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Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs

Mesure de débit des liquides dans les canaux découverts au moyen de déversoirs et de canaux-jaugeurs — Déversoirs rectangulaires à seuil épais

Reference number
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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.

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. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 3846 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

This second edition cancels and replaces the first edition (ISO 3846 : 1977), of which it constitutes a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs

1 Scope and field of application

This International Standard lays down requirements for the use of rectangular broad-crested weirs for the measurement of flow of clear water in open channels under free flow conditions.

Annexes A, B and C form an integral part of this International Standard.

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 1100-1, *Liquid flow measurement in open channels — Part 1: Establishment and operation of a gauging station.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO 8368, *Liquid flow measurement in open channels — Guidelines for the selection of flow gauging structures.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 772 apply. The symbols used in this International Standard are given in annex A.

4 Installation

The conditions regarding the preliminary survey, selection of site, installation, approach channel, maintenance, measurement of the head, and stilling or float wells which are generally necessary for flow measurement are given in 4.1, 4.2, clause 5 and clause 6. The particular requirements for the rectangular broad-crested weir are given separately in clause 7.

4.1 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 flow measurement by the weir.

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

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

b) the existing velocity distribution;

c) the avoidance of a steep channel, if possible (see 4.2.2);

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

e) the conditions downstream, including influences such as tides, confluences with other streams, sluice gates, mill dams and other controlling features, which 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 means of controlling seepage;

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, which can have a considerable effect on the flow in a river, or over a weir, especially when the river or weir is wide and the head is small and when the prevailing wind is in a transverse direction.

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

If an inspection of the stream shows that the existing velocity distribution is regular, then it may be assumed that the velocity distribution will remain satisfactory after the construction of the weir.

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 installation of the weir and to improving it if necessary.

Several methods are available for obtaining a more precise indication of irregular velocity distribution. These include velocity rods, floats or concentrations of dye, which can be used in small channels; the last is useful to check the conditions at the bottom of the channel. A complete and quantitative assessment of the velocity distribution may be made by means of a current-meter. More information about the use of current-meters is given in ISO 748.

4.2 Installation conditions

4.2.1 General requirements

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

Installation requirements include features such as the surface finish of the weir, the cross-sectional shape of the channel, the 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 above.

Once a weir has been installed, the user shall prevent any changes which could affect the discharge characteristics.

4.2.2 The approach channel

On all installations the flow in the approach channel shall be smooth, free from disturbance and have a velocity distribution as normal as possible over the cross-sectional area. This can usually be verified by inspection or measurement. In the case of natural streams or rivers, this can only be attained by having a long straight approach channel free from projections into the flow. The following general requirements shall be complied with.

a) The altered flow conditions owing to the construction of the weir might cause a build-up of shoals of debris upstream of the structure, which in time might affect the flow conditions. The likely consequential changes in the water level shall be taken into account in the design of gauging stations.

b) In an artificial channel the cross-section shall be uniform and the channel shall be straight for a length equal to at least 10 times its water-surface width.

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

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

e) Baffles shall not be installed closer to the points of measurement than a distance 10 times the maximum head to be measured.

f) Under certain conditions, a standing wave may occur upstream of the gauging device, e.g. if the approach channel is steep. Provided that this wave is at a distance of not 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 and that the Froude number in this section is less than 0,3.

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

4.2.3 The measuring structure

The structure shall be rigid and watertight and capable of withstanding flood flow conditions without distortion or fracture. It shall be at right angles to the direction of flow and shall conform to the dimensions given in the relevant clauses.

4.2.4 Downstream of the structure

The nappe shall not be ventilated in order to maintain water underneath the nappe when it separates from the crest, particularly for high values of h_1/L. This condition can only be met if the downstream channel is rectangular and of the same width as the weir for a distance equal to twice the maximum head downstream of the downstream face of the weir.

The channel further downstream of the structure is usually of no importance as such provided that the weir has been designed to ensure that the flow is modular under all operating conditions.

However, the water level may be raised sufficiently to drown the weir if the altered flow conditions due to the construction of the weir cause the build-up of shoals of debris immediately downstream of the structure or if river works are carried out at a later date.

Any accumulation of debris downstream of the structure shall therefore be removed.

5 Maintenance — General requirements

Maintenance of the measuring structure and the approach channel is important to secure 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 for at least the distance specified in 4.2.2. The float well and the entry from the approach channel shall also be kept clean and free from deposits.

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

6 Measurement of head(s)

6.1 General requirements

The head upstream of the 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 preferable to measure heads in a separate stilling well to reduce the effects of surface irregularities.

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

It shall, however, be ensured that the gauge is not located in a pocket or still pool, but that it measures the piezometric head.

6.2 Stilling or float well

Where provided, the stilling well shall be vertical and shall extend at least 0,6 m above the maximum estimated water level to be recorded in the well.

It shall be connected to the approach channel by an inlet pipe, or slot, large enough to permit the water in the well to follow the rise and fall of the head without significant delay. The level of the inlet pipe shall be at least 0,1 m below the crest level.

The connecting pipe or slot shall, however, be as small as possible consistent with ease of maintenance. Alternatively the connecting pipe or slot shall be fitted with a constriction to damp out oscillations due to short amplitude waves.

The well and the connecting pipe or slot shall be watertight. The well shall be of adequate diameter and depth to accommodate the float of a level recorder, if used.

The well shall also be deep enough to accommodate any sediment, which may enter, without the float grounding. The float well arrangement may include an intermediate chamber, between the stilling well and the approach channel, of similar proportions to those of the stilling well to enable sediment to settle out. For ease of maintenance, the pipework may be fitted with valves.

More detailed information on the stilling well may be obtained from ISO 1100-1.

6.3 Zero setting

A means of checking the zero setting of the head measuring device 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.

With decreasing size of the weir and the head, small errors in construction and in the zero setting and reading of the head measuring device become of greater importance.

7 Rectangular broad-crested weirs

7.1 Specification for the standard weir

The crest of the standard weir shall be a smooth, horizontal, rectangular plane surface (in these specifications a "smooth" surface shall have a surface finish equivalent to that of rolled sheet metal). The width of the crest perpendicular to the direction of flow shall be equal to the width of the channel in which the weir is located. The upstream and downstream end faces of the weir shall be smooth, plane surfaces and they shall be perpendicular to the sides and the bottom of the channel in which the weir is located. The upstream face, in particular, shall form a sharp right-angle corner at its intersection with the plane of the crest.

If the upstream corner of the weir is slightly rounded, the discharge coefficient can increase significantly.

A typical sketch of the weir is shown in figure 1.

7.2 Location of the head gauge section

Piezometers or a point-gauge station for the measurement of the head on the weir shall be located at a sufficient distance upstream from the weir to avoid the region of surface drawdown. They (or it) shall, however, be close enough to the weir for the energy loss between the section of the measurement and the control section on the weir to be negligible. It is recommended that the head measurement section be located at a distance equal to three to four times the maximum head (i.e. $3h_{1,\,max}$ to $4h_{1,\,max}$) upstream from the upstream face of the weir.

7.3 Provision for modular flow

Flow over a rectangular broad-crested weir is not affected by tailwater levels if the crest level is chosen such that the submergence ratio does not exceed the modular limit. The modular limit is given in annex B.

8 Discharge relationships

8.1 Discharge equation

The equation of discharge is based on the use of a gauged head:

$$Q = \left(\frac{2}{3}\right)^{3/2} g^{1/2} b C h_1^{3/2} \qquad \ldots (1)$$

where

Q is the discharge;

g is the acceleration due to gravity;

b is the width of the weir perpendicular to the direction of flow;

C is the gauged head discharge coefficient;

h_1 is the upstream gauged head related to the crest elevation.

8.2 Discharge coefficient

The gauged head discharge coefficient C is given in figure 2 and the table as a function of h_1/L and h_1/p, where L is the length of the weir in the direction of flow and p is the height of the weir with respect to the bottom of the approach channel.

Intermediate values of C may be obtained by linear interpolation.

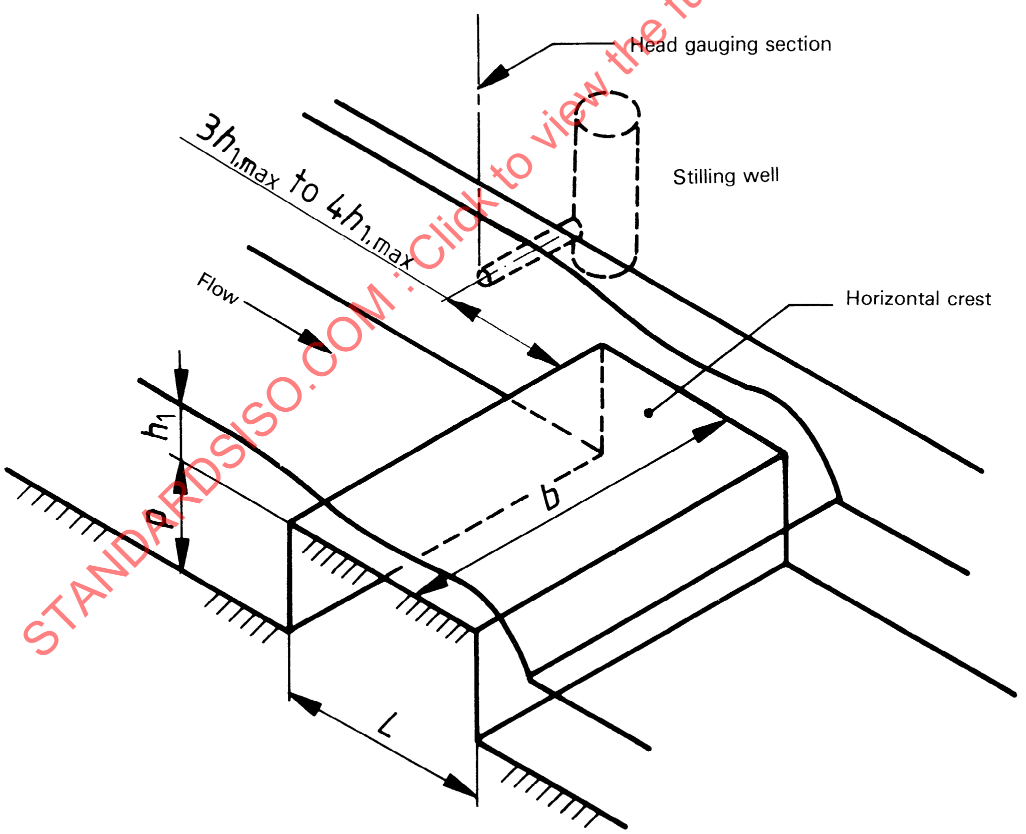
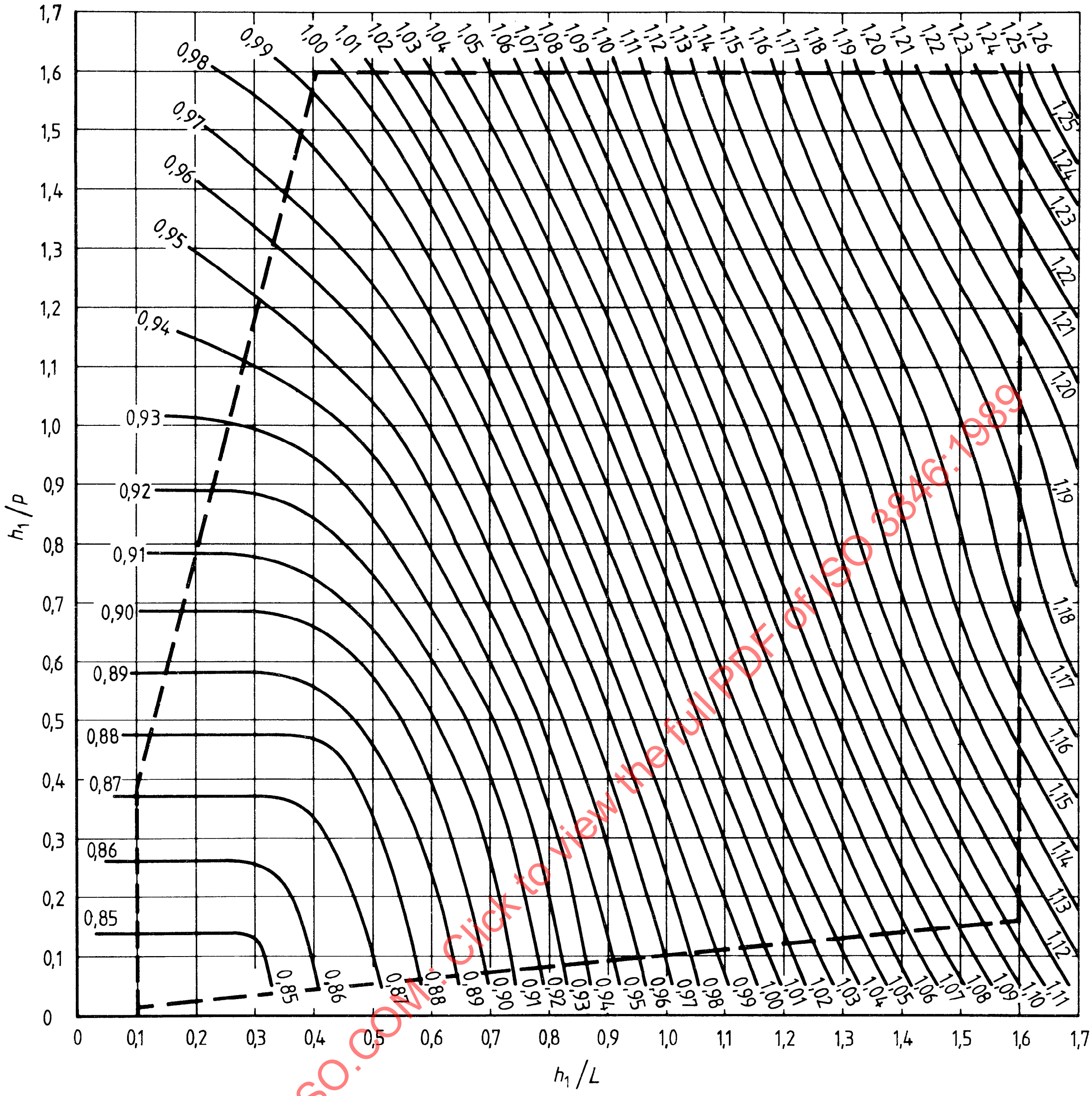


Figure 1 — Rectangular broad-crested weir



NOTE — For the meaning of the dashed lines, see 8.3.

Figure 2 — The coefficient of discharge C in terms of h_1/p and h_1/L

Table — Gauged head discharge coefficients

h_1/p	C for the following values of h_1/L																	
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8
0,1	0,850	0,850	0,850	0,861	0,870	0,885	0,893	0,925	0,948	0,971	0,993	1,016	1,039	1,062	1,085	1,106	1,130	1,148
0,2	0,855	0,855	0,855	0,864	0,874	0,888	0,907	0,930	0,954	0,977	1,001	1,026	1,050	1,074	1,096	1,120	1,142	1,159
0,3	0,864	0,864	0,864	0,868	0,879	0,894	0,913	0,936	0,961	0,986	1,011	1,037	1,061	1,085	1,110	1,132	1,152	1,169
0,4	0,873	0,873	0,873	0,874	0,885	0,901	0,920	0,945	0,969	0,995	1,021	1,047	1,072	1,097	1,122	1,144	1,163	1,180
0,5	0,882	0,882	0,882	0,883	0,894	0,909	0,929	0,954	0,978	1,005	1,032	1,057	1,083	1,109	1,133	1,154	1,173	1,188
0,6	0,892	0,892	0,892	0,894	0,904	0,920	0,941	0,964	0,990	1,016	1,043	1,067	1,094	1,120	1,143	1,164	1,182	1,196
0,7	0,901	0,901	0,901	0,906	0,916	0,932	0,952	0,975	1,000	1,026	1,052	1,077	1,104	1,129	1,152	1,171	1,188	1,203
0,8	0,911	0,911	0,912	0,916	0,926	0,942	0,962	0,985	1,010	1,036	1,062	1,086	1,112	1,136	1,158	1,176	1,194	1,209
0,9	0,921	0,921	0,922	0,926	0,936	0,952	0,972	0,996	1,021	1,046	1,072	1,096	1,120	1,143	1,163	1,181	1,199	1,214
1,0	0,929	0,929	0,931	0,936	0,946	0,962	0,982	1,006	1,031	1,056	1,081	1,106	1,128	1,150	1,169	1,187	1,204	1,220
1,1	0,935	0,937	0,940	0,946	0,956	0,972	0,993	1,017	1,042	1,066	1,092	1,115	1,138	1,159	1,177	1,195	1,212	1,228
1,2	0,941	0,944	0,949	0,956	0,966	0,982	1,004	1,028	1,053	1,077	1,103	1,126	1,148	1,168	1,186	1,204	1,222	1,237
1,3	0,946	0,951	0,957	0,966	0,977	0,993	1,016	1,040	1,063	1,089	1,114	1,136	1,158	1,178	1,196	1,214	1,232	1,250
1,4	0,953	0,959	0,967	0,975	0,986	1,005	1,028	1,050	1,075	1,101	1,124	1,147	1,168	1,187	1,206	1,224	1,244	1,266
1,5	0,961	0,968	0,975	0,984	0,997	1,018	1,040	1,061	1,086	1,111	1,134	1,156	1,176	1,196	1,215	1,235	1,258	1,277
1,6	0,972	0,978	0,985	0,994	1,010	1,030	1,050	1,073	1,096	1,119	1,142	1,164	1,184	1,204	1,224	1,245	1,268	1,289

NOTE — The recommended limits of application are those values which appear within the bold rules.

The coefficient of discharge C has a constant value of 0,85 in the range $0,1 \leqslant h_1/L \leqslant 0,3$ and for $h_1/p < 0,15$.

On the basis of the variation in C with h_1/L, distinction can be made between the following types of flow (see figure 3).

a) Broad-crested flow, $0,1 \leqslant h_1/L < 0,4$: the flow across the weir is parallel to the crest for a certain portion.

b) Short-crested flow, $0,4 \leqslant h_1/L \leqslant 1,6$: the flow is totally curvilinear.

NOTE — The distinction between the gauged head discharge coefficient and the total head discharge coefficient is explained in annex C.

8.3 Limitations

The following general limitations are recommended.

To avoid surface tension and viscous effects, $h_1 \geqslant 0,06$ m, $b \geqslant 0,30$ m and $p \geqslant 0,15$ m.

There are no calibration data available beyond the practical limits $0,1 < L/p < 4,0$ and $0,1 < h_1/L < 1,6$.

To avoid unstable water levels, $h_1/p < 1,6$.

These limitations have been indicated on figure 2 by dashed lines.

8.4 Accuracy

8.4.1 The relative accuracy of flow measurements made with these weirs depends on the accuracy of the head measurement and the measurements of the dimensions of the weir, and the accuracy of the coefficient as it applies to the weir in use.

8.4.2 With reasonable care and skill in the construction and installation of these weirs, the systematic uncertainty (in per cent) in the coefficient of discharge may be deduced from

$$X''_C = \pm [1,5 + (h_1/p)^2]$$

The random uncertainty, as derived from the research used to determine the coefficient, may be taken as $X'_C = \pm 1$ % in this case.

8.4.3 The method by which the uncertainties in the coefficients shall be combined with other sources of errors is given in clause 9.

9 Uncertainties in flow measurement

This clause is intended to provide sufficient information for the user of this International Standard to estimate the uncertainty in a measurement of discharge.

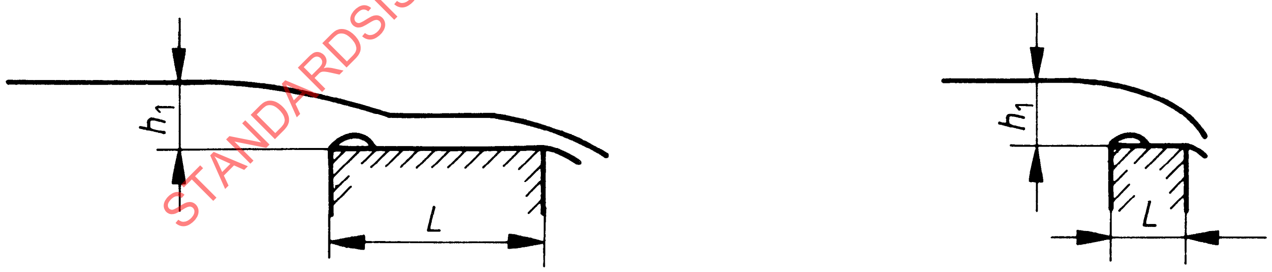
9.1 General

9.1.1 Reference should be made to ISO 5168.

9.1.2 The total uncertainty in any flow measurement can be estimated if the uncertainties from various sources are combined. In general, these contributions to the total uncertainty may be assessed and will indicate whether the discharge can be measured with sufficient accuracy for the purpose in hand.

9.1.3 The error may be defined as the difference between the actual rate of flow and that calculated in accordance with the equation for the weir, which is assumed to be constructed and installed in accordance with this International Standard.

The term "uncertainty" will be used to denote the deviation from the true rate of flow within which the measurement is expected to lie some 19 times out of 20 (for 95 % confidence limits).



a) Broad-crested weir
$0,1 \leqslant h_1/L < 0,4$

b) Short-crested weir
$0,4 \leqslant h_1/L \leqslant 1,6$

Figure 3 — Flow patterns over rectangular broad- and short-crested weirs

9.2 Sources of error

9.2.1 The sources of error in the discharge measurement may be identified by considering the discharge equation

$$Q = \left(\frac{2}{3}\right)^{3/2} g^{1/2} b C h_1^{3/2}$$

where

$\left(\frac{2}{3}\right)^{3/2}$ is a numerical constant not subject to error;

g is the acceleration due to gravity (this varies from place to place but, in general, the variation is small enough to be neglected in flow measurements).

9.2.2 The only sources of error which need to be considered further are

a) the discharge coefficient C (numerical estimates of the uncertainty in C are given in 8.4);

b) the dimensional measurement of the structure, e.g. the width b of the weir;

c) the measured head, h_1.

9.2.3 The uncertainties in b and h must be estimated by the user. The uncertainty in their dimensions will depend on the accuracy to which the device as constructed can be measured; in practice this uncertainty may prove to be insignificant in comparison with other uncertainties. The uncertainty in the head will depend on the accuracy of the head measuring device, the determination of the gauge zero, and the technique used. This uncertainty may be small if a vernier or micrometer instrument is used, with a zero determination of comparable precision.

9.3 Types of error

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

9.3.2 The standard deviation of a set of n measurements of a quantity Y under steady conditions may be estimated using the following equation:

$$s_Y = \left[\frac{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}{n - 1}\right]^{1/2}$$

where $\overline{Y}$ is the arithmetic mean of the n measurements.

The standard deviation of the mean is then given by

$$s_{\overline{Y}} = \frac{s_Y}{\sqrt{n}}$$

and the uncertainty in the mean is $2\,s_{\overline{Y}}$ (at the 95 % confidence level). This uncertainty is the contribution of random errors in any series of experimental measurements to the total uncertainty.

NOTE — The factor of 2 assumes that n is large. For $n = 6$ the factor should be 2,6; $n = 8$ requires a factor of 2,4; $n = 10$ requires a factor of 2,3; $n = 15$ requires a factor of 2,1.

9.3.3 A measurement may also be subject to systematic error; the mean of very many measured values would thus still differ from the true value of the quantity being measured. For example, an error in setting the zero of a water-level gauge to the crest level produces a systematic difference between the true mean of the measured head and the actual value. A repetition of the measurement does not eliminate systematic errors; the actual value can only be determined by an independent measurement which is known to be more accurate.

9.4 Uncertainties in coefficient values

9.4.1 The errors in this category are both random and systematic.

9.4.2 The values of the discharge coefficients C quoted in this International Standard are based on an appraisal of experiments, which may be presumed to have been carefully carried out, with sufficient repetition of the readings to ensure adequate precision. However, when measurements are made on other similar installations, systematic discrepancies between coefficients of discharge may well occur, which may be attributed to variations in the surface finish of the device, its installation, the approach conditions, the scale effect between model and site structures, etc.

9.4.3 The uncertainties in the discharge coefficients, quoted in 8.4, are calculated on the basis of the deviation of the experimental data (from various sources) from the theoretical equations given. The suggested uncertainty values thus represent the accumulation of evidence and experience available.

9.5 Uncertainties in measurements made by the user

9.5.1 Both random and systematic errors will occur in measurements made by the user.

9.5.2 Since neither the methods of measurement nor the way in which they are to be made is specified, no numerical values for uncertainties in this category can be given; they shall be estimated by the user. For example, consideration of the method of measurement of the width of the weir should permit the user to determine the uncertainty in this quantity.

9.5.3 The uncertainty in the value of the gauged head shall be determined from an assessment of the separate sources of uncertainty, e.g. the uncertaintites in the zero setting, the prevailing wind characteristics, the gauge sensitivity and the backlash in the indicating equipment (where appropriate), and the residual uncertainty in the mean of a series of measurements (where appropriate).

9.6 Combination of uncertainties

9.6.1 The total systematic or random uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties. Provided that the contributing uncertainties are independant, small and numerous, they may be combined together to give an overall random (or systematic) uncertainty at the 95 % confidence level.

9.6.2 All sources contributing uncertainties will have both random and systematic components. However, in some cases either the random or the systematic component may be predominant and the other component can be neglected by comparison.

9.6.3 Because of the different nature of random and systematic uncertainties, they should not normally be combined with each other. However, with the proviso of 9.6.1, random uncertainties from different sources may be combined together by the root-sum-of-squares rule; systematic uncertainties from different sources may be similarly combined.

9.6.4 The percentage random uncertainty X'_Q in the rate of flow may be calculated from the following equation:

$$X'_Q = \pm \sqrt{X'^2_C + X'^2_b + 1{,}5^2 X'^2_{h_1}}$$

where

X'_C is the percentage random uncertainty in C;

X'_b is the percentage random uncertainty in b;

X'_{h_1} is the percentage random uncertainty in h_1.

In the above

$$X'_b = 100 \frac{e_b}{b}$$

and

$$X'_{h_1} = ({}_1X'^2_{h_1} + {}_2X'^2_{h_1} + \ldots + X'^2_m)^{1/2}$$

where

e_b is the random uncertainty in the breadth measurement;

${}_1X'_{h_1}$, ${}_2X'_{h_1}$, ... are percentage random uncertainties in the head measurement (see 9.5.3);

X'_m is the percentage random uncertainty in the mean if a series of readings of head measurement are taken at constant water level.

The term X'_m is easily estimated if, for example, a point gauge is used for water level measurement. For continuous or digital recording equipment, the random uncertainty in reading a given water level can be assessed by using laboratory tests on that equipment.

9.6.5 The percentage systematic uncertainty X''_Q in the rate of flow may be calculated from the following equation:

$$X''_Q = \pm \sqrt{X''^2_C + X''^2_b + 1{,}5^2 X''^2_{h_1}}$$

where

X''_C is the percentage systematic uncertainty in C;

X''_b is the percentage systematic uncertainty in b;

X''_{h_1} is the percentage systematic uncertainty in h_1.

In the above

$$X''_{h_1} = ({}_1X''^2_{h_1} + {}_2X''^2_{h_1} + \ldots)^{1/2}$$

where ${}_1X''_{h_1}$, ${}_2X''_{h_1}$, ... are percentage systematic uncertainties in the head measurement (see 9.5.3).

9.7 Presentation of results

Although it is desirable, and frequently necessary, to list the total random and total systematic uncertainties separately, it is appreciated that a simpler presentation of results may be required. For this purpose, random and systematic uncertainties may be combined as shown in ISO 5168:

$$X_Q = \pm \sqrt{X'^2_Q + X''^2_Q}$$

10 Example

The following is an example of the computation of the discharge and the associated uncertainty in a single measurement of flow using a rectangular broad-crested weir for modular flow conditions. The crest height p above the bed of the approach channel is 0,3 m and the gauged head h_1 is 0,4 m. The width b of the weir crest and the width B of the approach are both equal to 10 m. The length L of the weir in the direction of flow is 0,5 m. A digital punched tape recorder operating at intervals of 1 mm is assumed to be used.

10.1 The discharge is calculated using equation (1), given in 8.1.

10.2 The value of the gauged head discharge coefficient C for the corresponding values of $h_1/L = 0{,}8$, $h_1/p = 1{,}333$ and $L/p = 1{,}667$ is determined from figure 2 to be $C = 1{,}043$.

10.3 Using equation (1):

$$Q = \left(\frac{2}{3}\right)^{3/2} g^{1/2} bCh_1^{3/2}$$

$$= 1{,}705 \times 10 \times 1{,}043 \times 0{,}4^{3/2}$$

$$= 4{,}50 \text{ m}^3/\text{s}$$

10.4 To calculate the uncertainty in this value of Q, the uncertainties (in per cent) in the coefficient value are first determined as follows:

$$X'_C = \pm 1\ \% \quad \text{(from 8.4)}$$

$$X''_C = \pm [1{,}5 + (h_1/p)^2] \quad \text{(from 8.4)}$$

$$= \pm 3{,}28\ \%$$

10.5 If it is assumed that several measurements of the width are taken, the random component of uncertainty in the width measurement can be considered to be negligible. The systematic uncertainty in the width measurement is assumed in this case to be 0,01 m.

Accordingly,

$$X'_b = 0$$

$$X''_b = \pm \frac{0{,}01}{10} \times 100 = \pm 0{,}10\ \%$$

10.6 The magnitude of the uncertainty associated with the head measuring device depends on the particular equipment used. It has been demonstrated that the gauge zero of a digital punched tape recorder can be set to an accuracy of ± 3 mm. This is a systematic uncertainty. There is no random uncertainty associated with the zero setting error because, until the zero is reset, the true zero will have the same magnitude and sign.

Therefore,

$${}_1X'_{h_1} = 0$$

$${}_1X''_{h_1} = \pm \frac{0{,}003}{0{,}4} \times 100 = \pm 0{,}75\ \%$$

10.7 Uncertainties associated with different types of water level observation equipment can be determined using careful tests under controlled conditions. The random component of uncertainty can be determined by taking a series of readings at a given water level; however, to distinguish this uncertainty from other sources of uncertainty it is necessary that these tests be carried out with the water level always rising (or falling). For the equipment used in this example, the random component of uncertainty in water level measurement is approximately ± 1 mm. Systematic uncertainties in water level measurement occur owing to backlash, tape stretching, etc. Where possible, corrections should be applied, but controlled tests for given types of equipment will indicate the magnitude of the residual systematic uncertainty. In this case, when a digital punched tape recorder is used, this value is approximately ± 2,5 mm.

Accordingly

$${}_2X'_{h_1} = \pm \frac{0{,}001}{0{,}4} \times 100 = \pm 0{,}25\ \%$$

$${}_2X''_{h_1} = \pm \frac{0{,}002\,5}{0{,}4} \times 100 = \pm 0{,}63\ \%$$

10.8 The combination of individual uncertainties to obtain the overall uncertainty in discharge can be carried out as follows.

Assuming that X'_m is negligible the uncertainties in water level measurement are

$$X'_{h_1} = \pm ({}_1X'^2_{h_1} + {}_2X'^2_{h_1})^{1/2} = \pm (0 + 0{,}25^2)^{1/2}\ \%$$

$$= \pm 0{,}25\ \%$$

$$X''_{h_1} = \pm ({}_1X''^2_{h_1} + {}_2X''^2_{h_1})^{1/2} = \pm (0{,}75^2 + 0{,}63^2)^{1/2}\ \%$$

$$= \pm 0{,}98\ \%$$

The total random uncertainty in the disharge measurement is

$$X'_Q = \pm (X'^2_C + X'^2_b + 1{,}5^2\, X'^2_{h_1})^{1/2}$$

$$= \pm (1^2 + 0 + 2{,}25 \times 0{,}25^2)^{1/2}\ \%$$

$$= 1{,}07\ \%$$

The total systematic uncertainty in the discharge measurement is

$$X''_Q = \pm (X''^2_C + X''^2_b + 1{,}5^2\, X''^2_{h_1})^{1/2}$$

$$= \pm (3{,}28^2 + 0{,}1^2 + 2{,}25 \times 0{,}98^2)^{1/2}\ \%$$

$$= \pm 3{,}60\ \%$$

To facilitate a simple presentation, the random and systematic uncertainties can be combined by the root-sum-of-squares rule as follows:

$$X_Q = \pm (X'^2_Q + X''^2_Q)^{1/2}$$

$$= \pm (1{,}07^2 + 3{,}60^2)^{1/2}\ \%$$

$$= \pm 3{,}76\ \%$$

The flow rate Q is therefore 4,50 m^3/s ± 3,8 %. The random uncertainty is ± 1,07 %.

Annex A

Nomenclature

(This annex forms an integral part of the standard.)

Symbol		Unit
A	area of the approach channel	m^2
B	width of the approach channel	m
b	width of the weir crest perpendicular to the flow direction	m
C	discharge coefficient (gauged head)	non-dimensional
C_D	discharge coefficient (total head)	non-dimensional
C_V	velocity of approach factor	non-dimensional
e_b	random uncertainty in the width measurement	m
g	acceleration due to gravity	m/s^2
H_1	upstream total head above crest level	m
h_1	upstream gauged head above crest level	m
h_2	downstream gauged head above crest level	m
L	length of the weir in the direction of flow	m
n	number of measurements in a set	non-dimensional
p	height of weir (difference between mean bed level and crest level)	m
Q	total discharge	m^3/s
S	submergence ratio, h_2/h_1	non-dimensional
S_1	modular limit	non-dimensional
s_Y	standard deviation of quantity Y	1)
$s_{\bar{Y}}$	standard deviation of the mean $\bar{Y}$	1)
v_1	mean velocity in the approach channel	m/s
X	overall percentage uncertainty	%
X_b	percentage uncertainty in b	%
X_C	percentage uncertainty in C	%
X_{h_1}	percentage uncertainty in h_1	%
X_m	percentage uncertainty in the mean of a set of head measurement readings	%
X_Q	percentage uncertainty in Q	%

Superscripts

′	random component of uncertainty
″	systematic component of uncertainty

1) The unit is the same as that of the quantity Y.