# International Standard ISO 8333

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## Liquid flow measurement in open channels by weirs and flumes — V-shaped broad-crested weirs

*Mesure de débit des liquides dans les canaux découverts au moyen de déversoirs et de canaux jaugeurs — Déversoirs à seuil épais en V*

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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.

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 8333 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

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.

# Liquid flow measurement in open channels by weirs and flumes — V-shaped broad-crested weirs



## 1 Scope and field of application

This International Standard specifies a method for the measurement of subcritical flow in small rivers and artificial channels using V-shaped broad-crested weirs.

The advantages of this type of weir are described in clause 8.

NOTE — A comparison of the different types of weirs and flumes will form the subject of a future International Standard.

## 2 References

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

ISO 4373, *Measurement of liquid flow in open channels — Water level measuring devices.*

ISO 4374, *Liquid flow measurement in open channels — Round-nose horizontal crest weirs.*

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

## 3 Definitions

For the purposes of this International Standard, the definitions given in ISO 772 apply.

## 4 Units of measurement

The units of measurement used in this International Standard are SI units.

## 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 1 in 250;

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

e) the consequential conditions downstream, including such influences 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 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;

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

k) the effects of wind (wind can have a considerable effect on the flow in a river or over a weir, especially if these are wide and the head is small and when 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 is 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.

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.

## 5.2 Installation conditions

### 5.2.1 General

The complete measuring installation consists of an approach channel, a 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 above.

Once an installation has been designed, the user shall eschew any changes which could affect the discharge characteristics.

### 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. 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. Unless otherwise specified in the appropriate clauses, the approach channel shall comply with the general requirements outlined below.

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 10 times its width.

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 10 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 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.

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

### 5.2.3 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 clauses (see also figure 1).

The V-shaped broad-crested weir may be constructed with either a fixed crest or a movable one with vertical slots (see figure 2).

### 5.2.4 Movable measuring structure

The movable V-shaped broad-crested weir can be constructed with one vertical slot in which the supporting plate of the weir

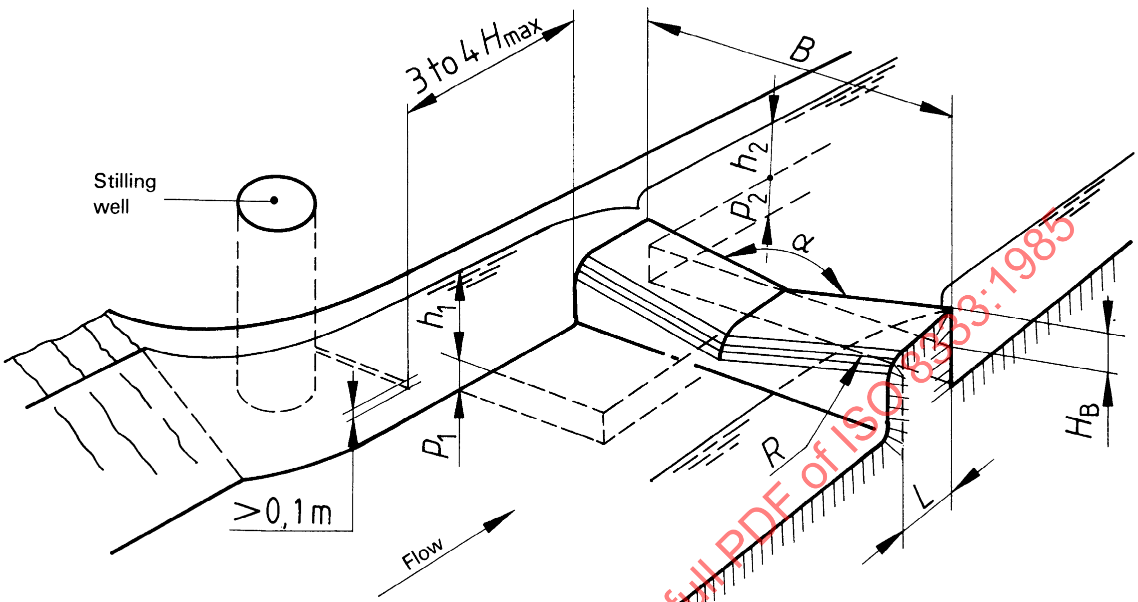
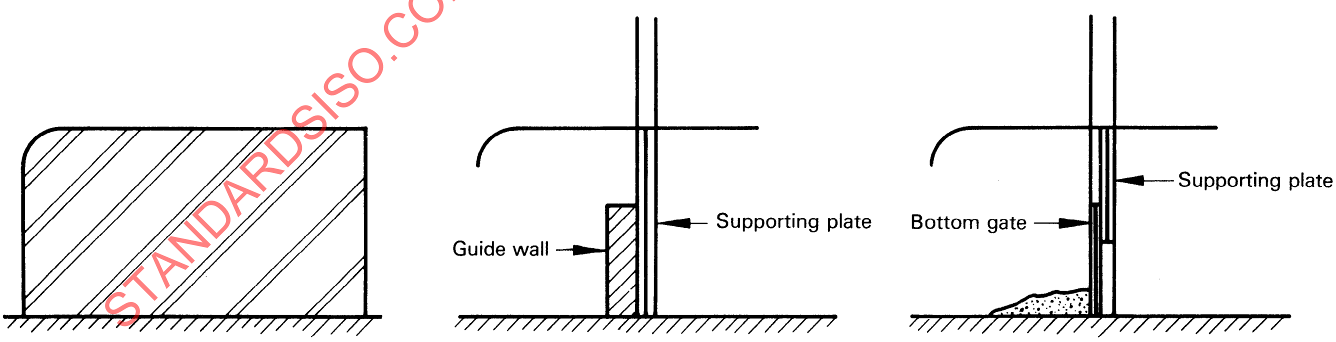



**Figure 1 — V-shaped broad-crested weir**






a) with fixed crest

b) movable with one vertical slot

c) movable with two slots

**Figure 2 — Longitudinal section of three types of construction**

crest can be raised or lowered according to the desired crest level. A vertical guide wall founded at the channel bottom and parallel to the supporting plate acts as a watertight barrier for the movable weir.

If regular flushing of sediment is expected to be necessary, the weir can be constructed with two slots. The movable weir can be operated in the downstream slot while a bottom gate is placed in the upstream slot. During measurement of flow, the gate is closed at the bottom. To flush sediment that has settled upstream of the weir, the gate can be opened by connecting it to the movable weir and raising the weir and gate together.

#### 5.2.5 Downstream channel

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

The altered flow conditions due to the construction of the weir may have the effect of building up shoals of debris immediately downstream of the structure, which in time may raise the water level sufficiently to drown the weir. Any accumulation of debris downstream of the structure shall therefore be removed.

## 6 General requirements for maintenance

Maintenance of the 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 for at least the distance specified in 5.2.2. 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.

## 7 Measurement of head

### 7.1 General

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 float-operated recording gauge where a continuous record is required, and, in many cases, it is preferable to measure heads in a separate stilling well to reduce the effects of surface irregularities. Other head-measuring methods (for example bubble tubes) may be used, provided sufficient accuracy is obtainable.

The discharges given by the working equation are volumetric figures, and the liquid density does not affect the volumetric discharge for a given head provided the head is calibrated 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 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 measures the piezometric head..

### 7.2 Stilling or float well

Where provided, the stilling well shall be vertical and shall extend at least 0,6 m above the maximum water level estimated 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 lowest point of the crest (vertex).

The connecting pipe or slot shall, however, be as small as possible insofar as is consistent with ease of maintenance, or, alternatively, it shall be fitted with a constriction to damp out oscillations due to short amplitude waves. This will be necessary, for example, if the chart of the recorder cannot be read to within ± 6 mm.

The well and the connecting pipe or slot shall be watertight. If provided for the accommodation of the float of a level recorder, the well shall be of adequate diameter and depth for that purpose.

The well shall also be sufficiently deep to ensure that any sediment which may enter does not lead to grounding of the float. The float well arrangement may include an intermediate chamber, between the stilling well and the approach channel, of similar proportions to the stilling well, to enable sediment to settle.

Additional specifications for stilling wells are given in ISO 4373.

### 7.3 Head-gauge datum

Accuracy of head measurements is critically dependent upon the determination of the head-gauge datum or gauge zero, which is the gauge reading corresponding to the level of the vertex — lowest point — of the V-shaped weir.

The gauge zero shall be determined with great care and shall be checked regularly.

#### 7.3.1 Determination of head-gauge datum for weirs with a fixed crest

An acceptable method of determining the head-gauge datum for V-shaped broad-crested weirs with a fixed crest height is specified in 7.3.1.1 to 7.3.1.6 (see also figure 3).

The advantage of this method is that it relates the head-gauge datum to the geometrical vertexline which is defined by the sides of the weir.

**7.3.1.1** Set still water in the approach channel to a level below the vertex of the weir.

**7.3.1.2** Mount a temporary point-gauge over the approach channel, with its point a short distance upstream from the vertex of the weir.

**7.3.1.3** Place a true cylinder of known diameter, with its axis horizontal, so that one end rests on the foremost part of the vertexline and the other end balances on a temporary support. Check the horizontal position of the cylinder using a spirit-level. Record the reading of the temporary point-gauge placed exactly on top of the cylinder.

**7.3.1.4** Lower the temporary point-gauge to the water surface in the approach channel and record the reading. At the same time, adjust the permanent gauge to read the level in the stilling well, and record this reading.

**7.3.1.5** Compute the distance, $Y$, from the top of the cylinder to the vertexline of the weir from a knowledge of the crest angle, $\alpha$, and the radius, $r$, of the cylinder, as follows:

$$Y = r/\sin(\alpha/2) + r$$

Subtract this distance from the reading of the temporary point-gauge in 7.3.1.3. The result is the reading of the temporary point-gauge at the vertexline of the weir.

**7.3.1.6** Add the difference between the calculated reading in 7.3.1.5 and the reading of the temporary point-gauge in 7.3.1.4 to the reading of the permanent gauge in 7.3.1.4. The result is the head-gauge datum for the permanent gauge.

### 7.3.2 Determination of head-gauge datum for weirs with a movable crest

In the case of a movable weir, both the upstream water level and the crest level vary. The elevation of the crestline can be read from a fixed gauge. A typical method is the installation of this gauge fixed at the abutment and parallel to the lifting beam on which a horizontal strip indicates the elevation of the crest.

The weir is brought to a certain level, the reading of the fixed gauge on the abutment is recorded and the zero setting described in 7.3.1 can be carried out.

A direct reading can be obtained by constructing the stilling well close to the lifting beam. The gauge is connected to the lifting beam so that it moves in the stilling well, while its zero coincides with the elevation of the vertexline. This method can also be applied for continuous recording purposes.



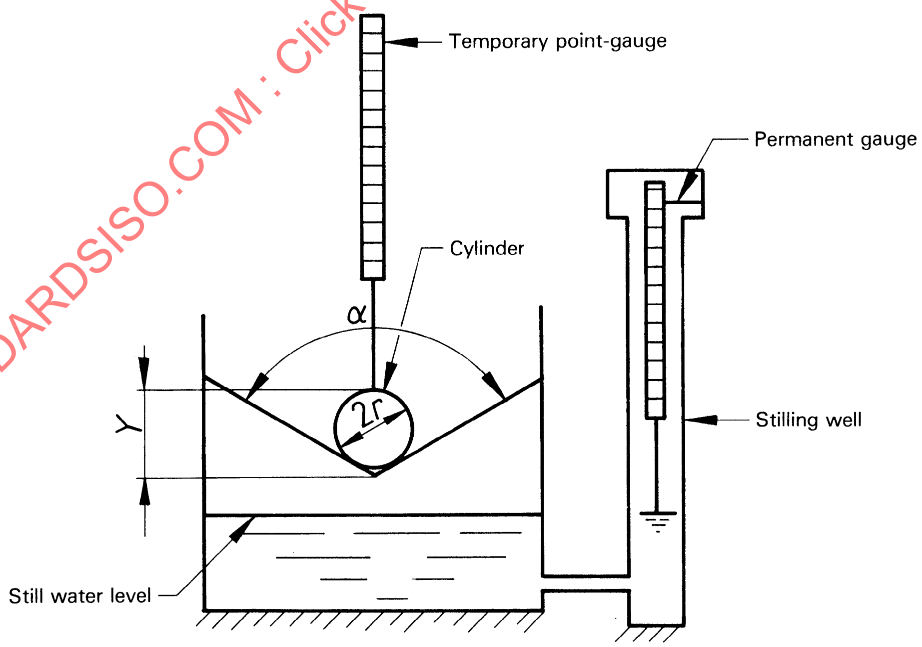



**Figure 3 — Determination of head-gauge datum**

## 8 V-shaped broad-crested weirs

**8.1** The V-shaped broad-crested weir has a V-shaped cross-section with a horizontal vertexline (see figure 4). It combines the advantages of the V-notch sharp-crested weir and the horizontal broad-crested weir. Its characteristics are as follows:

a) large and small discharges can be measured with relatively high accuracy;

b) the head-discharge relation is affected by the down-stream water level when a high submergence ratio is reached ($S$ = 80 % where $S = 100\ h_2/h_1$). Consequently, the weir is very suitable for water courses with little fall available.

**8.2** The sloping plates are rounded off at the upstream corner, similar to the horizontal broad-crested weir. For field structures, a radius in the range $0{,}20\ H_{max} < R < 0{,}40\ H_{max}$ is recommended.

The length $L$ of the crest is chosen so that nearly horizontal flow occurs on the crest. It should not be less than 2 $H_{max}$.

The choice of the crest angle, $\alpha$, depends on

— the accuracy required for the minimum discharge;

— the available fall difference between upstream and downstream water levels;

— the available width, $B$.

The crest angle is generally within the range $90° < \alpha < 150°$.

Determined by the magnitude of the head, $h_1$, two types of flow are possible over the V-shaped broad-crested weir. Under normal conditions, the type of flow is called "less than full", and $h_1 \leqslant 1{,}25\ H_B$. This condition is derived from the fact that the critical depth in a triangular cross-section is equal to 0,8 $H$. In exceptional circumstances, the type of flow is referred to as "more than full", and $h_1 > 1{,}25\ H_B$.

In the case of a movable weir, the weir body can be made of steel or aluminium plate. If the weir has a fixed crest, it can be made of metal plate or of well-finished concrete.

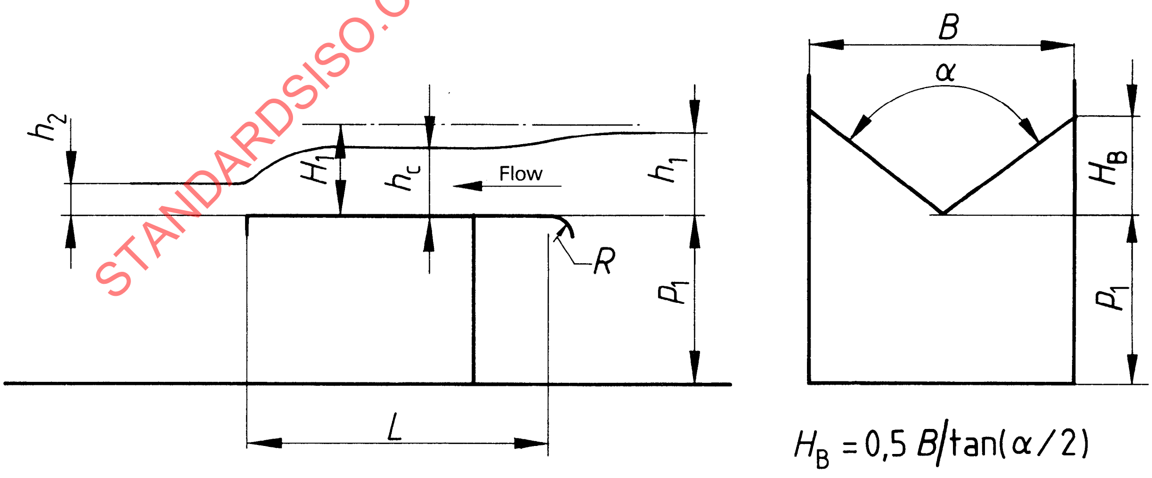
If the structure has to be used to regulate and to measure flow, which is often the case in irrigation, the construction is carried out as a vertical sliding overflow structure, movable by hand or mechanically.

**8.3** The upstream water level shall be measured at a distance of three to four times $H_{max}$ upstream from the weir face, using a stilling well.

The crest height, if movable, shall be measured simultaneously with the upstream water level (see 7.3).

The head, $h_1$, shall be determined within an absolute accuracy to keep the overall uncertainty of measured flow within design limits. The required accuracy for measurement of the head shall be checked using the methods specified in clause 10 over the whole design flow range. Regular inspection and maintenance of the whole structure is therefore indispensable.

Provisions for ventilation of the discharging nappe are not necessary.




Longitudinal section

Front

**Figure 4 — Dimensions of weir and flow**

## 9 Discharge equations

### 9.1 Equations

The discharge equation for free flow in the case of "less than full" flow is, provided that $h_1 \leqslant 1{,}25\ H_B$, as follows :

$$Q = \left(\frac{4}{5}\right)^{5/2} \cdot \left(\frac{g}{2}\right)^{1/2} \cdot \tan(\alpha/2) \cdot C_D \cdot C_V \cdot h_1^{5/2}$$

where

$Q$ is the discharge;

$g$ is the acceleration due to gravity;

$\alpha$ is the crest angle;

$C_D$ is the discharge coefficient;

$C_V$ is the approach velocity coefficient $[(H_1/h_1)^{5/2}]$;

$h_1$ is the measured upstream head;

$H_1$ is the total upstream head;

$H_B$ is the height of the crest triangle $[0{,}5\ B/\tan(\alpha/2)]$ (see figure 4).

The discharge equation for free flow in the "more than full" range is given in annex B.

The modular limit and the "drowned" flow reduction factor in the "less than full" range are given in annex C.

Submerged flow in the "more than full" range has not been investigated.

### 9.2 Coefficient of discharge

In the design stage, a mean value for $C_D$ of 0,95 can be used in the range $0{,}1 < h_1/L < 0{,}45$.

For measurement purposes, the discharge coefficient is shown in figure 5 as a function of $h_1/L$ and $\alpha$. An example of the flow pattern above the crest for free flow is shown in figure 6.

### 9.3 Practical limitations

The following practical limitations shall be noted :

a) $h_1$ shall not be less than 0,06 m or 0,05 $L$, whichever is the greater;

b) $h_1$ shall not be greater than the values of $h_1/L$ as indicated in figure 5 or 1,25 $H_B$, whichever is the smaller;

c) the crest angle, $\alpha$, should not be less than 90°;

d) the maximum value of $h_1/p_1$ will vary from $h_1/p_1 = 1{,}5$ for large crest angles to $h_1/p_1 = 3$ for small crest angles;

e) the radius, $R$, of the upstream rounding off shall be in the range $0{,}1\ L < R < 0{,}2\ L$.



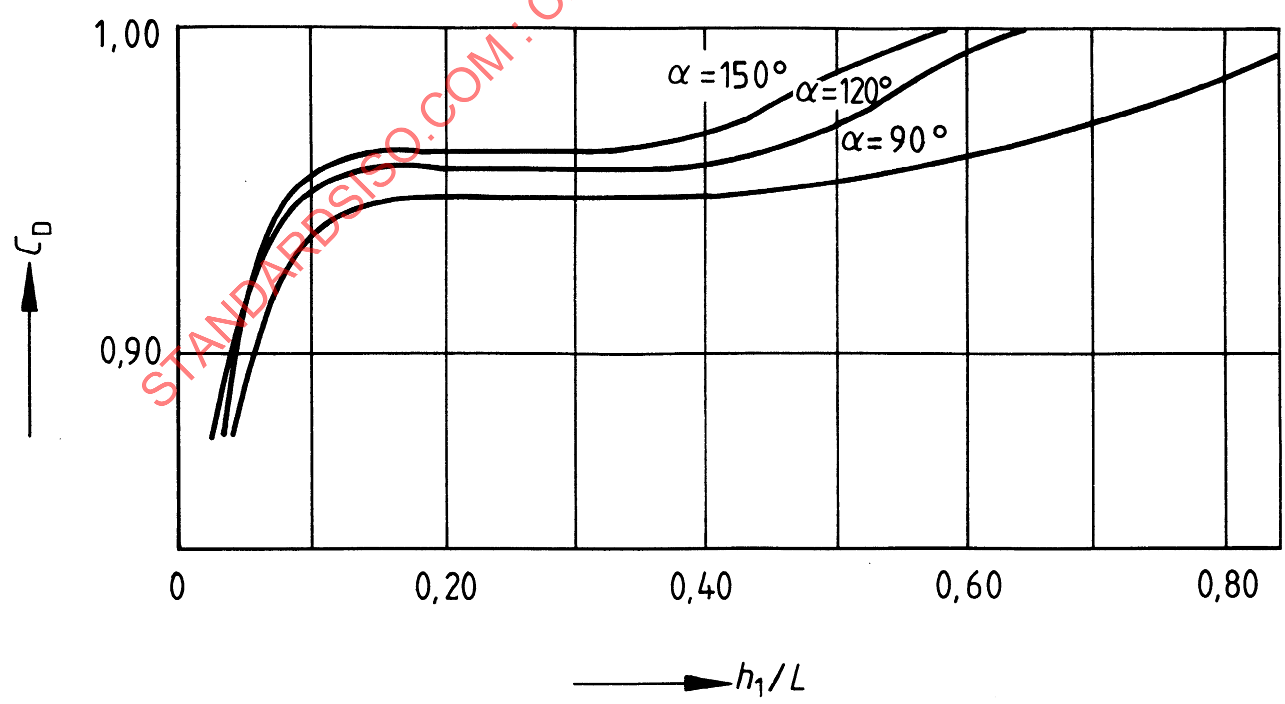



**Figure 5 — Discharge coefficient as a function of $h_1/L$**

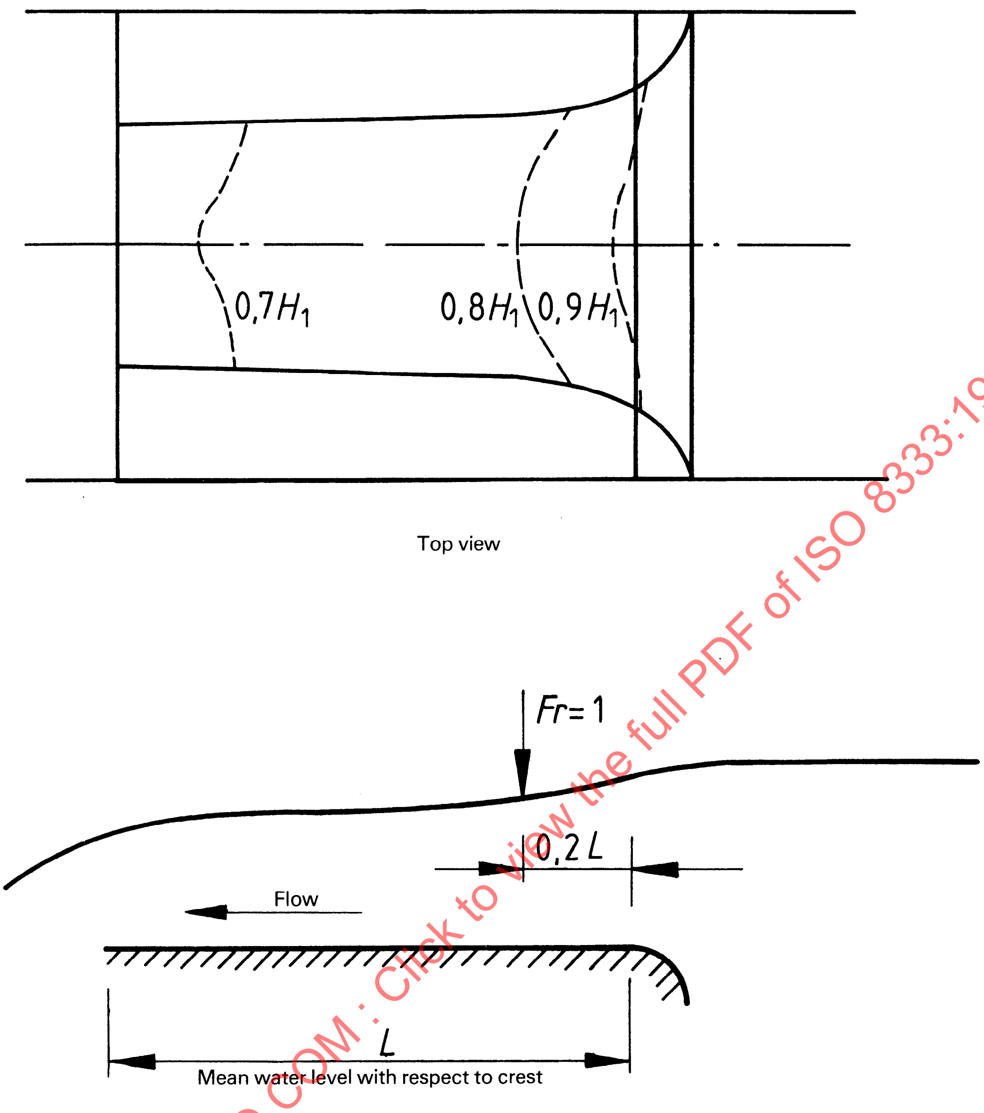



**Figure 6 — Flow-pattern above crest for free flow with $h_1/L$ = 0,353**



### 9.4 Accuracy

The relative accuracy of flow measurements made with these weirs depends on the accuracy of the head measurement, the measurements of the dimensions of weir and on the accuracy of the coefficients as they apply to the weir in use.

With reasonable care and skill in the construction and installation of a V-shaped broad-crested weir, the systematic error in the coefficient of discharge may be deduced from the equation

$$X''_c = \pm (2,0 + 0,15\ L/h_1)\ \%$$

The random error depends on the quality of the research used to determine the coefficient and may be taken as $X'_c = \pm 0,5$ % in this case.

The method by which the errors in the coefficients are to be combined with other sources of errors is described in clause 10.

In general, calibration experiments are carried out on model structures of small dimensions and, when transferred to larger structures, there may be small changes in the discharge coefficients due to a scale effect (see annex A).

## 10 Errors in flow measurement (see also ISO 5168)

### 10.1 General

**10.1.1** The total uncertainty of 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 rate of flow can be measured with sufficient accuracy for the purpose in hand.

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

**10.1.2** The error may be defined as the difference between the true rate of flow and that calculated in accordance with the equations used for calibrating the 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 range within which the true value of the measured flow is expected to lie some nineteen times out of twenty (with 95 % confidence limits).

## 10.2 Sources of error

**10.2.1** The sources of error in the discharge measurement may be identified by considering a generalized form of the discharge equation for weirs :

$$Q = \left(\frac{4}{5}\right)^{5/2} \cdot \left(\frac{g}{2}\right)^{1/2} \cdot \tan(\alpha/2) \cdot C_D \cdot C_V \cdot h_1^{5/2}$$

where

$\left(\frac{4}{5}\right)^{5/2}$ is a numerical constant not subject to error;

$g$ is the acceleration due to gravity, which varies from place to place, but the variation is small enough to be disregarded in flow measurements. In general, $g$ = 9,81 m/s$^2$.

**10.2.2** The sources of error which need to be considered further are :

a) the discharge coefficient, $C_D$;

A numerical estimate of this error is given in 9.4.

b) the approach velocity coefficient, $C_V$;

This is subject to changes in the cross-section of the head-gauging section. In the case of regular maintenance of the approach channel, the error in $C_V$ can be disregarded.

c) the crest angle, $\alpha$, as a dimensional measurement of the structure;

The uncertainty will depend upon the degree of accuracy to which the device as constructed can be measured. In practice, this uncertainty may prove to be insignificant in comparison with other uncertainties. A small deviation of the desired crest angle can be corrected directly.

d) the measured head, $h_1$.

This is insignificant in comparison with other uncertainties. The uncertainty in the head will depend upon the accuracy of the head-measuring device, the determination of the head-gauge datum and upon the technique used. This uncertainty may be small if a vernier or micrometer instrument is used, with a zero determination of comparable precision.

## 10.3 Types of error

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

**10.3.2** The standard deviation of a set of $n$ measurements of a quantity $Y$ under steady conditions may be estimated from the equation

$$s_Y = \left(\frac{\sum_1^n (Y_i - \bar{Y})^2}{n - 1}\right)^{1/2} \quad \ldots (1)$$

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

The standard deviation of the mean is then given by :

$$s_{\bar{Y}} = \frac{s_Y}{\sqrt{n}} \quad \ldots (2)$$

and the uncertainty of the mean is 2 $s_{\bar{Y}}$ (to 95 % probability)[1]. This uncertainty is the contribution of the observations of $Y$ to the total uncertainty.

**10.3.3** A measurement may also be subject to systematic errors. The mean of very many measured values would thus still differ from the true value of the quantity being measured. An error in setting the zero of a water level gauge to invert level, for example, produces a systematic difference between the true mean measured head and the actual value. As repetition of the measurement does not eliminate systematic errors, the actual value could only be determined by an independent measurement known to be more accurate.

## 10.4 Errors in values of coefficients

**10.4.1** The value of the discharge coefficient, $C_D$, quoted in this International Standard is 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. Random and systematic errors from this source are small. However, when measurements are made on other similar installations, systematic discrepancies between discharge coefficients 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 structure, etc.

**10.4.2** The uncertainty in the coefficients quoted in this International Standard are based on a consideration of the deviation of experimental data from various sources from the equations given. The suggested uncertainties thus represent the accumulation of evidence and experience available.

1) This factor of two assumes that $n$ is large. For $n$ = 6, the factor should be 2,6, while for $n$ = 8 it should be 2,4, for $n$ = 10 it should be 2,3, and for $n$ = 15 it should be 2,1.

### 10.5 Errors in measurements made by the user

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

**10.5.2** Since neither the method of measurement nor the way in which they are to be made are specified, no numerical values can be suggested for uncertainties in this category : they shall be estimated by the user. For example, consideration of the method of measuring the weir width should permit the user to estimate the uncertainty in this quantity.

**10.5.3** The uncertainty in the gauged head shall be determined from an assessment of the separate sources of uncertainty, for example the uncertainty of the zero setting, wind set-up, the gauge sensitivity, backlash in the indicating equipment (where appropriate), the residual uncertainty in the mean of a series of measurements (where appropriate), etc.

### 10.6 Combination of uncertainties

**10.6.1** The total systematic or random uncertainty is the result of several contributory uncertainties, which may themselves be composite uncertainties. Provided the contributing uncertainties are independent, small and numerous, they may be combined together to give, overall, a random (or systematic) uncertainty at the 95 % confidence level.

**10.6.2** 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 disregarded in comparison.

**10.6.3** Because of the different nature of random and systematic uncertainties, they should not normally be combined with each other. However, taking into account the proviso of 10.6.1, 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.

**10.6.4** The percentage random uncertainty, $X'$, in the rate of flow may be calculated from the equation

$$X' = \pm \sqrt{X_c'^2 + X_\alpha'^2 + 6{,}25\, X_h'^2}$$

where

$X_c'$ is the percentage random uncertainty in $C_D$;

$X_\alpha'$ is the percentage random uncertainty in tan $(\alpha/2)$;

$X_h'$ is the percentage random uncertainty in $h_1$.

In the above equation, $X_\alpha'^2$ is generally disregarded and

$$X_h' = ({}_1X_h'^2 + {}_2X_h'^2 + \ldots + X_m'^2)^{1/2}$$

where

${}_1X_h'$, ${}_2X_h'$, etc. are percentage random uncertainties in head measurements (see 10.5.3);

$X_m'$ is the percentage random uncertainty of 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 measurements. For continuous or digital recording equipment, the random uncertainty in reading a given water level can be assessed by laboratory tests on the equipment.

**10.6.5** The percentage systematic uncertainty, $X''$, in the rate of flow may be calculated from the equation

$$X'' = \pm \sqrt{X_c''^2 + X_\alpha''^2 + 6{,}25\, X_h''^2}$$

where

$X_c''$ is the percentage systematic uncertainty in $C_D$;

$X_\alpha''$ is the percentage systematic uncertainty in tan $(\alpha/2)$;

$X_h''$ is the percentage systematic uncertainty in $h_1$.

In the above equation

$$X_h'' = ({}_1X_h''^2 + {}_2X_h''^2 + \ldots)^{1/2}$$

where

${}_1X_h''$, ${}_2X_h''$, etc. are percentage systematic uncertainties in head measurement (see 10.5.3);

$X_\alpha''$ is eliminated by direct correction, if necessary.

### 10.7 Presentation of results

Although it is desirable, and frequently necessary, to list 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 described in ISO 5168.

### 10.8 Example

**10.8.1** The following is an example of the application of the formula to a single measurement with a V-shaped broad-crested weir with the following parameters

a) crest angle, $\alpha = 120°$

b) crest length, $L = 1{,}00$ m, rounding $R = 0{,}15$ m

c) width of weir, $B = 1{,}25$ m

d) crest height, $p_1 = 0{,}60$ m

e) approach-channel bottom width, $b = 1{,}20$ m, side slopes 1 : 2.

A digital head-measuring device is used, operating at 1 mm intervals. The weir is operating at gauged head of 0,25 m.

**10.8.2** Uncertainties in the coefficient values are as follows :

$$X'_{c} = \pm 0{,}5\ \%\ \text{(from 9.4)}$$

and

$$X''_{c} = \pm(2{,}0 + 0{,}15\ L/h_1)\ \%\ \text{(from 9.4)}$$

Since $L = 1{,}00$ m and $h_1 = 0{,}25$ m, $X''_{c} = 2{,}6$ %.

**10.8.3** Assuming that several measurements of the crest angle, $\alpha$, are made, the random component of uncertainty in tan $(\alpha/2)$ is likely to be negligible. The systematic error is eliminated by direct correction. Hence

$$X'_{\alpha} = 0$$

$$X''_{\alpha} = 0$$

**10.8.4** With the equipment used, it has been demonstrated that the gauge zero could be set to within ± 3 mm. This is a systematic uncertainty; however, the magnitude of the uncertainty shall be related to the equipment used. There is no random uncertainty associated with the zero setting error, because, until the zero is re-set, the true zero will have the same magnitude and sign. Therefore

$$_{1}X'_{h} = 0$$

$$_{1}X''_{h} = \frac{0{,}003}{0{,}25} = 1{,}20\ \%$$

**10.8.5** Uncertainties associated with different types of water level observation equipment can be determined by careful tests under controlled conditions. The random component of uncertainty can be determined by carrying out a series of readings at a given water level; however, in order to distinguish the random uncertainty from other sources of uncertainty, it is necessary that these tests are carried out with the water level always rising (or falling). For the equipment used, the random component of uncertainty in water level measurement was approximately ± 1 mm.

Systematic uncertainties in water level measurement occur due to backlash, tape stretching, etc. If 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, this was approximately ± 2,5 mm. Accordingly :

$$_{2}X'_{h} = \frac{0{,}001}{0{,}25} \times 100 = 0{,}40\ \%$$

$$_{2}X''_{h} = \frac{0{,}002\ 5}{0{,}25} \times 100 = 1{,}00\ \%$$

**10.8.6** When the uncertainties are combined, the uncertainties in water level measurement, assuming $X'_{m}$ is negligible, are:

$$X'_{h} = \pm\sqrt{(_{1}X'_{h})^2 + (_{2}X'_{h})^2} = \pm\sqrt{0 + (0{,}4)^2} = \pm 0{,}40\ \%$$

$$X''_{h} = \pm\sqrt{(_{1}X''_{h})^2 + (_{2}X''_{h})^2} = \pm\sqrt{(1{,}20)^2 + (1{,}00)^2} =$$

$$= \pm 1{,}56\ \%$$

The total random uncertainty in the discharge measurement is:

$$X' = \pm\sqrt{(X'_{c})^2 + (2{,}5\ X'_{h})^2}$$

$$= \pm\sqrt{(0{,}5)^2 + 6{,}25\ (0{,}40)^2}$$

$$= \pm 1{,}12\ \%$$

The total systematic uncertainty in the discharge measurement is :

$$X'' = \pm\sqrt{(X''_{c})^2 + (2{,}5\ X''_{h})^2}$$

$$= \pm\sqrt{(2{,}6)^2 + 6{,}25\ (1{,}56)^2}$$

$$= \pm 4{,}69\ \%$$

In order to facilitate a simple presentation, the random and systematic uncertainties may be combined by the root-sum of squares rule, as follows:

$$X = \pm\sqrt{(1{,}12)^2 + (4{,}69)^2} = \pm 4{,}82\ \%$$

The flow rate, $Q$, may be reported, in the case of $h_1 = 0{,}25$ m, as $Q \pm 4{,}82$ %, with a random uncertainty of ± 1,12 %.

# Annex A

## Scaling effects

The boundary layer development is affected by scaling effects if the flow in the control section leads to length Reynolds numbers $Re_L = v \cdot L/\nu$ less than $5 \times 10^5$.

In order to prevent the scaling effects, the condition $Re_L \geqslant 5 \times 10^5$ should be fulfilled. This means, for V-shaped broad-crested weirs, and water temperatures of 20 °C, approximately $h_1^{0,5} \cdot L \geqslant 0,25\ m^{1,5}$.

*Example :*

For $h_{min} = 0,06$ m, the crest length, $L$, shall be at least 1,00 m.

For $h_{min} = 0,10$ m, $L_{min} = 0,80$ m.

For very small structures ($h_1^{0,5} \cdot L < 0,25\ m^{1,5}$), a calibration at 1 : 1 scale is recommended.

# Annex B

## "More than full" flow

If the width of the V-shaped broad-crested weir is limited by vertical side walls, then the type of flow can be "more than full" (see figure 7). As critical flow on a triangular cross-section occurs theoretically with $h_c \approx 0{,}8\, h_1$, it may be assumed that the "less than full" type of flow proceeds on to the "more than full" type of flow for $h_1 = 1{,}25\, H_B$.

The discharge equation for free flow, provided $h_1 > 1{,}25\, H_B$, is given by :

$$Q = \left(\frac{2}{3}\right)^{3/2} \cdot g^{1/2} \cdot B \cdot C_D \cdot C_V \cdot (h_1 - 0{,}5\, H_B)^{1{,}5}$$

where

$Q$ is the discharge;

$g$ is the acceleration due to gravity;

$B$ is the width of the weir;

$C_D$ is the discharge coefficient;

$C_V$ is the approach velocity coefficient;

$h_1$ is the measured upstream head;

$H_B$ is the height of the crest triangle $[0{,}5\, B/\tan(\alpha/2)]$.

The discharge coefficient $C_D$ is a function of $h/L$, $\alpha$ and $B$. The relation $C_D$ against $h/L$ can be established by drawing a transition curve between

a) the "less than full" relation valid until $h_1 = 1{,}25\, H_B$, and

b) a relation $C_D$ against $h/L$ for round-nose horizontal broad-crested weirs with a crest level at $0{,}5\, H_B$ from $h_1 = 1{,}75\, H_B$ using the equation

$$C_D = \left(1 - 2\frac{\delta}{L}\cdot\frac{L}{B}\right)\left(1 - \frac{\delta}{L}\cdot\frac{L}{H_1}\right)^{1{,}5}$$

where

$L$ is the length of the weir;

$H_1$ is the total upstream head;

$\delta$ is the boundary displacement thickness at the critical section. Under normal circumstances, $\delta/L$ can be assumed to be equal to 0,003 without too much error being introduced.

For more precise determination of $C_D$, see ISO 4374.

The approach velocity coefficient is

$$C_V = \left(\frac{H_1 - 0{,}5\, H_B}{h_1 - 0{,}5\, H_B}\right)^{1{,}5}$$



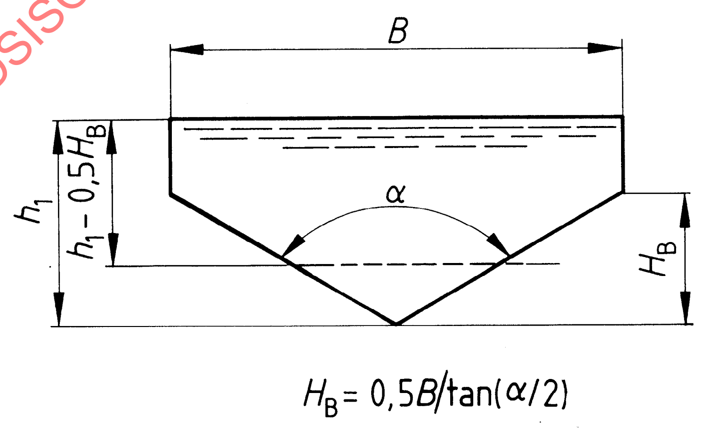



**Figure 7 — Dimensions for "more than full" flow**

# Annex C

## Submerged flow

The modular limit $S_1$ is defined as the submergence ratio for which the deviation between submerged flow calculated with the free flow head-discharge relation and the real free flow is 1 %, i.e.

- if $S < S_1$, the flow is free flow;
- if $S > S_1$, the flow is submerged flow.

In the broad-crested range, the modular limit is about 80 %. Figure 8 shows the modular limit for the range $0{,}10 < h/L < 0{,}70$.

For submerged flow the discharge calculation in "less than full" type of flow requires a drowned flow reduction factor, $C_{dr}$, as shown in figure 9. In figure 9 $Q/Q_E$ represents the ratio between the real flow, $Q$, and a flow, $Q_E$, calculated with the same upstream head, but with the effect of submergence being ignored.