International Standard ISO 4360

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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

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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.

International Standard ISO 4360 was developed by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, and was circulated to the member bodies in April 1977.

It has been approved by the member bodies of the following countries :

Australia	Germany, F.R.	Portugal
Austria	India	Romania
Canada	Ireland	South Africa, Rep. of
Chile	Italy	Spain
Czechoslovakia	Mexico	Switzerland
Finland	Netherlands	Turkey
France	Norway	USA

The member body of the following country expressed disapproval of the document on technical grounds :

United Kingdom

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 limited to steady flows which are uniquely dependent on the upstream head.

Drowned flows, which depend on downstream as well as upstream levels, are not covered.

The advantages and disadvantages of this type and other types of weirs and flumes, as well as the relative accuracies of these devices, are given in the annex.

2 REFERENCES

ISO 31, *General principles concerning quantities, units and symbols.*

ISO 748, *Liquid flow measurement in open channels — Velocity area methods.*[1]

ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols.*[1]

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units.*

3 DEFINITIONS

For the purpose 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 in accordance with ISO 31 and ISO 1000.

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 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 floods 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) 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

1) Under revision.

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 have an important influence on the performance of a weir, these being determined by the features mentioned above.

Once an installation has been designed, 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 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 10 times its width.

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 greater length of straight approach channel will be required to achieve a regular velocity distribution.

There shall be no baffle nearer to the points of measurements 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 will be 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 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 channel*

The channel downstream of the structure is usually of no importance as such, provided that the weir has been so designed that it cannot become drowned under the operating conditions.

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

A downstream gauge shall be provided to check the modular conditions.

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 float-operated recording-gauge where a continuous record is required, and 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 that 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 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- 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 approach channel 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 shall alternatively 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. 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 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 the stilling-well to enable sediment to settle down.

7.3 Zero setting

A means of checking the zero setting of the head-measuring device shall be provided, consisting of a pointer with its points set exactly level with the crest of the weir and fixed permanently in the approach channel or alternatively in the stilling-well or float-well where provided.

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 TRIANGULAR PROFILE WEIRS

8.1 Specification for the standard weir

8.1.1 *Description*

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 precast concrete sections, carefully aligned and jointed, or may have a non-corrodible metal insert, as an alternative to in-situ construction throughout.

8.1.2 *Dimensions*

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.

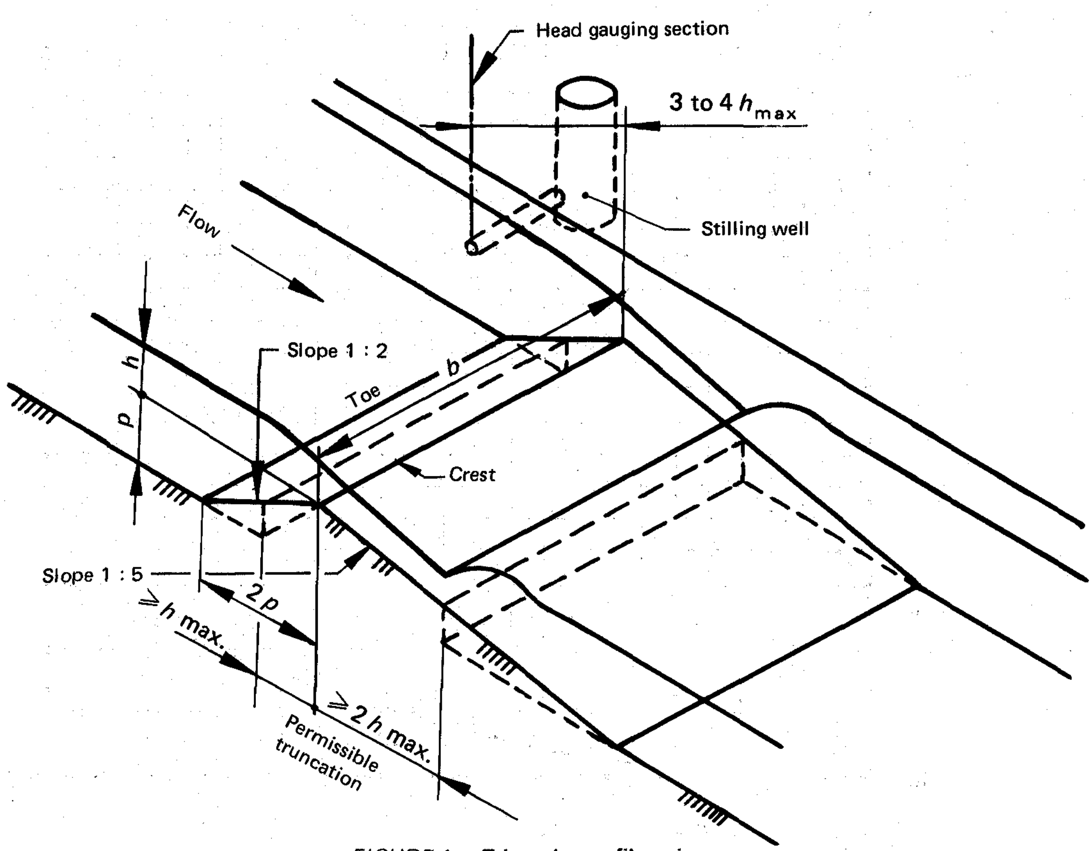

FIGURE 1 — **Triangular profile weir**

8.2 Location of head measurement section

Piezometers or a point-gauge station for the measurement of head on the weir shall be located at 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 three to four times the maximum head ($3\,h_{max}$ to $4\,h_{max}$) upstream from the upstream face of the weir.

8.3 Condition for modular flow

Flow is modular when it is independent of variations in tailwater level. For all flow conditions, the tailwater total head level shall not rise above 75 % of the upstream total head H above crest height, if the flow is not to be affected by more than 1 % for subcritical conditions in the tailwater.

9 DISCHARGE EQUATION

9.1 Equation

The discharge equation is given below :

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

where

Q is the discharge across the weir;

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;

b is the width of the weir;

g is the acceleration due to gravity;

h is the measured head.

9.2 Coefficients

9.2.1 The coefficient C_v is obtained from figure 2. In this figure, A represents the area of the wet cross-section upstream of the weir.

9.2.2 For water at ordinary temperatures, C_D is independent of h, except at very low heads when fluid properties influence the coefficient. For $h \geqslant 0{,}15$ m, C_D is constant and equals 1,150. For $h < 0{,}15$ m, C_D is given by the following equation :

$$C_D = 1{,}150 \left(1 - \frac{0{,}000\,3}{h}\right)^{3/2}$$

where h is in metres.

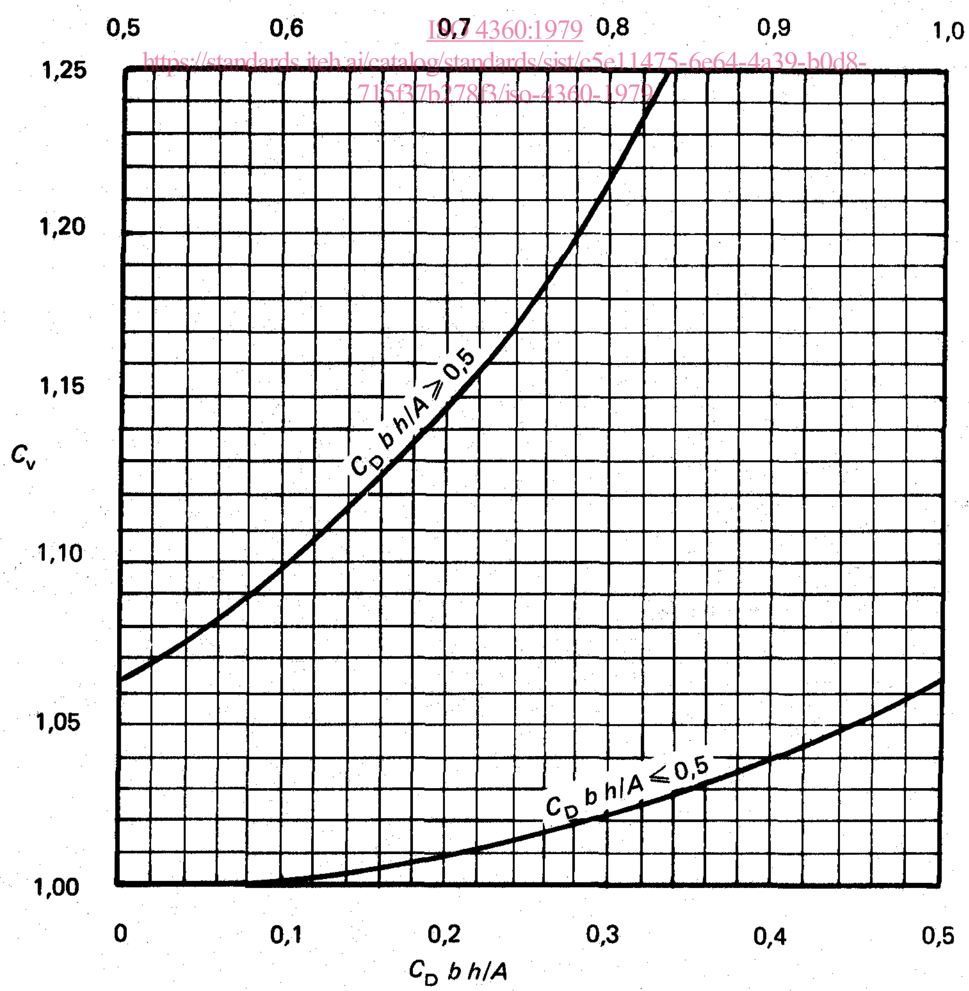

FIGURE 2 — **Coefficient of approach velocity, C_v**

9.3 Limitations

The following general limitations are recommended :

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

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

$p \geqslant 0{,}06$ m;

$b \geqslant 0{,}3$ m;

$h/p \leqslant 3{,}0$;

$b/h \geqslant 2{,}0$.

9.4 Uncertainty of measurement

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

With reasonable care and skill in the construction and installation of a triangular profile weir, the uncertainty in the combined coefficient $C_D C_v$ may be deduced from the equation

$$X_C = \pm (10\, C_v - 9)\ \%$$

The method by which the uncertainties in the coefficients shall be combined with other sources of uncertainty is given in clause 10.

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 effects.

10 UNCERTAINTIES IN FLOW MEASUREMENT

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 they will indicate whether the discharge 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 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 nineteen times out of twenty (the 95 % confidence limits).

The uncertainty shall be calculated according to the method in this clause and quoted under this reference term wherever a measurement is claimed to be in conformity with this International Standard.

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 :

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

where

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

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

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

1) the discharge coefficient C_D and the velocity of approach coefficient C_v. Numerical estimates of uncertainty in the combined coefficient $C_D C_v$ are given in 9.4;

2) the dimensional measurement of the structure, for example the width of weir, b;

3) the measured head, h.

10.2.3 The uncertainty in b and h must 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 uncertainty may prove to be 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 gauge zero, 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 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 measurements under steady conditions may be estimated from the equation :

$$S_y = \left[\frac{\sum_{i=1}^{n} (y_i - \bar{y})}{n-1}\right]^{1/2}$$

where $\bar{y}$ is the arithmetic mean of 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 $S_{\bar{y}}$ (for 95 % probability).[1)] This uncertainty is the contribution of random errors in any series of experimental measurements 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 crest 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 Uncertainties in coefficient values

10.4.1 All errors in this category are systematic.

10.4.2 The values of the 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. 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.

10.4.3 The uncertainty in the coefficients quoted in the preceding sections of this International Standard are based on a consideration of the deviation of experimental data from various sources from the equations given. The suggested uncertainty values 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 methods of measurement nor the way in which they are to be made are specified, no numerical values for uncertainties in this category can be given : they must be estimated by the user. For example, consideration of the method of measuring the weir should permit the user to determine the uncertainty in this quantity.

10.5.3 The uncertainty of the gauged head shall be determined from an assessment of the individual sources of error, for example zero error, the gauge sensitivity, backlash in the indication mechanism, the residual random uncertainty in the mean of a series of measurements, etc. The uncertainty of the gauge head is the square root of the sum of the squares of the individual uncertainties.

10.6 Combination of uncertainties to give total uncertainty on discharge

10.6.1 The total uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties (see 10.5.3).

When partial uncertainties, the combination of which gives the total uncertainty, are independent of one another, are small and numerous and have a Gaussian distribution, there is a probability of 0,95 that the true error is less than the total uncertainty.

10.6.2 The uncertainty on the rate of flow shall be calculated from the following equation :

$$X = \pm \sqrt{X_C^2 + X_b^2 + 1{,}5^2\, X_h^2}$$

where

X_C is the percentage uncertainty on $C_D C_v$;

X_b is the percentage uncertainty on b;

X_h is the percentage uncertainty on h.

In the above, $X_b = \pm\, 100 \times \frac{\epsilon_b}{b}$

and

$$X_h = \frac{\pm\, 100\, ({}_1\epsilon_h^2 + {}_2\epsilon_h^2 + \ldots + 4\, S_{\bar{h}}^2)^{1/2}}{h}$$

where

ϵ_b is the uncertainty in width measurement;

${}_1\epsilon_h$, ${}_2\epsilon_h$, etc. are uncertainties in head measurement (see 10.5.3);

$2S_{\bar{h}}$ is the uncertainty of the mean if a series of readings of the head measurement are taken (see 10.3.2 including footnote).

10.6.3 It should be realized that the uncertainty X is not single valued for a given device, but will vary with discharge. It may therefore be necessary to consider the uncertainty at several discharges covering the required range of measurement.

10.6.4 *Example*

The following is an example of the application of the formula to a single measurement with a triangular profile weir at a crest height above the bed of the approach channel, p, of 1 m and operating at a gauged head of 0,67 m with a breadth of weir crest, b, and breadth of approach channel, B, of 10 m.

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.

The uncertainty on the combined coefficient $C_D C_v$ is given in 9.4 as

$$X_C = \pm (10\, C_v - 9)\ \%$$

$$\frac{C_D\, b\, h}{A} = 1{,}15 \times 10 \times \frac{0{,}67}{10\,(0{,}67 + 1)} = 0{,}461$$

Referring this value to figure 2, $C_v = 1{,}051$.

Hence $X_C = \pm\ 1{,}51\ \%$.

A digital head-measuring device is assumed, operating at 1 mm intervals but with an actual accuracy of ± 3 mm and with zero set to within ± 5 mm.

Thus

$$X_h = \pm\ 100 \times \frac{(0{,}003^2 + 0{,}005^2)^{1/2}}{0{,}67}$$

$$= \pm\ 0{,}87\ \%.$$

If the width of the weir, b, was measured on site to 0,01 m in a total width 10 m,

$$X_b = \pm\ 100 \times \frac{0{,}01}{10} = \pm\ 0{,}10\ \%$$

Thus

$$X = \pm\ (1{,}51^2 + 0{,}10^2 + 1{,}5^2 \times 0{,}87^2)^{1/2}$$

$$= \pm\ 2{,}0\ \%.$$