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Liquid flow measurement in open channels — Round-nose horizontal crest weirs

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Foreword

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

Australia	India	Spain
China	Italy	Switzerland
Czechoslovakia	Netherlands	United Kingdom
France	Romania	USA
Germany, F. R.	South Africa, Rep. of	USSR

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

Belgium

Liquid flow measurement in open channels — Round-nose horizontal crest weirs

1 Scope and field of application

1.1 This International Standard deals with the measurement of flow in rivers and artificial channels under steady flow conditions using round-nose horizontal crest weirs (see figure 1).

1.2 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.

1.3 The round-nose horizontal crest weir has a good discharge range and modular limit and is more appropriate for use in small and medium sized installations. It is particularly robust and insensitive to minor damage.

1.4 Annex A gives the guidelines for the selection of weirs and flumes for the measurement of the discharge of water in open channels.

2 Reference

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

3 Definitions and symbols

For the purpose of this International Standard, the definitions given in ISO 772 apply. A full list of symbols with the corresponding units of measurement is given in annex B.

4 Units of measurement

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

5 Installation

5.1 Selection of site

5.1.1 The weir shall be located in a straight section of channel avoiding local obstructions, roughness or unevenness of the bed.

5.1.2 A preliminary study should be made of the physical and hydraulic features of the proposed site, to check that it conforms (or can be made to conform) to the requirements necessary for measurement of discharge by the weir. Particular attention should be paid to the following features in selecting the site :

a) The adequacy of the length of channel or regular cross-section available (see 5.2.2.2.).

b) The uniformity of the existing velocity distribution (see annex C).

c) The avoidance of a steep channel (but see 5.2.2.6).

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

e) The 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 means of controlling seepage.

g) The necessity for flood banks, to confine the maximum discharge to the channel.

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

j) Uniformity of the section of the approach channel.

k) Effect of wind. Wind can have a considerable effect on the flow over a river, flume or weir, especially when it is wide and the head is small and when the prevailing wind is in a transverse direction.

l) Aquatic weed growth.

m) Sediment transportation.

5.1.3 If the site does not possess the characteristics necessary for satisfactory measurements, or if an inspection of the stream shows that the velocity distribution in the approach channel deviates appreciably from the examples shown in annex C, the site should not be used unless suitable improvements are practicable. Alternatively, the performance of the installation should be checked by independent flow measurement.

5.2 Installation conditions

5.2.1 General requirements

5.2.1.1 The complete measuring installation consists of an approach channel, a weir structure and a downstream channel. The condition of each of these three components affects the overall accuracy of the measurements. Installation requirements include such features as the surface finish of the weir, cross-sectional shape of channel, channel roughness and the influence of control devices upstream or downstream of the gauging structure.

5.2.1.2 The distribution and direction of velocity may have an important influence on the performance of a weir (see 5.2.2 and annex C).

5.2.1.3 Once a weir has been installed, any changes in the systems which affect the basis of the design will change the discharge characteristics.

5.2.2 Approach channel

5.2.2.1 If the flow in the approach channel is disturbed by irregularities in the boundary, for example large boulders or rock outcrops, or by a bend, sluice gate or other feature which causes asymmetry of discharge across the channel, the accuracy of gauging may be significantly affected. The flow in the approach channel should have a symmetrical velocity distribution (see annex C) and this can most readily be achieved by providing a long straight approach channel of uniform cross-section.

5.2.2.2 A length of straight approach channel five times the water surface width at maximum flow will usually suffice, provided flow does not enter the approach channel with high velocity via a sharp bend or angled sluice gate. However, a greater length of uniform approach channel is desirable if it can readily be provided.

5.2.2.3 The length of uniform approach channel suggested in 5.2.2.2 refers to the distance upstream of the head measuring position. However, in a natural channel it would be uneconomic to line the bed and banks with concrete for this distance, and it would be necessary to provide a contraction in plan if the width between the vertical walls of the lined approach to the weir is less than the width of the natural channel. The unlined channel upstream of the contraction should nevertheless comply with the requirements of 5.2.2.1 and 5.2.2.2.

5.2.2.4 Vertical side walls to effect a contraction in plan should be symmetrically disposed with respect to the centre-line of the channel and should preferably be curved with a radius not less than 2 H_{max}. The downstream tangent point shall be at least H_{max} upstream of the head measurement section. The height of the side walls should be chosen such that the design maximum discharge can be contained.

5.2.2.5 In a channel where the flow is free from floating and suspended debris, good approach conditions can also be provided by suitably placed baffles formed of vertical laths, but no baffle should be nearer to the point at which head is measured than 10 H_{max}.

5.2.2.6 Under certain conditions, a hydraulic jump may occur upstream of the measuring structure, for example if the approach channel is steep. Provided the hydraulic jump is at a distance upstream of not less than about 30 H_{max}, flow measurement will be feasible, subject to confirmation that an even velocity distribution exists at the gauging station.

5.2.2.7 Conditions in the approach channel can be verified by inspection or measurement for which several methods are available such as current meters, floats, velocity rods, or concentrations of dye, the last 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. The velocity distribution should then be assessed by reference to annex C.

5.3 Weir structure

5.3.1 The structure shall be rigid and watertight and capable of withstanding flood flow conditions without damage from outflanking or from downstream erosion. The weir crest shall be at right angles to the direction of flow and the geometry shall conform to the dimensions given in relevant clauses.

5.3.2 The surface of the weir, and of the vertical abutments flanking the weir shall be smooth; they can be constructed in concrete with a smooth cement finish, or surfaced with a smooth non-corrodible material. In laboratory installations, the finish should be equivalent to rolled sheet metal or planed, sanded and painted timber. The surface finish is of particular importance on the horizontal crest, but can be relaxed a distance along the profile 1/2 H_{max} upstream and downstream of the crest proper.

5.3.3 In order to minimize uncertainty in the discharge, the following tolerances are acceptable :

— On the crest width, 0,2 % of this width with a maximum 0,01 m.

— On the horizontal surfaces, slopes of 0,1 % (1 mm/m).

The structure shall be measured on completion and at regular intervals thereafter and if it varies from the design dimensions by more than the permissible tolerances, the discharge shall be re-computed.

5.4 Downstream conditions

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

6 Maintenance — General requirements

Maintenance of the measuring structure and the approach channel is important to secure accurate measurements. It is essential that the approach channel is kept clean and free from silt and vegetation as far as practicable for at least the distance specified in 5.2.2.2. 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 taken in the process of cleaning to avoid damage to the weir crest.

7 Measurement of head

7.1 General requirements

7.1.1 Where spot measurements are required, the head upstream of the weir crest can be measured by a vertical or inclined gauge, a hook, point, wire or tape gauges. Where a continuous record is required, a recording gauge shall be used. The location of the head measurement section is dealt with in 8.2.

7.1.2 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 devices become of greater relative importance.

7.2 Gauge well

7.2.1 It is usual to measure the head in a separate gauge well to reduce the effects of surface irregularities. When this is done, it is also desirable to measure the head in the approach channel as a check.

7.2.2 The gauge well shall be vertical and of sufficient height and/or depth to cover the full range of water levels, and have a minimum margin of 0,3 m over the maximum water level estimated to be measured at the recommended position for the measurement of head. The well should be connected to the approach channel by means of a pipe or slot.

7.2.3 Both the well and the connecting pipe or slot shall be watertight, and where the well is provided for the accommodation of the float of a level recorder, it should be of adequate size and depth to give clearance around the float at all stages. The float should not be nearer than 0,075 m to the wall of the well.

7.2.4 The pipe or slot should have its invert not less than 0,06 m below the lowest level to be gauged, and it should terminate flush with the boundary of the approach channel and at right angles thereto. The approach channel boundary should be plain and smooth (equivalent to carefully finished concrete) within a distance of ten times the diameter of the pipe or width of slot from the centreline of the connection. The pipe may be oblique to the wall only if it is fitted with a removable cap or plate, set flush with the wall, through which a number of holes are drilled. The edges of those holes should not be rounded or burred.

7.2.5 Adequate additional depth should be provided in the well to avoid the danger of the float grounding on the bottom or any accumulation of silt or debris. The gauge well arrangement may include an intermediate chamber of similar size and proportions between it and the approach channel, to enable silt and other debris to settle out where they may be readily seen and removed.

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

7.2.7 No firm rule can be laid down for determining the size of the connecting pipe or slot, because this is dependent on the circumstances of the particular installation, for example whether the site is exposed and thus subject to waves, and whether a large diameter well is required to house the floats of recorders. It is preferable to make the connection too large, rather than too small, because a restriction can easily be added later if short period waves are not adequately damped out. A 100 mm diameter pipe is usually suitable for flow measurement in the field. Three millimetres may be appropriate for precision head measurement with steady flows in the laboratory.

7.3 Zero setting

7.3.1 Initial accurate setting of the zero of the head measuring device with respect to the crest level of the weir, and regular checking of this setting thereafter, is essential if overall accuracy is to be attained.

7.3.2 An accurate means of checking the zero shall be provided. The instrument zero should be obtained by a direct reference to the weir crest, and a record of the setting made in the approach channel and in the gauge well. A zero check based on the water level (either when the flow ceases or just begins) is liable to serious errors due to surface tension effects and shall not be used.

8 Round-nose horizontal crest weirs

8.1 Definition

8.1.1 The standard weir comprises a truly level and horizontal crest, between abutments. The upstream corner should be rounded in such a manner that flow separation does not occur, and downstream of the horizontal crest there should be either

a) a rounded corner,

b) a downward slope or,

c) a vertical face.

The weir should be set at right angles to the direction of flow in the approach channel.

8.1.2 The dimensions of the weir and its abutments shall comply with the requirements indicated in figure 1. The radius of the upstream crest shall not be less than 0,2 H_{max}. The length of the horizontal portion of the weir crest should not be less than 1,75 H_{max} nor should the sum of the crest length and nose radius be less than 2,25 H_{max}.

8.2 Location of head measurement section

The head on the weir should be measured at a point far enough upstream of the crest to be clear of the effects of draw-down, but close enough to the weir to ensure that the energy loss between the section of measurement and the upstream edge of the weir crest shall be negligible. It is recommended that the head measurement section be located a distance of between three and four times H_{max} upstream of the weir block.

8.3 Provision for modular flow

Flow is modular when it is independent of variations in tailwater level. For this to occur, assuming subcritical conditions in the tailwater channel, the tailwater total head level must not rise beyond a certain percentage of H. With a vertical downstream face, this percentage is dependent on H/p_d : 63 % for low values of H/p_d, rising to 75 % at H/p_d of 0,5 and 80 % at H/p_d of 1,0 and over. If the weir block has a downstream slope flatter than 1 in 5, the modular limit may be taken as 5 % higher throughout. In the above, p_d is the height of the crest above downstream bed level.

9 Discharge equations

9.1 Basic equation

9.1.1 Critical depth theory, augmented by experimental data, has shown that the discharge over a round-nose horizontal crest weir may be represented by the following equation :

$$Q = \left(\frac{2}{3}\right)^{3/2} C_D\, b \sqrt{g}\, H^{3/2} \qquad \ldots (1)$$

where

Q is the discharge;

C_D is the coefficient of discharge (non dimensional);

g is the gravitational acceleration;

b is the width of weir crest;

H is the total head.

9.1.2 Since the total head, H, cannot be measured directly, the discharge equation in terms of gauged head, h, relative to crest level may be written as follows :

$$Q = \left(\frac{2}{3}\right)^{3/2} C_D\, C_v\, b \sqrt{g}\, h^{3/2} \qquad \ldots (2)$$

where C_v is a further dimensionless coefficient allowing for the effect of approach velocity on the measured water level upstream of the weir.

By definition

$$C_v = \left(\frac{H}{h}\right)^{3/2} \qquad \ldots (3)$$

9.1.3 The total head is related to the gauged head by the equation :

$$H = h + \alpha \bar{v}^2/2g \qquad \ldots (4)$$

where $\bar{v}$ is the local mean velocity in the approach channel at the cross-section where the head is measured and α is a coefficient (the kinetic energy or Coriolis coefficient) which takes account of the fact that the kinetic energy head exceeds $\bar{v}^2/2g$ if the velocity distribution across the section is regular but not uniform[1]. In applying this equation in this International Standard, α may be taken as unity, with the tolerances given in later clauses and the provisions of 5.2 and annex C in mind.

9.1.4 From equations (2), (3) and (4), it may be deduced that

$$\frac{3\sqrt{3}\,(C_v^{2/3} - 1)^{1/2}}{C_v} = \frac{2\, C_D\, b\, h}{A} \qquad \ldots (5)$$

where A is the cross-sectional area of the approach channel below the observed water level, at the gauging section.

Thus C_v may be deduced in terms of $C_D\, b\, h/A$. To avoid the complicated solution of equation (5) in deducing C_v, figure 2 has been prepared to give the relation between C_v and $C_D\, b\, h/A$. The value of C_D can be obtained by using equation (6) or [6a)].

9.2 Computation of discharge

9.2.1 There are two common methods of computing discharge from gauged head readings. The first obtains results by successive approximation techniques and utilises the basic "total head" equations. This method is admirably suited to solutions by computer techniques since the computer provides

1) The formulae given in this International Standard were derived from experiments where the approach channel velocity distribution was fairly uniform and hence α approximates to unity. If a velocity study at the gauging section indicates that $\alpha > 1{,}25$ the station clearly does not meet the provisions of 5.2 and improvements to the approach channel are necessary. Very approximately :

$$\alpha = 1 + 3e^2 - 2e^3$$

where $e = \frac{v_{max}}{\bar{v}} - 1$

v_{max} being the highest velocity observed at the cross-section where the head is measured.

an efficient way of carrying out the repetitive calculations involved. The second method utilises relationships which can be derived between gauges and total heads for particular weir and flow geometries. These enable the coefficient of velocity, C_v, in the discharge equation to be assessed from tables and graphs.

9.2.2 The basic discharge equation is given in 9.1 in terms of both total and gauged head. Equation (2) may be used to evaluate discharge, with the appropriate value of C_v, read from figure 2.

9.2.3 For water at ordinary temperatures, C_D is a function of head, h, the crest length in the direction of flow, the roughness of the crest, and the ratio h/b. It can be expressed by the equation

$$C_D = \left(1 - \frac{2xL}{b}\right)\left(1 - \frac{xL}{h}\right)^{3/2} \qquad \ldots (6)$$

where

L is the length of the horizontal section of the crest in the direction of flow;

$x = \frac{\delta_*}{L}$ is a factor which allows for the influence of the boundary layer of the crest.

Where δ_* is the boundary layer thickness.

For most installations with a good surface finish the value of δ_*/L will in practice lie in the range 0,002 to 0,004. Provided $10^5 > L/k > 4\,000$ (k is the roughness value) and $Re > 2 \times 10^5$ (Re is the Reynolds number), δ_*/L may be assumed equal to 0,003 without introducing much error. Equation (6) then becomes :

$$C_D = \left(1 - \frac{0{,}006\,L}{b}\right)\left(1 - \frac{0{,}003\,L}{h}\right)^{3/2} \qquad \ldots (6a)$$

An example illustrating a more accurate method of calculating C_D based on the boundary layer displacement thickness concept is shown in annex D.

9.3 Limits of application

9.3.1 The practical lower limit of h is related to the magnitude of the influence of fluid properties and boundary roughness. The recommended lower limit is 0,06 m or 0,03 L, whichever is the greater.

9.3.2 The limitations on H/p arise from difficulties experienced when the Froude number in the approach channel exceeds 0,5, coupled with inadequate experimental confirmation at high values of H/p. The recommended upper limit is $H/p = 1{,}5$.

9.3.3 H/L shall not exceed 0,57 and this limitation on H/L arises from the necessity to ensure parallel flow at the critical section on the crest.

9.3.4 The height of the weir, p, should not be less than 0,15 m. The crest width b shall not be less than 0,30 m nor less than H_{max}, nor less than $L/5$.

9.4 Accuracy

With reasonable care and skill in the construction and installation of a round-nose horizontal crest weir, the uncertainty in the coefficient of discharge (including C_v) may be deduced from the equation :

$$X_c = \pm 2(21 - 20\,C_D)\ \% \qquad \ldots (7)$$

The method by which the uncertainty in the coefficient may be combined with other sources of uncertainty is described in 10.6.

10 Errors in flow measurement

10.1 General

10.1.1 The uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. The assessment of these contributions to the total uncertainty will indicate whether the rate of flow can be measured with sufficient accuracy for the purpose in hand. This clause is intended to provide sufficient information for the user of this International Standard to estimate the uncertainties of measurement of discharge (see ISO 5168).

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").

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 :

$$Q = \left(\frac{2}{3}\right)^{3/2} C_D\, C_v\, b\,\sqrt{g}\, h^{3/2} \qquad \ldots (2)$$

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 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 :

a) The discharge coefficient C_D and the velocity of approach coefficient C_v. Numerical estimates and uncertainties in the combined coefficient $C_v\,C_D$ are given in 9.4.

b) The dimensional measurement of the structure, for example the width of weir, b.

c) The measured head, h.

10.2.3 The uncertainties in b and h have to be estimated by the user. The uncertainty in dimension 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 may be small if a Vernier or micrometer instrument is used, with a zero determination of comparable precision.

10.3 Kinds of errors

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

10.3.2 The standard deviation of a set of measurements of a variable Y under steady conditions may be estimated from the equation :

$$s_Y = \left[\int_1^n \frac{(\bar{Y} - Y)^2}{n - 1} \right]^{1/2} \qquad \ldots (8)$$

where $\bar{Y}$ is the observed mean.

The standard deviation of the mean is then given by :

$$s_{\bar{Y}} = \frac{s_Y}{\sqrt{n}} \qquad \ldots (9)$$

and the uncertainty of the mean is twice $s_{\bar{Y}}$ (for 95 % probability) if the number of measurements is large.

This is the contribution of random uncertainty in experimental measurements to the total uncertainty of the mean.

10.3.3 A measurement can 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 the 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 can only be determined by an independent measurement known to be more accurate.

10.4 Errors in coefficient values

10.4.1 All errors in this category are systematic.

10.4.2 The values of the discharge coefficient C_v and C_D 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 occur, which may be attributed to variations in the surface finish of the device, its installation, the approach conditions, etc.

10.4.3 The uncertainties in the coefficients quoted in the preceding clauses of this International Standard are based on a consideration of the spread of experimental data from various sources about the mean values of these coefficients. The uncertainties thus represent the accumulation of evidence at the time of publication.

10.5 Errors in measurement

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 discharges given by the equation are volumetric figures, and the fluid density does not affect the volumetric discharge for a given head provided the operative head is gauged in fluid 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 fluid. However, it is assumed here that the densities are equal.

10.5.4 The uncertainty of the gauged head should be determined from an assessment of the separate sources of uncertainty for example, the zero uncertainty, 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 gauged head is the square root of the sum of the squares of the separate uncertainties.

10.5.5 The above component uncertainties should be calculated as percentage standard deviations at the 95 % confidence limits but when the value of a component uncertainty is determined from only a single measurement, the uncertainty is said to be rectangularly distributed and can be taken, for the purposes of this International Standard, to be the (plus or minus) limits within which the true value is known to lie with certainty (i.e. half the estimated maximum deviation)[1].

1) The standard deviation of a rectangular distribution between limits $\pm\, X$ is $X/\sqrt{3}$ and the 95 % confidence limits, treating this standard deviation as if it referred to a normal distribution, are $\pm\, 2\, X/\sqrt{3}$ or $\pm$ 1,15 X. It is thus sufficient to take the tolerance as equal to $\pm\, X$.

10.6 Combination of uncertainties to give overall uncertainty on discharge

10.6.1 The total uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties (see 10.5.4).

10.6.2 The uncertainty of the rate of flow is to be calculated from the following equation :

$$X = \pm \sqrt{(X_c^2 + X_b^2 + 2{,}25\, X_h^2)}$$

where

X_c is the percentage uncertainty in $C_v C_D$;

X_b is the percentage uncertainty in b;

X_h is the percentage uncertainty in h.

In the above, $X_b = 100 \times \dfrac{\varepsilon\, b}{b}$

and $X_h = \dfrac{\pm 100 \left[{}_1\varepsilon_h^2 + {}_2\varepsilon_h^2 + \ldots (2\, s_{\bar{h}})^2\right]^{1/2}}{h}$

where

ε_b is the uncertainty in width measurement;

${}_1\varepsilon_h^2$, ${}_2\varepsilon_h^2$, etc., are uncertainties in head measurement (see 10.5.4); and

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

10.6.3 The uncertainty X[1)] 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 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 of 10 m and weir crest length L of 2 m. Ten successive readings of the head gave a standard deviation of the mean $s_{\bar{h}}$ as 1 mm.

$$C_D = \left(1 - \frac{0{,}006\, L}{b}\right)\left(1 - \frac{0{,}003\, L}{h}\right)^{3/2}$$

$$= \left(1 - \frac{0{,}006 \times 2}{10}\right)\left(1 - \frac{0{,}003 \times 2}{0{,}67}\right)^{3/2}$$

$$= 0{,}998\,8 \times (0{,}991)^{3/2}$$

$$= 0{,}998\,8 \times 0{,}986\,5$$

$$C_D = 0{,}985\,3$$

The uncertainty of coefficient is given in 9.4 :

$$X_c = \pm\, 2\,(21 - 20\, C_D)\ \%$$

$$X_c = \pm\, 2\,(21 - 19{,}71)$$

$$X_c = \pm\, 2{,}58\ \%$$

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

$$X_h = \frac{\pm 100\, [0{,}003^2 + 0{,}005^2 + (2 \times 0{,}001)^2]^{1/2}}{0{,}67}$$

$$X_h = \pm\, 0{,}92\ \%$$

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

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

Thus

$$X = \pm\, (2{,}58^2 + 0{,}1^2 + 2{,}25 \times 0{,}92^2)^{1/2}$$

$$X = \pm\, 2{,}93\ \%$$

Annex A

Guide for the selection of weirs and flumes for the measurement of the discharge of water in open channels

(This annex forms part of the standard.)

A.1 Scope and field of application

This annex lays down guidelines for the selection of weirs and flumes for the measurement of discharge in open channels. Consideration is limited to the steady, uniform flow of water at ordinary temperatures (approximately 5 to 30 °C).

Despite the great number of types of weirs and flumes available, some of which may offer advantages for specific purposes, only the following types are presently standardized. Criteria for selection from among the standard types are given in clause A.3.

A.2 Types of standard weirs and flumes

A.2.1 Thin-plate weir

A weir constructed with a crest of vertical thin plate, shaped in such a manner that the nappe springs clear of the crest, the discharge being determined by the head on the weir and the width of the crest (or the angle of the notch).

The following types are included :

- rectangular full-width weir;
- rectangular-notch weir;
- triangular-notch (V-notch) weir.

A.2.2 Broad crested weir

A weir with substantial crest dimension in the direction of flow formed in such a manner that critical flow occurs on the crest of the weir within the breadth, the discharge being determined by the head on the weir and the width of the crest.

- rectangular-profile weir with sharp upstream edge;
- rectangular-profile weir with rounded upstream edge.

A.2.3 Triangular-profile weir

A weir having a triangular profile in the direction of flow, the discharge being determined by the head over the weir and the width of the crest.

The following type is included :

- triangular-profile weir having 1 : 2 slope upstream and 1 : 5 downstream.

A.2.4 Standing-wave flume (free flow)

A flume with side contractions with or without bottom contractions, within which the flow changes from sub-critical to supercritical, the discharge being determined by the cross-sectional area and velocity of flow at critical depth within the throat of the flume.

The following types are included :

- with rectangular throat;
- with trapezoidal throat;
- with U-throat.

A.2.5 Free overfall

An abrupt drop in the floor of a rectangular channel, the discharge being determined by the depth at the brink of the drop and the width of the channel at the brink section.

A.3 Criteria for the selection of standard weirs or flumes

The essential criteria for selection from among the standard weirs and flumes are given below :

A.3.1 Available difference in water levels

Thin-plate weirs and free overfalls require a sufficient difference between upstream and downstream water levels which will ensure free, fully-ventilated flow under conditions of maximum discharge.

Broad crested weirs may be used with relatively smaller differences in water level; triangular-profile weirs and standing-wave flumes may be used with even smaller differences in water level.

For all types of weirs and flumes included in this International Standard, the discharge should be free or independent of the downstream water level.

A.3.2 Accuracy of measurement

The accuracy in a single determination of discharge depends upon the estimation of the component uncertainties involved but approximate ranges of uncertainties for the weirs and flumes (at 95 % confidence levels) are as follows :

- rectangular thin-plate weirs (full width and notch) : 1 to 4 %;

— triangular-notch weirs (notch angles between $\pi/9$ and $5\pi/9$ radians) : 1 to 2 %;

— broad crested weirs : 3 to 5 %;

— triangular-profile weirs : 2 to 5 %;

— standing-wave flumes : 2 to 5 %;

— free overfall : 5 to 10 %.

Deviations from standard construction, installation or use may result in larger measurement errors. The larger figures given above are recommended conservative values for use under conditions of strict conformance with standard specifications. The smallest values can be obtained only for weirs under rigorous control, such as may be built and installed in well-equipped laboratories. Under field conditions, thin-plate weirs are specially subject to errors caused by natural hazards.

A.3.3 Dimensions and shape of open channel

Rectangular full-width weirs and notch weirs (both rectangular and triangular), of large size relative to the size of the approach channel, should be located in vertical-walled level-floored rectangular channels, or in weir boxes of rectangular cross-section for a distance extending upstream not less than ten times the width of the nappe at maximum head. For thin-plate weirs of small size relative to the size of the approach channel, especially if the velocity of approach is negligible, the size and shape of the channel is of no importance.

Broad crested weirs are best used in rectangular channels, but they can be used with good accuracy in non-rectangular channels if a smooth, rectangular approach channel extends upstream from the weir a distance not less than twice the maximum head.

Flumes can be used in channels of any shape if flow conditions in the approach channel are reasonably uniform and steady.

For weirs and flumes of all types the size and shape of the downstream channel are of no significance except that they must permit free, fully-ventilated flow under all conditions of use.

A.3.4 Flow conditions in the approach channel

For weirs of all types, flow in the approach channel shall be sub-critical, uniform and steady. Ideally, especially for relatively high velocities of approach, the velocity distribution should approximate that in a channel of sufficient length to develop normal (resistance-controlled) flow in straight, smooth channels. For relatively low velocities of approach and for flumes, flow conditions in the channel are of less importance. In short channels and weir boxes, baffles and flow-straighteners may be used to establish a normal velocity distribution. Care should be taken to ensure that erosion and/or deposition upstream of the weir or flume do not significantly alter the velocity of approach or velocity distribution to the measurement structure.

Sub-critical flow is ensured when

$$\bar{v} < \sqrt{\frac{g A}{B_s}}$$

where

$\bar{v}$ is the average velocity in the approach channel, in metres per second;

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

A is the cross-sectional area of the approach channel, in square metres;

B_s is the width of the approach channel at the water surface, in metres.

A.3.5 Flow with sediment load

For flows with suspended load, the use of thin-plate weirs should be avoided because the crest edge may be damaged or worn by the suspended materials. On streams with bed load use of measurement structures which significantly reduce the stream velocity is not recommended as it may result in changing deposition-scour dependent on flow regime. Flumes will generally perform better than weirs on streams with sediment load.

A.3.6 Flow with floating debris

Broad crested weirs, triangular-profile weirs, standing wave flumes and free overfall structures will normally pass floating debris more effectively than thin-plate weirs. The use of the triangular notch (V-notch) weir in particular should be avoided unless a debris trap is installed upstream.

A.3.7 Magnitude of discharge to be measured

For reasons related to accuracy and construction, thin-plate weirs are best used for the measurement of relatively small discharges. Broad crested weirs, triangular-profile weirs and flumes are best used for large discharges.

A.3.8 Range of discharge to be measured

For best overall accuracy over a wide range of small discharges, a triangular-notch (V-notch) weir should be used in preference to a rectangular-notch or rectangular full-width weir. For a wide range of larger discharges, a trapezoidal-throat or U-throat flume should be used in preference to a broad crested weir, free overfall, rectangular-throated flume or triangular-profile weir.

A.3.9 Construction

Thin-plate weirs should be constructed with precision tools under machine-shop conditions. Flumes, broad crested weirs, triangular-profile weirs and free overfalls can be constructed satisfactorily in the field. In all cases, great care must be exercised in making the structures conform with standard specifications.

Broad crested weirs, triangular-profile weirs, free overfalls and flumes are inherently stronger and more easily maintained under conditions of high heads in large channels.