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Measurement of liquid flow in open channels by weirs and flumes — Streamlined triangular profile weirs

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

Reference number
ISO 9827:1994(E)

Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9827 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 2, *Notches, weirs and flumes*.

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Measurement of liquid flow in open channels by weirs and flumes — Streamlined triangular profile weirs

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1 Scope

This International Standard specifies methods for the measurement of the flow of water in open channels under steady flow conditions using streamlined triangular profile weirs. The flow conditions considered are free flow, which is dependent on the upstream head only, and drowned flow, which depends on both upstream and downstream water levels.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 748:—[1], *Measurement of liquid flow in open channels — Velocity-area methods.*

ISO 772:—[2], *Measurement of liquid flow in open channels — Vocabulary and symbols.*

ISO 5168:—[3], *Measurement of fluid flow — Evaluation of uncertainties.*

3 Definitions

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

4 Units of measurement

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

5 General requirements

Conditions regarding preliminary survey, selection of site, installation, approach channel, maintenance, measurement of head and wells which are generally necessary for flow measurement are given in 5.1 and 5.2. The particular requirements for streamlined triangular profile weirs are given separately in clause 8.

5.1 Site selection

A preliminary survey shall 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 by a weir.

Particular attention shall be paid to the following features:

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

b) flow velocity distribution;

c) absence of a steep channel, if possible;

1) To be published. (Revision of ISO 748:1979)

2) To be published. (Revision of ISO 772:1988)

3) To be published. (Revision of ISO 5168:1978)

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

e) sediment content of the stream and possibility of heavy deposition just upstream of the weir, affecting its performance;

f) permeability of the ground on which the structure is to be founded and the need for piling, grouting or other sealing-in river installations;

g) necessity for flood banks to confine the maximum discharge to the channel;

h) stability of the banks and the necessity for trimming and/or revetment of natural channels;

i) removal of rocks or boulders from the bed of the approach channel;

j) effects of wind, which 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 the weir.

If the existing velocity distribution is irregular and no other site for a gauge is feasible, the distribution shall be checked after the installation of the weir and improved 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 using a current meter. Further information on 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 condition of each of these components affects the overall accuracy of the measurements.

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

The distribution and direction of velocity have an important influence on the performance of a weir, which is determined by the features mentioned above.

Once an installation has been designed and constructed, the user shall avoid 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. These criteria can usually be verified by inspection or measurement. In the case of natural streams or rivers, they can only be met by 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 change in flow conditions due to construction of the weir may cause buildup of shoals of debris upstream of the structure, which in time might affect the flow conditions.

In an artificial channel the cross-section shall be uniform and the channel shall be straight for a length equal to at least 5 times its width measured from the upstream toe of the weir.

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. Baffles in the approach channel shall not be closer to the point of measurement than a distance of 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 approach to the weir. If a standing wave occurs within this distance the approach conditions and/or gauging device shall be modified.

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5.2.3 Measuring structure

The gauging structure shall be rigid, watertight and capable of withstanding flood flow conditions without displacement, 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. The construction shall satisfy the following tolerances:

— on the width and height of the weir: 0,5 %;

— on the radius of the crest: 1 %;

— on the upstream and downstream slopes: 1 %.

5.2.4 Downstream of the structure

The channel downstream of the structure is usually of no importance if the weir has been designed to operate under modular conditions. However, if the weir is designed to measure the flow also under drowned conditions, the downstream channel shall be straight for a length of at least 8 times the maximum head to be measured. The flow must be subcritical in the downstream channel.

A downstream gauge shall be provided to obtain the submergence ratio.

6 Maintenance

Maintenance of the measuring structure and the approach channel is an important factor for accurate continuous measurements.

It is essential that the approach channel to weirs be kept clean and free from silt and vegetation as far as practicable for at least the distance specified in 5.2.2 and 5.2.4. 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 during cleaning to avoid damage to the weir crest.

7 Measurement of head

7.1 General

The heads upstream and downstream 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. It is preferable to measure heads in a separate stilling well to reduce the effects of surface irregularities. Other head measuring methods may be used provided that sufficient accuracy is obtainable.

The discharges given by the working equations are volumetric, the liquid density having no effect on 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 here that the densities are equal.

7.2 Stilling or float well

Where provided, the stilling well should 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 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 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 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.

7.3 Zero setting

A means of checking the zero setting of the head measuring device shall be provided, consisting of a pointer 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 flow ceases is liable to serious error from surface tension effects and shall not be used.

The smaller the size of the weir and the head on it, the greater the importance of small errors in construction and in the zero setting and reading of the head-measuring device.

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8 Streamlined triangular profile weirs

8.1 Specification for a standard weir

The streamlined triangular profile weir is a triangular profile weir in which the sharp edge between the two sloping faces is replaced by a circular arc connecting the two faces tangentially. The weir comprises an upstream slope of 1 (vertical) to Z_1 (horizontal) and a downstream slope of 1 (vertical) to Z_2 (horizontal), with a circular arc connecting the two slopes tangentially. The crest of the standard weir shall be horizontal and at right angles to the direction of flow in the approach channel. The crest and the sloping surfaces shall be smooth. The width of the weir perpendicular to the direction of the flow shall be equal to the width of the channel in which the weir is located. The details of weirs covered by this International Standard are given in table 1.

Table 1 — Details of weirs

Weir No.	Z_1	Z_2	L/P	R_c/P	R_c/P^*	P/P^*
1	1	3	4,50	0,87	0,77	0,89
2	1	5	6,50	0,98	0,91	0,92
3	2	5	7,50	1,47	1,37	0,93
4	0	2	2,25	0,20	0,18	0,89
5	0,577	4,7	5,46	0,22	0,21	0,97

In table 1, L is the length of the weir in the direction of flow, P is the height of the weir with respect to the bottom of the approach channel (see figure 1), R_c, the radius of the circular arc crest and P^* are defined in figure 2.

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 is negligible. It is recommended that the head-measurement section be located at a distance equal to 3 to 4 times the maximum head ($3\ h_{max}$ to $4\ h_{max}$) upstream from the crest of the weir, as shown in figure 1.

8.3 Location of tail water level measurement section

Piezometers or a point-gauge station for the measurement of tail water level shall be located at sufficient distance downstream from the weir to avoid regions of fluctuations. Generally, it is recommended that the tail water level measurement section be located at a distance of 5 to 6 times the maximum head ($5\ h_{max}$ to $6\ h_{max}$) downstream from the toe of the downstream face of the weir, so that the measurement is free of unstable water surface or is downstream of a jump if it occurs.

8.4 Conditions for modular flow

Flow is modular when it is independent of variations in the tail water level. For each shape of weir covered by this International Standard, values for the modular limit σ_c are given in 9.2.2. The tail water head shall not rise above σ_c times the upstream head above the crest level, so that the flow is not affected by more than 1 %.

9 Discharge calculation

9.1 Discharge equation

The discharge equation is as follows:

$$Q = \left(\frac{2}{3}\right)^{3/2} C_{dr}\, C \sqrt{g}\ b\ h^{3/2}$$

where

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

C is the coefficient of discharge based on gauged head, non-dimensional;

h is the measured head, in metres;

C_{dr} is the submerged or drowned flow coefficient, non-dimensional;

b is the width of the weir perpendicular to the direction of flow, in metres;

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

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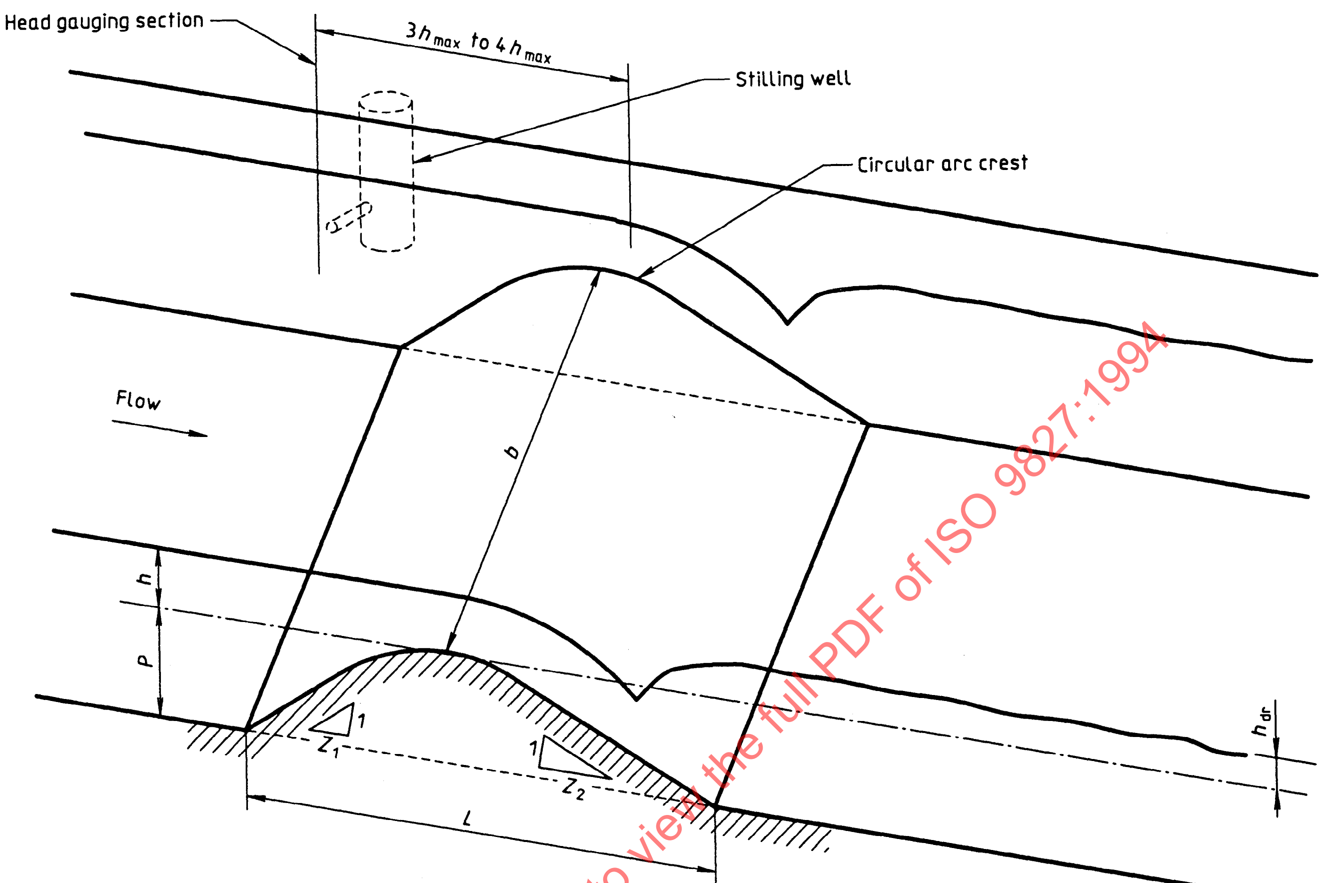

Figure 1 — Streamlined triangular profile weir

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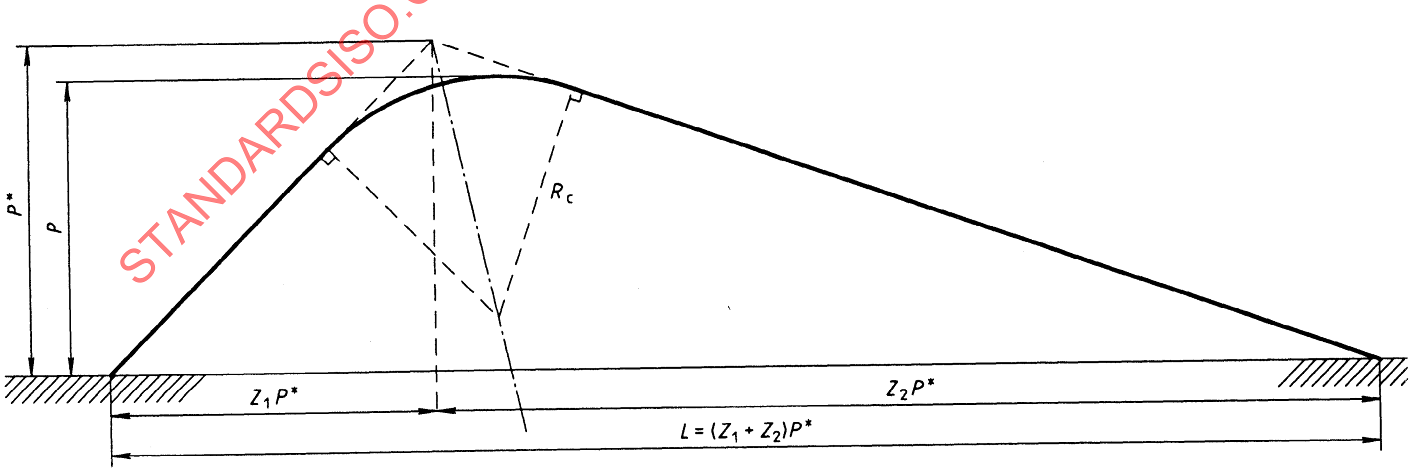

Figure 2 — Detail of weir profile

9.2 Coefficients

9.2.1 Discharge coefficient, C

The relationship of the coefficient C as a function of h/P is given in figures 3 to 7 for the five weirs given in table 1.

9.2.2 Modular limit, σ_c

The modular limit σ_c is taken as that submergence ratio $\sigma = h_{dr}/h$ (where h_{dr} is the tail water head over the crest) above which reduction of the discharge exceeds 1 % of its free or modular flow discharge. The modular limits for the weir shapes listed in table 1, excepting weir No. 5, are given in table 2.

Table 2 — Modular limit

Weir No.	Modular limit σ_c
1	0,75
2	0,81
3	0,81
4	0,68

9.2.3 Drowned flow coefficient, C_{dr}

For free flow and submerged flow with submergence ratio less than the modular limit specified in 9.2.2, the drowned flow coefficient C_{dr} may be taken to be unity. For submergence ratios beyond the modular limit, the relationship of C_{dr} as a function of σ is given in figures 8 to 11 for the first four weir shapes listed in table 1. For weir No. 5, drowned flow data are not available and hence its use is to be restricted to modular flow.

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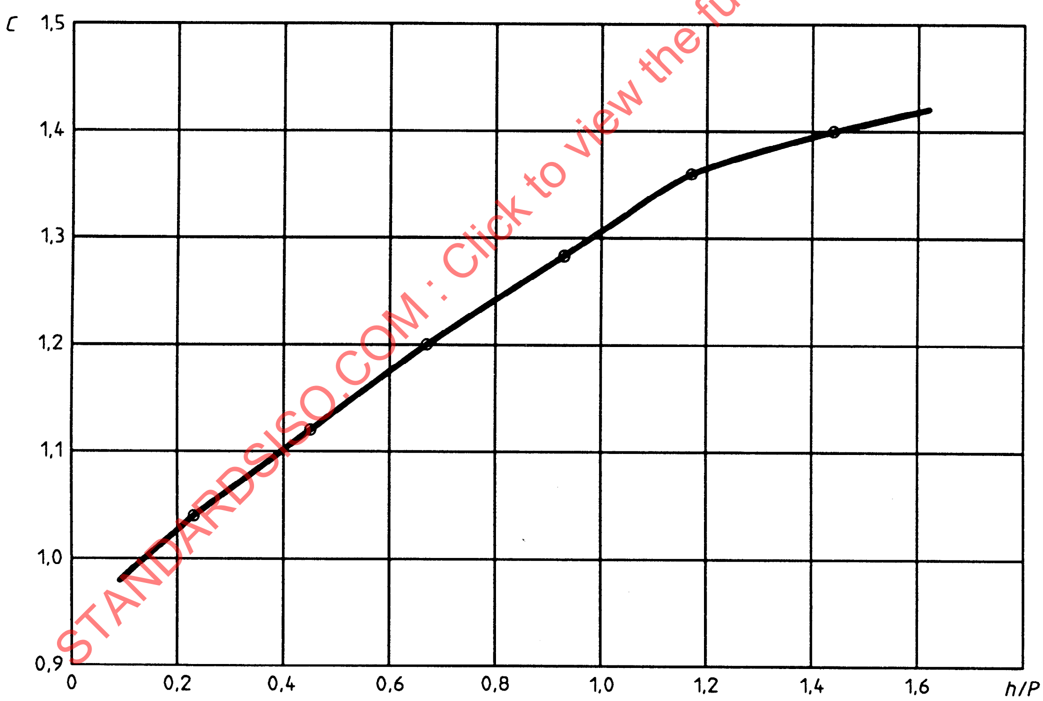

Figure 3 — Variation of coefficient of discharge for weir 1

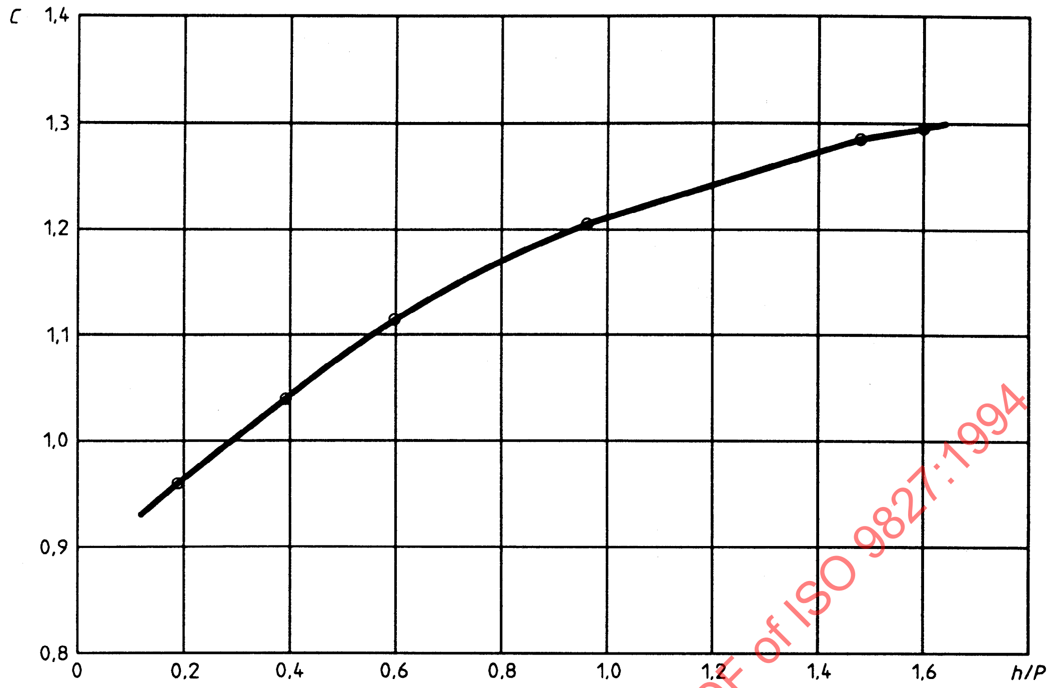

Figure 4 — Variation of coefficient of discharge for weir 2

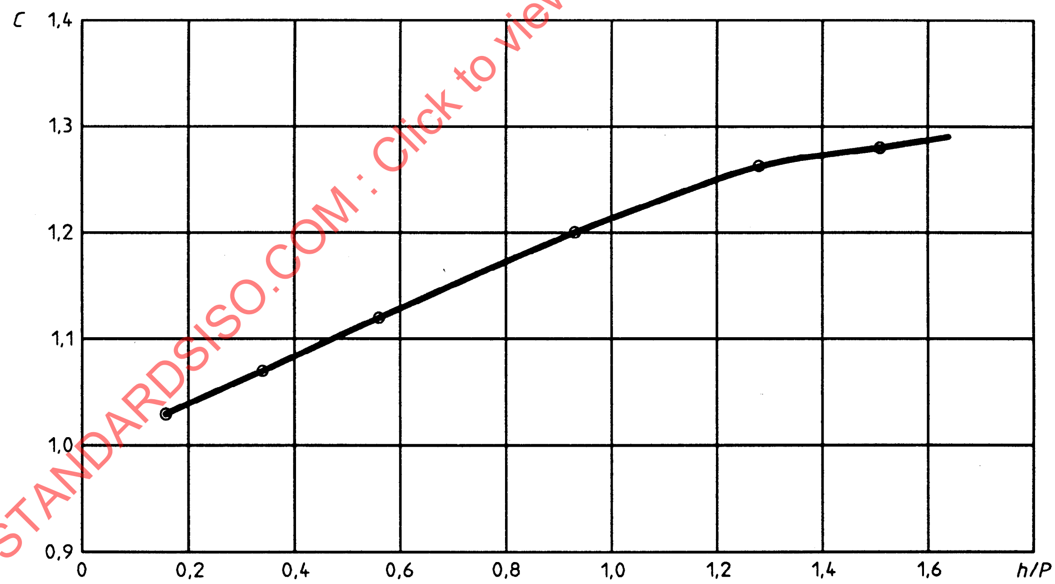

Figure 5 — Variation of coefficient of discharge for weir 3

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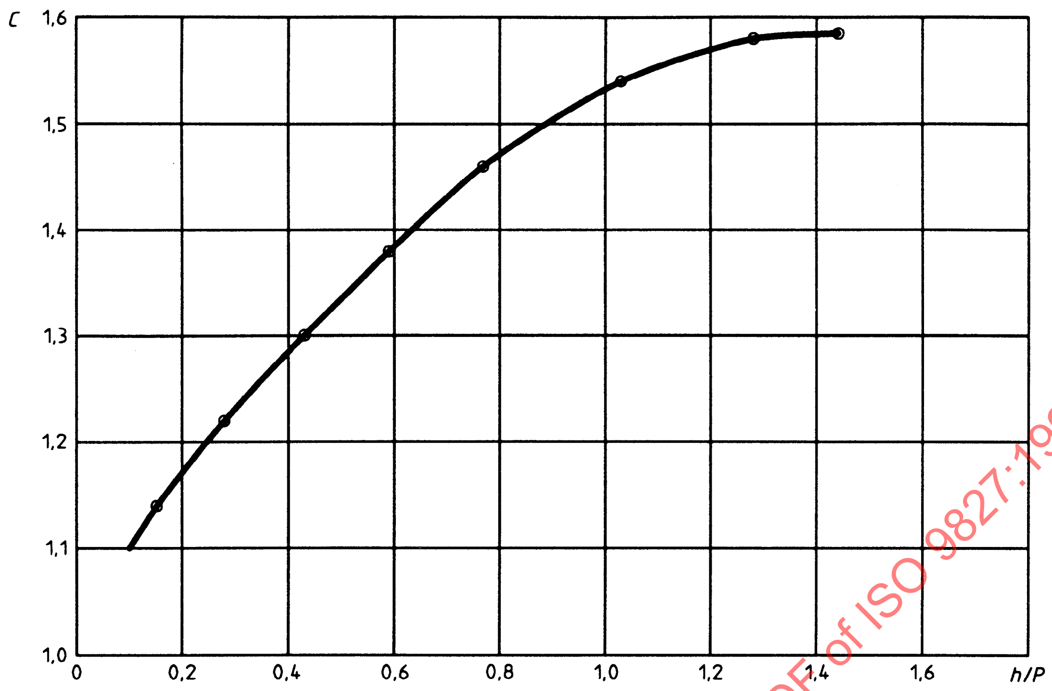

Figure 6 — Variation of coefficient of discharge for weir 4

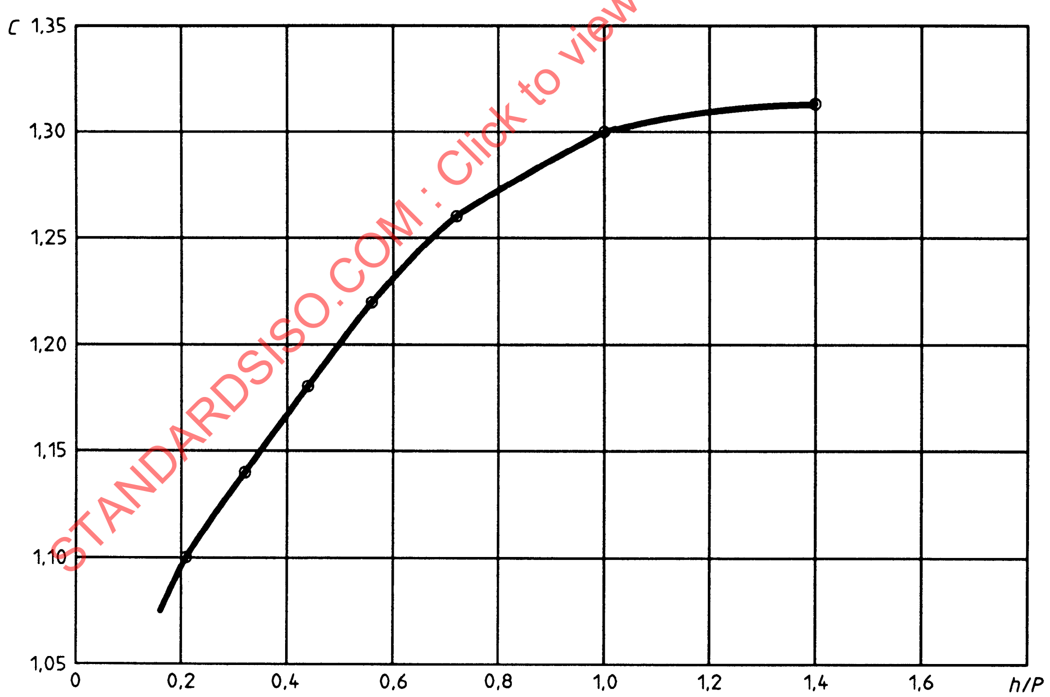

Figure 7 — Variation of coefficient of discharge for weir 5

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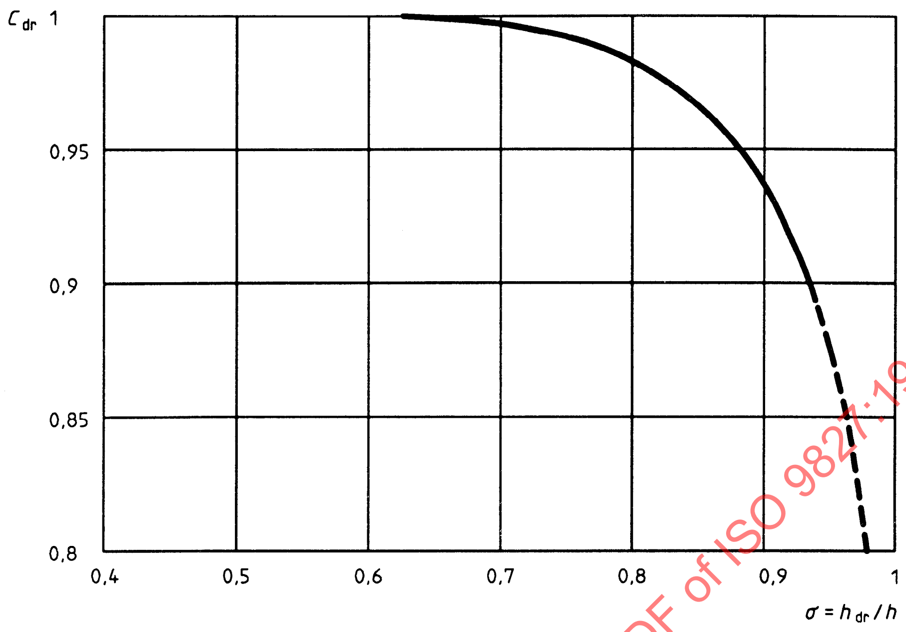

Figure 8 — Variation of discharge reduction factor for submerged flow (weir 1)

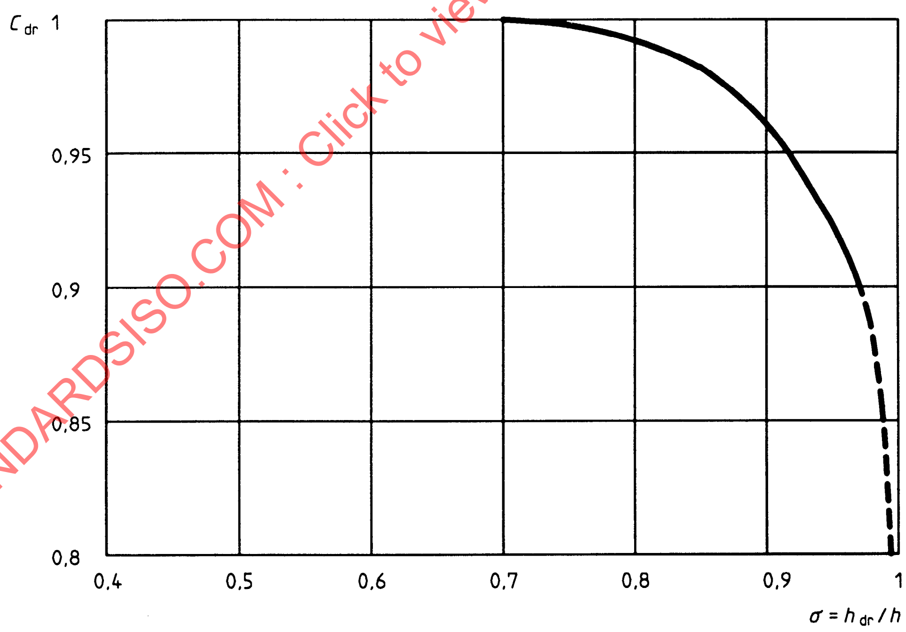

Figure 9 — Variation of discharge reduction factor for submerged flow (weir 2)

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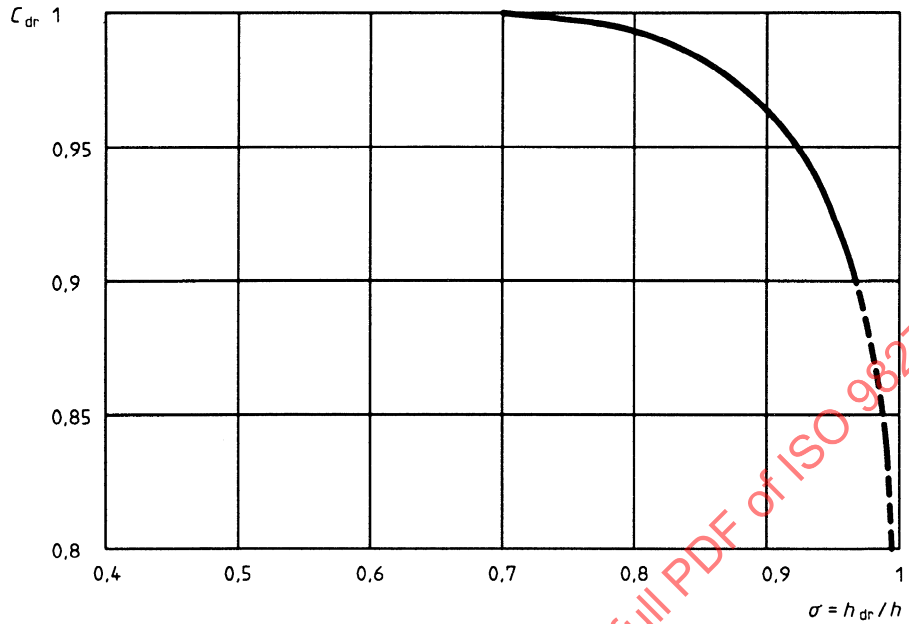

Figure 10 — Variation of discharge reduction factor for submerged flow (weir 3)

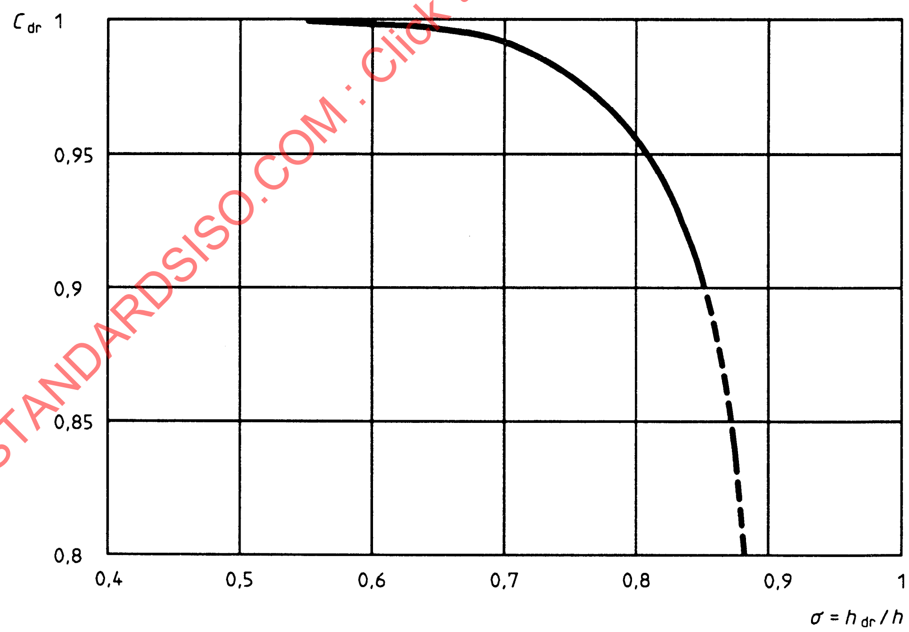

Figure 11 — Variation of discharge reduction factor for submerged flow (weir 4)

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9.3 Limitations

The following general limitations are recommended to avoid surface tension and viscosity effects:

$h \geqslant 0,05$ m

$P \geqslant 0,15$ m

$b \geqslant 0,30$ m

In addition to these, the following specific limitations are recommended in view of the limited availability of experimental data:

for weir Nos. 1 to 3: $\frac{h}{P} \leqslant 1,6$

for weir No. 4: $\frac{h}{P} \leqslant 1,45$

for weir No. 5: $\frac{h}{P} \leqslant 1,4$

Weir No. 5 should be operated under modular flow only. Weirs 1 to 4 can be operated under nonmodular flow also, but σ should not exceed a value such that C_{dr} becomes less than 0,9.

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 the 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 streamlined triangular profile weir, the systematic uncertainty in the coefficient C will be within 2,5 %. There is no uncertainty in the coefficient C_{dr} for modular flow. For nonmodular flow, the uncertainty in C_{dr} increases as the submergence ratio increases. For those submergence ratios for which C_{dr} is more than 0,9, the systematic uncertainty in the combined coefficient CC_{dr} is within 5 %.

The random uncertainty in the combined coefficient CC_{dr} reflects the real but marginal changes in the coefficient values during changing discharge, and may be taken as 0,5 %.

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 Reference shall also be made to ISO 5168.

10.1.2 Whenever a measurement of discharge is made, the value obtained is simply the best possible estimate of the true discharge. In practice, the true discharge may be slightly greater or less than this value. This International Standard gives the procedure for the evaluation of uncertainties in individual flow measurements arising from both random and systematic errors.

10.1.3 The error may be defined as the difference between the actual rate of flow and that calculated in accordance with the equation for the weir, which is assumed to be constructed and installed in accordance with this International Standard. The term "uncertainty" is used to denote the deviation from the true rate of flow within which the measurement is expected to lie 19 times out of 20 (95 % confidence level).

10.1.4 The total uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. As the discharge is obtained as a function of weir dimensions, measuring head and discharge coefficients, errors in these quantities contribute to the total uncertainty in discharge measurement. The assessment of these contributions to the total uncertainty will indicate whether or not the rate of flow can be determined with sufficient accuracy for the purpose in hand.

10.2 Sources of error

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

$$Q = \left(\frac{2}{3}\right)^{3/2} C_{dr}\, C \sqrt{g}\; b\, h^{3/2}$$

where

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

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

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

a) the discharge coefficient C and the drowned flow coefficient C_{dr}; numerical estimates of uncertainty in the combined coefficient CC_{dr} are given in 9.4;

b) the dimensions of the structure, i.e. the width of the weir, b;

c) the measured head, h.

10.2.3 The uncertainty in b and h need to 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 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 errors and systematic errors. Random errors are caused by numerous, small independent influences which prevent a measurement system from delivering the same reading from the same input value of the quantity being measured. The random error in the result can be reduced by making a number of measurements and using the arithmetic mean value.

10.3.2 The standard deviation is used as a measure of the random error. The standard deviation of a set of measurements under steady conditions may be estimated from the equation:

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

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

The standard deviation of the mean is then given by

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

The uncertainty of the mean at 95 % confidence level is given by $t_{95} s_{\overline{Y}}$. This uncertainty is the contribution of random errors in any series of experimental measurements to the total uncertainty. The value of t_{95} is 2,0 for $N \geqslant 30$. It is 2,6 for $N = 6$; 2,4 for $N = 8$; 2,3 for $N = 10$ and 2,1 for $N = 15$.

10.3.3 Systematic errors are those which cannot be reduced by increasing the number of measurements if the equipment and conditions of measurement remain unchanged. For example, an error in setting the zero of a water level gauge to crest level produces a systematic difference between the measured head and the actual value. The uncertainty associated with systematic errors cannot be assessed experimentally without changing the equipment or conditions of measurement. Generally, as subjective judgement is involved in the estimation of systematic uncertainty, the stated confidence level of 95 % has to be treated as approximate for systematic errors.

10.4 Uncertainties in values of coefficients C and C_{dr}

10.4.1 All errors in this category are systematic.

10.4.2 The values of the coefficients C and C_{dr} quoted in this International Standard are based on 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 correlation given. The suggested uncertainty values thus represent an accumulation of the 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 measurements nor the way in which they are to be made are specified, no numerical values for uncertainties in this category can be given: they need to be estimated by the user. For example, consideration of the method of measuring the width of the weir should permit the user to determine the uncertainty in this quantity.

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