
International Standard



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Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs

Mesure de débit des liquides dans les canaux découverts au moyen de déversoirs et de canaux jaugeurs — Déversoirs à profil triangulaire

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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.

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Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs

1 Scope and field of application

This International Standard specifies methods for the measurement of the flow of water in open channels under steady flow conditions using triangular profile weirs. The flow conditions considered are steady flows which are uniquely dependent on the upstream head and drowned flows which depend on downstream as well as upstream levels.

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

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

3 Definitions and symbols

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

4 Units of measurement

The units of measurement used in this International Standard are seconds and metres.

5 Installation

Conditions regarding preliminary survey, selection of site, installation, the approach channel, maintenance, measurement of head, and stilling or float wells which are generally necessary for flow measurement are given in the following sub-clauses. The particular requirements for the triangular profile weir are given separately in clause 8.

5.1 Selection of site

5.1.1 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 by a weir.

Particular attention should be paid to the following features in selecting the site :

- a) 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;
- d) the effects of any increased upstream water level due to the measuring structure;
- e) conditions downstream including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features which might cause submerged flow;
- 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 effect of wind; wind can have a considerable effect on the flow in a river or over a weir, especially when 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 necessary for satisfactory measurement, 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 a 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 : 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. Complete information about the use of current-meters is given in ISO 748.

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 conditions of each of these three components affect the overall accuracy of the measurements.

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

The distribution and direction of velocity, determined by the features outlined in 5.1.1, have an important influence on the performance of the weir.

Once an installation has been constructed, the user shall prevent any change which could affect the discharge characteristics.

5.2.2 Approach channel

On 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 either at the side or on the bottom. Unless otherwise specified in the appropriate clauses, the following general requirements shall be complied with.

The altered flow-conditions due to the construction of the weir might have the effect of building up 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.

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 breadth.

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 of 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 may be required to achieve a regular velocity distribution.

There shall be no baffle nearer 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 not less than 30 times the maximum head upstream, flow measurement will be feasible, subject to confirmation that a regular velocity distribution exists at the gauging station.

5.2.3 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.

5.2.4 Downstream of the structure

The channel downstream of the structure is of no importance as such if the weir has been so designed that the flow is modular under all operating conditions. A downstream gauge shall be provided to measure tailwater levels to determine when submerged flow occurs.

In the event of the possibility of scouring downstream, which phenomenon may also lead to the instability of the structure, particular measures to prevent this happening may be necessary.

A crest tapping and separate stilling well shall be fitted if the weir is designed to operate in a drowned condition or if there is a possibility that the weir may drown in the future.

The latter circumstance may arise if the altered flow conditions due to the construction of the weir have the effect of building up shoals of debris immediately downstream of the structure or if river works are carried out downstream at a later date.

6 Maintenance

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 should 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 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 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 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 water surface irregularities.

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 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 herein that the densities are equal.

7.2 Stilling-well or float-well

Where provided, the stilling-well shall be vertical and have a margin of 0,6 m over the maximum water level estimated to be recorded in the well.

It shall be connected to the river by an inlet pipe or slot, large enough to permit the water in the well to follow the rise and fall of head without significant delay.

The connecting pipe or slot shall, however, be as small as possible, consistent with ease of maintenance, or, alternatively, 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. Where provided for the accommodation of the float of a level recorder, the well shall be of adequate diameter and depth to accommodate the float.

The well shall also be deep enough to accommodate any silt 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 the stilling-well to enable silt and other solids to settle out. For ease of maintenance the pipework may be valved.

For a detailed description of the stilling-well, see ISO 4373.

7.3 Zero setting

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.

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.

8 Specification for the standard weir

8.1 Description

8.1.1 The weir comprises an upstream slope of 1 (vertical) to 2 (horizontal) and a downstream slope of 1 (vertical) to 5 (horizontal). The intersection of these two surfaces forms a straight line crest, horizontal and at right angles to the direction of flow in the approach channel. Particular attention shall be given to the crest itself, which shall possess a well-defined

corner of durable construction. The crest may be made of preformed sections, carefully aligned and jointed, or may have a non-corrodible metal insert, as an alternative to *in situ* construction throughout.

8.1.2 The dimensions of the weir and its abutments shall conform to the requirements indicated in figure 1. Weir blocks may be truncated but not so as to reduce their dimensions in plan to less than $1,0 h_{\max}$ for the 1:2 slope and $2,0 h_{\max}$ for the 1:5 slope.

8.2 Location of head measurement section

Piezometers or point-gauge stations for the measurement of head on the weir shall be located at a sufficient distance upstream from the weir to avoid the region of surface drawdown. On the other hand, they shall be close enough to the weir to ensure that the energy loss between the section of measurement and the control section on the weir shall be negligible. In this International Standard, it is recommended that the head-measurement section shall be located at a distance equal to twice the maximum head ($2 h_{\max}$) upstream of the crest.

8.3 Condition for modular flow

8.3.1 Flow is modular when it is independent of variations in tailwater level. This requirement is met when the tailwater total head above crest level is equal to or less than 75 % of the upstream total head above crest level.

8.3.2 A significant error in the calculated discharge will develop if this ratio is exceeded, unless a crest tapping is provided and two independent head measurements are made.

8.4 Location of crest tapping

8.4.1 The crest tapping shall consist of five to ten holes of 10 mm diameter drilled in the weir block with centres 75 mm apart, 20 mm down from the weir crest on the 1:5 slope. The edges of the holes shall not be rounded or burred. The number of holes shall be sufficient to ensure that the water level in the stilling-well follows variations in crest separation pocket pressure without significant delay.

8.4.2 The optimum position for the crest tapping is at the centre of the weir crest. The tapping may be off-centre on weirs wider than 2,0 m provided that the distance from the centreline of the crest tapping to the nearest side wall or pier is greater than 1,0 m.

9 Discharge characteristics

9.1 Equations

9.1.1 The discharge equation for modular flow is

$$Q = (2/3)^{3/2} C_d C_v \sqrt{g} b h^{3/2}$$

where

Q is the discharge over the weir, in cubic metres per second;

C_d is the coefficient of discharge (non-dimensional);

C_v is the coefficient allowing for the effect of approach velocity $\left(\frac{H}{h}\right)^{3/2}$ (non-dimensional);

H is the total head, in metres;

b is the breadth of the weir, in metres;

g is the acceleration due to gravity, in metres per second squared;

h is the measured head, in metres.

9.1.2 The discharge equation for drowned flow is

$$Q = (2/3)^{3/2} C_d C_v f \sqrt{g} b h^{3/2}$$

where f is the drowned flow reduction factor (non-dimensional).

9.2 Coefficients

9.2.1 The coefficient C_v for the modular flow equation is obtained from figure 2 where A is the area of the approach channel.

9.2.2 The combined coefficient $C_v f$ for the drowned flow equation is obtained from figure 3 where h_p is the measured crest tapping head above crest level. Under modular flow conditions, the value of h_p/h is constant at 0,20 and the value of f is 1,00. Hence, under these conditions, values of $C_v f$ read from figure 3 coincide with values of C_v from figure 2.

9.2.3 For water at ordinary temperatures C_d is almost independent of h , except at very low heads when fluid properties influence the coefficient. C_d is given by the following equation

$$C_d = 1,163 \left(1 - \frac{0,0003}{h}\right)^{3/2}$$

where h is in metres. For practical purposes, C_d can be set equal to 1,163 for $h \geq 0,1$ m.

9.3 Limitations

The following general limitations are recommended :

$h \geq 0,03$ m (for a crest section of smooth metal or equivalent);

$h \geq 0,06$ m (for a crest section of fine concrete or equivalent);

$p \geq 0,06$ m;

$b \geq 0,3$ m;

$h/p \leq 3,5$;

$b/h \geq 2,0$.

9.4 Accuracy

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

9.4.2 With reasonable care and skill in the construction and installation of a triangular profile weir, the percentage systematic error in the coefficient of discharge (including C_v and f) may be deduced from the equation

$$X_c'' = \pm \left(\frac{10 C_v}{f} - 9 \right)$$

Numerical values of X_c'' are given in table 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.

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

9.4.4 In general, calibration experiments have been 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 scale effect.

10 Uncertainties in flow measurement

10.1 General

10.1.1 Reference should be made to ISO 5168.

10.1.2 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.

10.1.3 The error may be defined as the difference between the true rate of flow and that calculated in accordance with the equation 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 (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 discharge equation for weirs :

$$Q = (2/3)^{3/2} C_d C_v f \sqrt{g} b h^{3/2}$$

where

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

g is the acceleration due to gravity, varying from place to place, but the variation is small enough to be neglected in flow measurement.

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

- a) the discharge coefficient C_d , the velocity of approach coefficient C_v , and the drowned flow reduction factor f . Numerical estimates and uncertainties in the combined coefficient $C_d C_v f$ are given in 9.4;
- b) the dimensional measurement of the structures, for example the breadth of the weir, b ;
- c) the measured head, h .

10.2.3 The uncertainties in b and h shall be estimated by the user. The uncertainty in dimensional measurement will depend upon the accuracy to which the device as constructed can be measured : in practice, this error may prove to be insignificant in comparison with other errors. The uncertainty in the head will depend upon the accuracy of the head-measuring device, the determination of the gauge zero and upon the technique used. The error may be small if a vernier or micrometer instrument is used, with a zero determination of comparable precision.

10.3 Kinds 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 :

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

where \bar{Y} is the arithmetic mean of the n measurements. The standard deviation of the mean is then given by :

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

and the uncertainty of the mean is twice $s_{\bar{Y}}$ (to 95 % confidence level¹⁾). 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 error; 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 coefficient values

10.4.1 The values of the discharge coefficients C_d and C_v 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. Random and systematic errors from this source are small. 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 structure, etc.

10.4.2 The uncertainty in the coefficients quoted in the preceding clauses of 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.

10.5 Uncertainties 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).

10.6 Combination of uncertainties

10.6.1 The total systematic or random uncertainty is the resultant 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.

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

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 neglected by comparison.

10.6.3 Because of the different nature of random and systematic uncertainties, they should not normally be combined with each other. However, with the proviso of 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'_Q in the rate of flow may be calculated from the following equation :

$$X'_Q = \pm \sqrt{X'_c{}^2 + X'_b{}^2 + 1,5^2 X'_h{}^2}$$

where

X'_c is the percentage random uncertainty in $C_d C_v f$;

X'_b is the percentage random uncertainty in b ;

X'_h is the percentage random uncertainty in h .

In the above, $X'_b = 100 \times \frac{\varepsilon_b}{b}$

and

$$X'_h = ({}_1X'_h{}^2 + {}_2X'_h{}^2 + \dots + X'_m{}^2)^{1/2}$$

where

ε_b is the random uncertainty in breadth measurement;

${}_1X'_h, {}_2X'_h, \dots$, are percentage random uncertainties in head measurement (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 measurement. 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''_Q in the rate of flow may be calculated from the following equation :

$$X''_Q = \pm \sqrt{X''_c{}^2 + X''_b{}^2 + 1,5^2 X''_h{}^2}$$

where

X''_c is the percentage systematic uncertainty in $C_d C_v f$;

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

X''_h is the percentage systematic uncertainty in h .

In the above, $X''_h = ({}_1X''_h{}^2 + {}_2X''_h{}^2 + \dots)^{1/2}$

where ${}_1X''_h, {}_2X''_h, \dots$, are percentage systematic uncertainties in head measurement (see 10.5.3).

10.7 Presentation of results

10.7.1 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 shown in ISO 5168.

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

11 Examples

11.1 Example 1

The following is an example of the computation of the flow rate and associated uncertainty in a single measurement of flow using a triangular profile weir, for modular flow conditions. The crest height p above the bed of the approach channel is 1 m and the gauged head h is 0,67 m. The breadth of the weir crest b and the breadth of the approach channel B are both equal to 10 m. A digital punched tape recorder is assumed.

11.1.1 For calculation of the discharge, the equation in 9.1.2 is used. Since the gauged head h is greater than 0,1 m, $C_d = 1,163$. For modular flow the drowned flow reduction factor equals 1.

11.1.2 In order to read C_v from figure 2, it is necessary to evaluate $2/3 \sqrt{2/3} C_d b h/A$ where A is the cross-sectional area of flow in the approach channel, in this case equal to $B(h + p)$ or $10(0,67 + 1) = 16,7 \text{ m}^2$.

Then $2/3 \sqrt{2/3} C_d b h/A = 2/3 \sqrt{2/3} \times 1,163 \times 10 \times 0,67/16,7 = 0,254$.

With this value, from figure 2, $C_v = 1,054$.

11.1.3 Using the equation in 9.1.2,

$$\begin{aligned} Q &= (2/3)^{3/2} C_d C_v f \sqrt{g} b h^{3/2} \\ &= (2/3)^{3/2} \times 1,163 \times 1,054 \times 1 \times \sqrt{9,81} \times 10 \times 0,67^{3/2} \\ &= 11,46 \text{ m}^3/\text{s} \end{aligned}$$

11.1.4 To calculate the uncertainty in this value of Q , the uncertainties in the coefficient values are first determined :

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

$$X''_c = \pm \left(\frac{10 C_v}{f} - 9 \right) \quad (\text{from 9.4})$$

$$= \pm \left(\frac{10 \times 1,054}{1} - 9 \right)$$

$$= \pm 1,54 \%$$

11.1.5 Assuming that several measurements of breadth are taken, the random component of uncertainty in width measurement is likely to be negligible. The systematic uncertainty in length measurement is assumed in this case to be 0,01 m. Accordingly,

$$X'_b = 0$$

$$X''_b = \frac{0,01}{10} \times 100 = \pm 0,1 \%$$

11.1.6 With the equipment used it had 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 reset the true zero will have the same magnitude and sign. Therefore,

$${}_1X'_h = 0$$

$${}_1X''_h = \frac{0,003}{0,67} \times 100 = 0,45 \%$$

11.1.7 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 should be 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. Where possible, corrections should be applied, but controlled tests for given types of equipment will indicate the magnitude of the residual systematic uncertainty. In the present case this was approximately $\pm 2,5$ mm. Accordingly,

$${}_2X'_h = \frac{0,001}{0,67} \times 100 = 0,15 \%$$

$${}_2X''_h = \pm \frac{0,0025}{0,67} \times 100 = 0,37 \%$$

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

The uncertainties in water level measurement are, assuming X'_m is negligible :

$$X'_h = \pm \sqrt{{}_1X'^2_h + {}_2X'^2_h} = \pm \sqrt{0 + 0,15^2} = \pm 0,15 \%$$

$$X''_h = \pm \sqrt{{}_1X''^2_h + {}_2X''^2_h} = \pm \sqrt{0,45^2 + 0,37^2} = \pm 0,58 \%$$

Total random uncertainty in discharge measurement

$$\begin{aligned} X'_Q &= \pm (X'_c{}^2 + X'_b{}^2 + 1,5^2 X'_h{}^2)^{1/2} \\ &= \pm (0,5^2 + 0 + 2,25 \times 0,15^2)^{1/2} \\ &= \pm 0,55 \% \end{aligned}$$

Total systematic uncertainty in discharge measurement

$$\begin{aligned} X''_Q &= \pm (X''_c{}^2 + X''_b{}^2 + 1,5^2 X''_h{}^2)^{1/2} \\ &= \pm (1,54^2 + 0,1^2 + 2,25 \times 0,58^2)^{1/2} \\ &= \pm 1,77 \% \end{aligned}$$

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

$$X_Q = \pm \sqrt{0,55^2 + 1,77^2} = \pm 1,85 \%$$

The flow rate Q may be reported as

$$11,46 \text{ m}^3/\text{s} \pm 1,85 \%; \text{ Random uncertainty} = \pm 0,55 \%$$

11.2 Example 2

The following is an example of the computation of the flow rate and associated uncertainty in a single measurement of flow using a triangular profile weir, for drowned flow conditions. The crest height p is 1 m, and the gauged height h is 2,2 m. The crest tapping head h_p is 1,7 m. The breadth of weir crest b and the breadth of the approach channel B are both equal to 10 m. The same digital punched type recorder is assumed as in the previous example.

11.2.1 Since the gauged head h is greater than 0,1 m, $C_d = 1,163$.

11.2.2 In order to read $C_v f$ from figure 3, it is necessary to evaluate $2/3 \sqrt{2/3} C_d b h/A$ and h_p/h .

$$A = 10 (2,2 + 1) = 32 \text{ m}^2$$

$$\text{Then } 2/3 \sqrt{2/3} C_d b h/A = 2/3 \sqrt{2/3} \times 1,163 \times 10 \times 2,2/32 = 0,436.$$

$$\text{Also, } h_p/h = 1,7/2,2 = 0,773.$$

Then, from figure 3, $C_v f = 0,88$.

11.2.3 Using the equation in 9.1.2,

$$\begin{aligned} Q &= (2/3)^{3/2} C_d C_v f \sqrt{g b h^3/2} \\ &= (2/3)^{3/2} \times 1,163 \times 0,88 \sqrt{9,81 \times 10 \times 2,2^3/2} \\ &= 56,94 \text{ m}^3/\text{s} \end{aligned}$$

11.2.4 The uncertainties in the coefficient values are calculated as follows :

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

Referring to table 1, with $h_p/h = 0,773$ and $2/3 \sqrt{2/3} C_d b h/A = 0,436$, by interpolation $X''_c = \pm 7,6 \%$ approximately.