recorded to convert gauged to total heads. Discharge equations in terms of total heads are used at other sections of the compound structure and no conversions are required. An example calculation is given in annex C.

8.2 Non-modular (drowned) flow conditions

When a compound structure is designed to operate in the non-modular flow range, a triangular profile or flat-V weir with a crest tapping shall be used in those sections of the compound weir that are likely to drown. For trapezoidal profile weirs, Parshall flumes, streamlined triangular weirs and V-shaped broad-crested weirs, only one gauge well is required in the downstream channel.

Upstream total heads are determined as for the modular flow case but discharges at those individual sections of the compound structure that are drowned are obtained by considering both the upstream total head and the crest-tapping pressure or downstream water level. An example calculation is given in annex C.

9 Errors in flow measurement

9.1 General

The total uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. The assessment of these contributions to the total uncertainty will indicate whether the rate of flow can be measured with sufficient accuracy for the intended purpose. This clause is intended to provide sufficient information for the user of this International Standard to estimate the uncertainties of measurements of discharges.

The error is the difference between the true rate of flow and that calculated in accordance with the equations in the appropriate standard for the particular structure used for calibrating the flow-measuring structure (which is assumed to be constructed and installed in accordance with this International Standard). The term 'uncertainty' is used here to denote the deviation from the true rate of flow within which the measured flow is expected to lie some 19 times out of 20 (with 95 % confidence limits).

9.2 Sources of error

The sources of error in the discharge measurement for each individual section of the compound structure are as given in the errors sections of the International Standards relating to the appropriate type of structure (see B.1). Additional errors arise due to the method used for estimating water levels or total head levels at individual sections, when (as is usual) these are not measured separately at each section. Available evidence is limited, but it suggests that the percentage uncertainty in discharge, X_{tu}, associated with transposing upstream water levels or total head levels is random, with a magnitude within the range of $\pm$ 5 %. In particular cases, more reliable estimates can be made of this value by making field or laboratory observations. For cases involving drowned flow, little information is available about the possible value of X_{td} the additional uncertainty in discharge associated with transposing downstream water levels or total head levels, which is likely to be of the order of $\pm$ 10 %.

9.3 Kinds of error

9.3.1 Errors can be classified as random or systematic, the former affecting the reproducibility (precision) of measurement and the latter affecting its true accuracy.

