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Second edition
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Hydrometric determinations — Flow measurement in open channels using structures — Trapezoidal broad-crested weirs

Déterminations hydrométriques — Mesure de débit dans les canaux découverts au moyen de structures — Déversoirs trapézoïdaux à seuil épais

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 4362 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 2, *Notches, weirs and flumes.*

This second edition cancels and replaces the first edition (ISO 4362:1992), which has been extended to include the use of the weir in trapezoidal channels in addition to its use in rectangular channels.

Hydrometric determinations — Flow measurement in open channels using structures — Trapezoidal broad-crested weirs

1 Scope

This International Standard specifies a method of steady-flow measurement in open channels using a trapezoidal broad-crested weir under modular and non-modular conditions. Consideration is given to the use of the weir in both rectangular and trapezoidal channels.

Limitations to the use of the weir are given in 7.6 and 8.6.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, the document do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772:1996, *Hydrometric determinations — Vocabulary and symbols.*

3 Terms and definitions

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

4 Installation — General considerations

NOTE Particular requirements for trapezoidal broad-crested weirs are given in clause 7 for trapezoidal broad-crested weirs in rectangular channels; in clause 8 for trapezoidal broad-crested weirs in trapezoidal channels.

4.1 Selection of site

A preliminary survey shall be made of the physical and hydraulic features of the proposed site, to check that it conforms (or may be made to conform) with the requirements necessary for discharge measurement by a weir.

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

a) the 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 an excessive increase in upstream water level owing to installation of the measuring structure;

e) the sediment content of the stream and whether heavy deposition just upstream of the weir is likely to occur;

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;

i) the need for clearance of rocks or boulders from the bed of the approach channel;

j) the effect of wind on the flow over the weir, especially when the weir is wide and the head is small and when the prevailing wind is in a direction transverse to the direction of flow.

If the site does not possess the characteristics necessary for satisfactory measurements, it shall not be used unless suitable improvements are practicable.

The existing velocity distribution in the approach channel shall be checked by inspection and measurement using, for example, current-meters, velocity rods and floats.

NOTE 1 Concentrations of dye are also useful to check the conditions at the bottom of the channel.

NOTE 2 A complete and quantitative assessment of the velocity distribution may be made by using a current-meter. More information on the use of current-meters is given in ISO 748.

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 weir has been constructed.

If the existing velocity distribution is irregular and no other site for a weir is feasible, due consideration shall be given to checking the distribution after the installation of the weir and to improving it if necessary.

4.2 Installation conditions

4.2.1 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.

In addition, features such as the surface finish of the weir, the cross-sectional shape of the channel and its roughness, and the influences of the control section and devices upstream or downstream of the gauging structure shall be taken into consideration.

These features together determine the distribution and direction of velocity, which have an important influence on the performance of a weir.

Once an installation has been designed and constructed, the user shall prevent or rectify any physical changes in the installation which could affect the discharge characteristics.

4.2.2 Approach channel

The flow in the approach channel shall be smooth, free from disturbances and shall have a velocity distribution as symmetrical as possible over the cross-sectional area.

NOTE This can usually be verified by inspection or measurement.

In the case of natural streams or rivers, these flow conditions can only be attained by having a long straight approach channel of uniform cross-section, free from projections at the side or on the bottom.

Unless otherwise specified, the following general requirements shall be met.

a) After construction of the weir, the flow conditions in the approach channel can alter owing to the build-up of shoals of debris upstream of the structure. The likely consequential changes in the water level shall be taken into account in the design of the structure.

b) 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.

c) If the entry of the approach channel is through a bend or if the flow is discharged into the channel either through a conduit of smaller cross-section or at an angle, then a greater length of straight approach channel is required to achieve a regular velocity distribution. There shall be no baffle nearer to the points of measurement than 10 times the maximum head to be measured.

d) Under certain conditions, a standing wave may occur upstream of the gauging device, for example if the approach channel is steep. Provided that this wave is at a distance upstream of not less than 30 times the maximum head, flow measurement is feasible, subject to confirmation that a regular velocity distribution exists at the gauging station. If a standing wave occurs within this distance, the approach conditions and/or the gauging device shall be modified.

4.2.3 Weir structure

The structure shall be rigid and 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 the geometry of the weir shall conform with the dimensions given in this International Standard.

4.2.4 Downstream channel

The channel downstream of the structure is usually of no importance if the weir has been designed to operate under free-flow conditions. If the weir is designed to operate under drowned conditions also, the downstream channel shall be straight for a length of at least eight times the maximum head to be measured.

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

5 Maintenance

Maintenance of the measuring structure and the approach channel is important to secure accurate continuous measurements.

It is essential that, as far as practicable, the approach channel to the weir be kept clean and free from silt and vegetation for the minimum distance specified in 4.2.2. 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.

6 Measurement of water levels

6.1 General

Where spot measurements are required, water levels (heads) upstream and downstream of the measuring structure may be measured by using a hook gauge, a point gauge or a staff gauge. Where continuous records are required, a float-operated recording gauge may be used; however, to reduce the effects of water surface irregularities, it is preferable to measure water levels in a separate stilling well. Other head-measuring methods may be used provided that sufficient accuracy is obtainable.

The discharges calculated using the working equations given in this International Standard are volumetric figures. The liquid density does not affect the volumetric discharge for a given water level provided that the operative level 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 of the liquid in the well is significantly different from that of the flowing liquid. However, it is assumed herein that the densities are equal.

6.2 Stilling or float well

Where provided, the stilling well shall be vertical and shall be 0,6 m higher than the maximum water level to be recorded in the well. The bottom of the well shall be lower than the elevation of the weir crest.

The well shall be connected to the channel by an inlet pipe or slot, which is 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-period 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 give clearance around and beneath the float at all stages. Adequate additional depth shall be provided in wells to avoid the danger of floats grounding on any accumulation of silt or debris. The float well arrangement may include an intermediate chamber of similar size and proportions between the stilling well and the approach channel to enable silt and other debris to settle out where they may be readily removed.

6.3 Zero setting

An accurate means of checking the zero setting of the water-level measuring device shall be provided. For this purpose, 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, may be used.

A zero check based on the level of the water when the flow either ceases or just begins is liable to serious errors due to surface tension effects, and shall not be used.

With decreasing size of the weir and the water level, small errors in construction and in the zero setting and reading of the water-level measuring device become of greater importance.

7 Trapezoidal broad-crested weirs in rectangular channels

7.1 Specification for the standard weir

The weir comprises an upstream slope of 1:Z_1, a horizontal crest, and a downstream slope of 1:Z_2 (see Figure 1), constructed in a rectangular channel section.

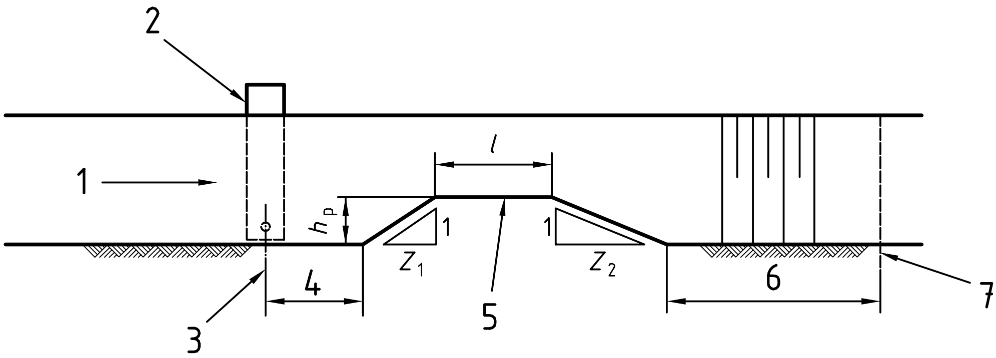
The values of Z_1 and Z_2 for standard trapezoidal broad-crested weirs in rectangular channels in accordance with this International Standard are specified in Table 1.

Table 1 — Upstream and downstream slope combinations

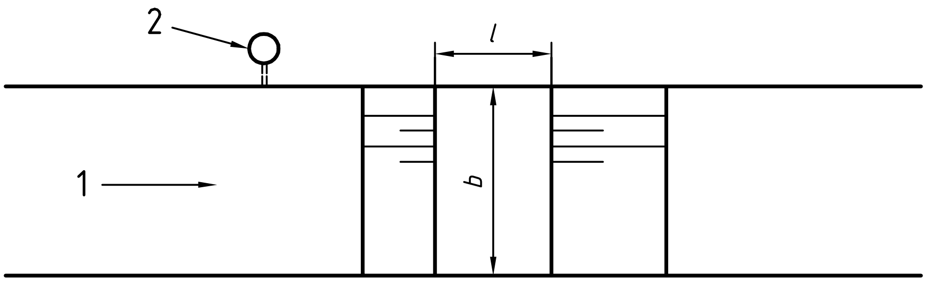
Upstream slope 1:Z_1	Downstream slope 1:Z_2
1:1	1:5
1:2	1:2
1:2	1:3
1:2	1:5
1:3	1:3
1:3	1:5

The intersection of the surfaces of the upstream and downstream slopes with the horizontal crest shall form a well-defined straight sharp corner which shall be horizontal and at right angles to the direction of flow in the approach channel. The crest shall be horizontal and shall have a rectangular plane surface. The surfaces of the crest and the slopes shall be smooth. The width b of the crest perpendicular to the direction of flow shall be equal to the width of the channel in which the weir is located.

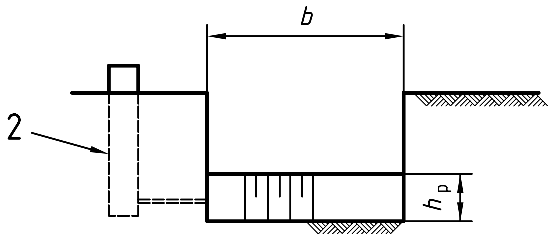
A sketch of a typical trapezoidal broad-crested weir in a rectangular channel is given in Figure 1.



a) Longitudinal section



b) Plan view



c) Cross-section

Key

1 Direction of flow

2 Stilling well

3 Head measurement section

4 3 h_{max} to 4 h_{max}

5 Horizontal crest

6 5 h_{max} to 6 h_{max}

7 Tailwater level measurement section

Figure 1 — Trapezoidal broad-crested weir in a rectangular channel

7.2 Location of head measurement section

Piezometers or a point-gauge station for the measurement of the head on the weir shall be located at a sufficient distance upstream from the weir to avoid the region of surface drawdown. However, they (it) 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 three to four times the maximum head (i.e. $3h_{max}$ to $4h_{max}$) upstream from the toe of the upstream face of the weir, as shown in Figure 1.

7.3 Location of tailwater level measurement section

Piezometers or a point-gauge station for the measurement of the tailwater level shall be located at a sufficient distance downstream from the weir to avoid regions of fluctuation.

Generally, it is recommended that the tailwater level measurement section be located at a distance of five to six times the maximum head (i.e. $5h_{max}$ to $6h_{max}$) downstream from the toe of the downstream face of the weir, so that the measurement is downstream of any unstable water surface or jump.

7.4 Conditions for free flow

Flow is free flow when it is independent of variations in the tailwater level. For each upstream and downstream slope combination of the weir, correlations for the modular limit σ_c are given in 7.5.2. The tailwater head shall not rise more than σ_c times the upstream head above the crest level, if the flow is not to be affected by more than 1 % for subcritical conditions in the tailwater.

7.5 Determination of discharge

7.5.1 Determination of discharge under free flow conditions

7.5.1.1 Discharge equation

The discharge equation for trapezoidal broad-crested weirs in rectangular channels is as follows:

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

where

- b is the width of the weir perpendicular to the direction of flow, in metres;
- C_{dr} is the drowned-flow coefficient, which is dimensionless;
- C_D is the coefficient of discharge, which is dimensionless;
- C_v is the approach velocity coefficient, which is dimensionless [= $(H/h)^{3/2}$, where H is the total head, in metres];
- g is the acceleration due to gravity, in metres per second squared;
- h is the measured head, in metres;
- Q is the discharge across the weir, in cubic metres per second.

7.5.1.2 Approach velocity coefficient, C_v

C_v is given by the following implicit equation:

$$C_v = \left[1 + \frac{4}{27} C_v^2 \left(\frac{C_D bh}{A}\right)^2\right]^{3/2}$$

Values of C_v may be determined from Figure 2 which gives C_v as a function of $C_D bh/A$, where A is the cross-sectional area of the channel at the head measurement section, in square metres.

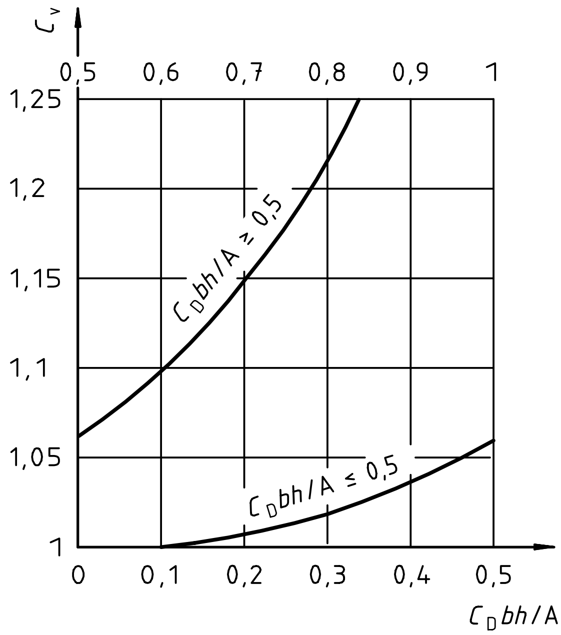


Figure 2 — Approach velocity coefficient, C_v

7.5.1.3 Coefficient of discharge, C_D

Values of C_D as a function of h/l are given in Figures 3 and 4, and Table 2 for the upstream and downstream slope combinations given in Table 1.

7.5.2 Modular limit, σ_c

The modular limit is a function of h/l and the upstream and downstream slopes. It is taken to be equal to the value of the submergence ratio $\sigma = h_{dr}/h$ (where h_{dr} is the tailwater head above the crest) above which the reduction in discharge exceeds 1 % of the free flow (or modular flow) discharge. Values of σ_c as a function of h/l are given in Figures 5 to 10 for the various slope combinations specified in Table 1.

7.5.3 Determination of discharge under submerged-flow conditions

C_{dr} is a function of h/l and the upstream and downstream slopes. For free-flow and submerged-flow conditions where the submergence ratio is less than the modular limit specified in 7.5.2, the drowned-flow coefficient C_{dr} may be taken to be unity.

For flow conditions where the submergence ratio is greater than the modular limit, the value of C_{dr} may be determined from Figures 11 to 16, where C_{dr} is given as a function of h/l and σ for the various slope combinations specified in Table 1.

Table 2 — Variation in the coefficient of discharge C_D

h/l	C_D for the following upstream and downstream slope combinations					
	$Z_1 = 1, Z_2 = 5$	$Z_1 = 2, Z_2 = 2$	$Z_1 = 2, Z_2 = 3$	$Z_1 = 2, Z_2 = 5$	$Z_1 = 3, Z_2 = 3$	$Z_1 = 3, Z_2 = 5$
0,1	0,908	0,936	0,936	0,936	0,946	0,946
0,2	0,920	0,952	0,952	0,952	0,963	0,963
0,3	0,928	0,964	0,964	0,964	0,974	0,974
0,4	0,938	0,974	0,974	0,974	0,984	0,984
0,5	0,949	0,985	0,985	0,985	0,992	0,992
0,6	0,962	1,000	0,999	0,998	1,003	1,003
0,7	0,976	1,018	1,014	1,012	1,014	1,012
0,8	0,988	1,036	1,029	1,025	1,028	1,022
0,9	1,002	1,052	1,042	1,035	1,041	1,032
1,0	1,014	1,066	1,054	1,046	1,054	1,042
1,1	1,026	1,080	1,067	1,056	1,066	1,050
1,2	1,038	1,094	1,080	1,066	1,076	1,058
1,3	1,049	1,106	1,092	1,076	1,086	1,064
1,4	1,060	1,120	1,102	1,085	1,096	1,071
1,5	1,072	1,130	1,112	1,092	1,103	1,078
1,6	1,082	1,140	1,121	1,098	1,110	1,084
1,7	1,090	1,150	1,130	1,104	1,116	1,090
1,8	1,098	1,158	1,138	1,109	1,122	1,096
1,9	1,103	1,165	1,145	1,114	1,128	1,102
2,0	1,108	1,173	1,152	1,119	1,133	1,106
2,1	1,113	1,180	1,158	1,123	1,138	1,110
2,2	1,116	1,187	1,164	1,127	1,142	1,114
2,3	1,119	1,194	1,168	1,130	1,146	1,116
2,4	1,121	1,200	1,171	1,133	1,149	1,120
2,5	1,124	1,206	1,174	1,136	1,152	1,122
2,6	1,126	1,212	1,176	1,139	1,156	1,126
2,7	1,128	1,216	1,178	1,140	1,160	1,128
2,8	1,130	1,220	1,181	1,142	1,164	1,132
2,9	1,132	1,222	1,183	1,143	1,166	1,134
3,0	1,134	1,224	1,185	1,144	1,168	1,135

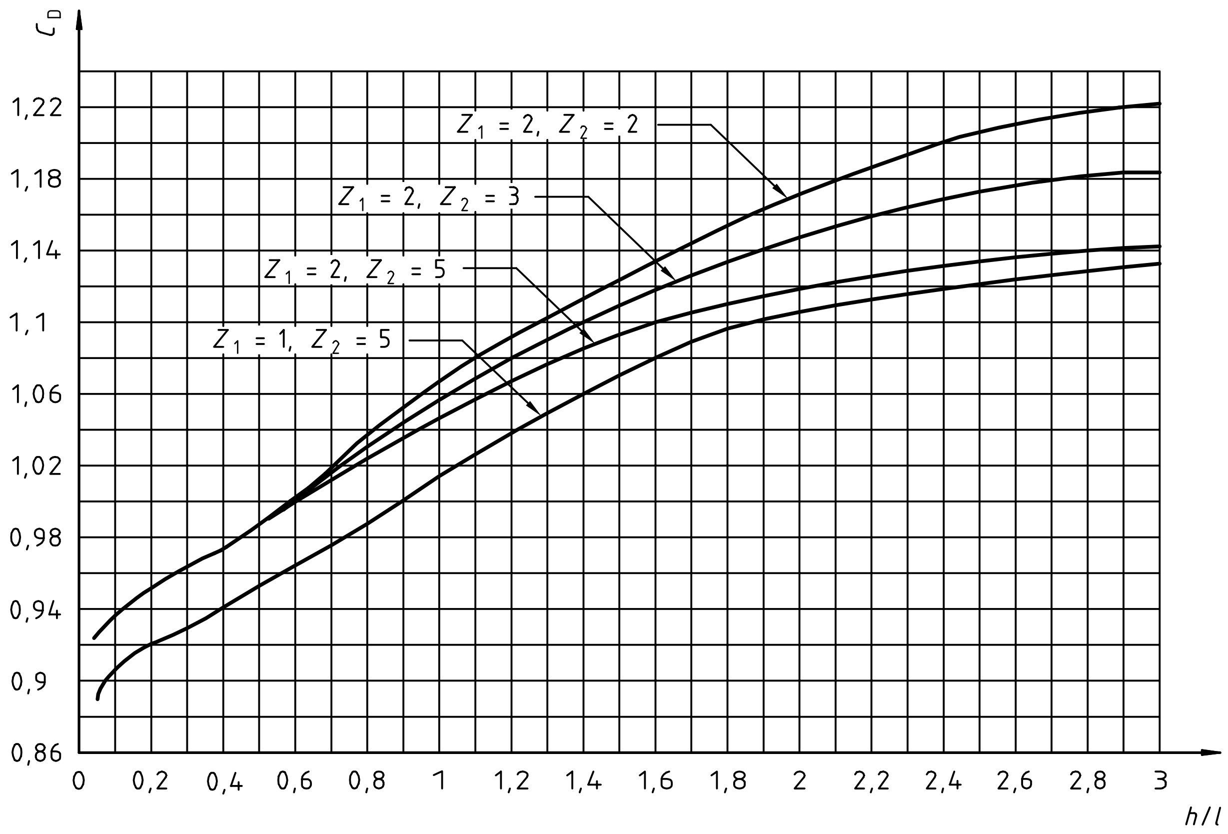


Figure 3 — Variation in the coefficient of discharge for Z_1 = 1 and Z_1 = 2

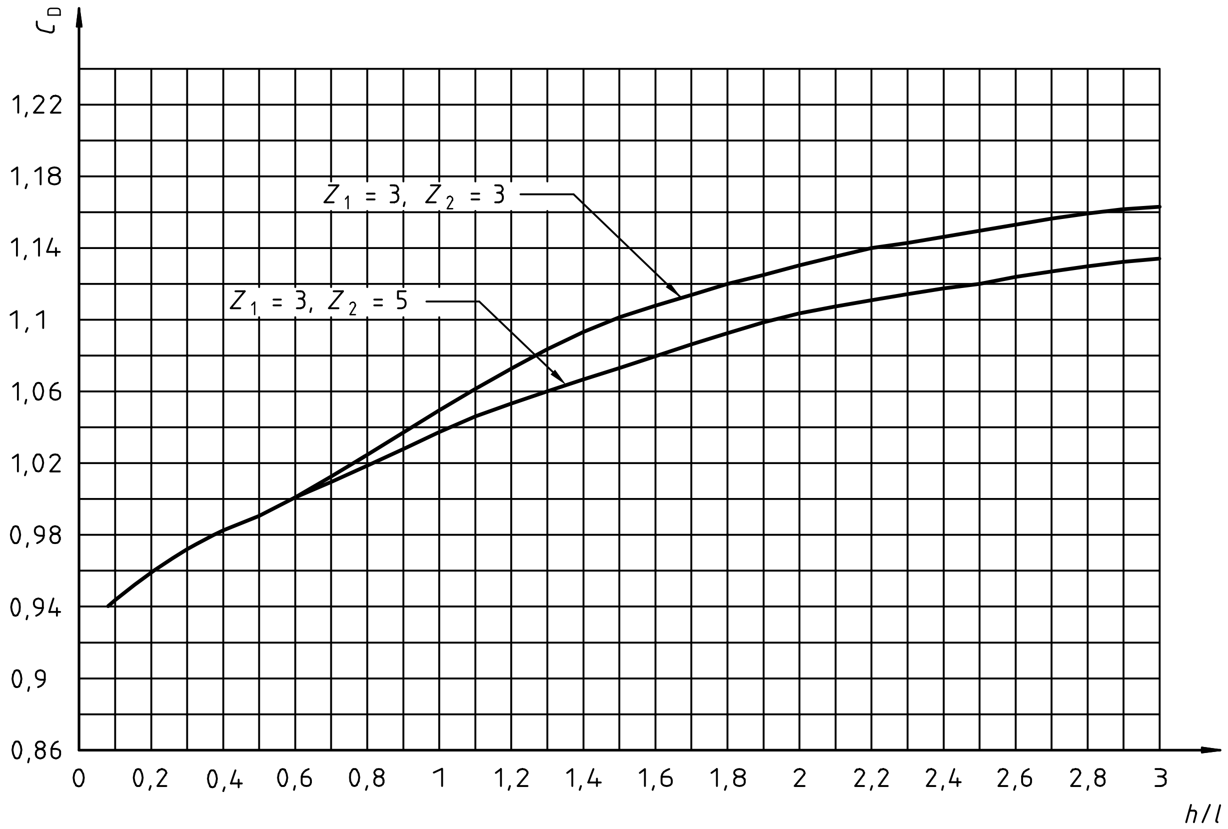


Figure 4 — Variation in the coefficient of discharge for Z_1 = 3

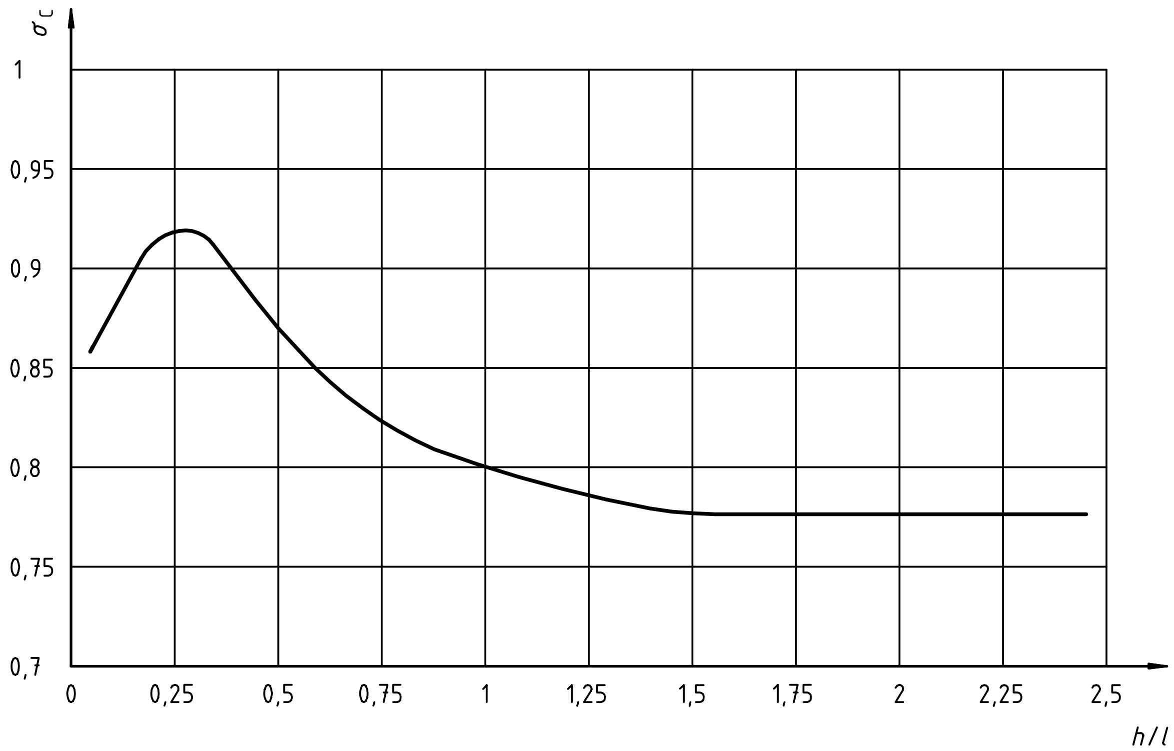


Figure 5 — Variation in the modular limit σ_c for Z_1 = 1 and Z_2 = 5

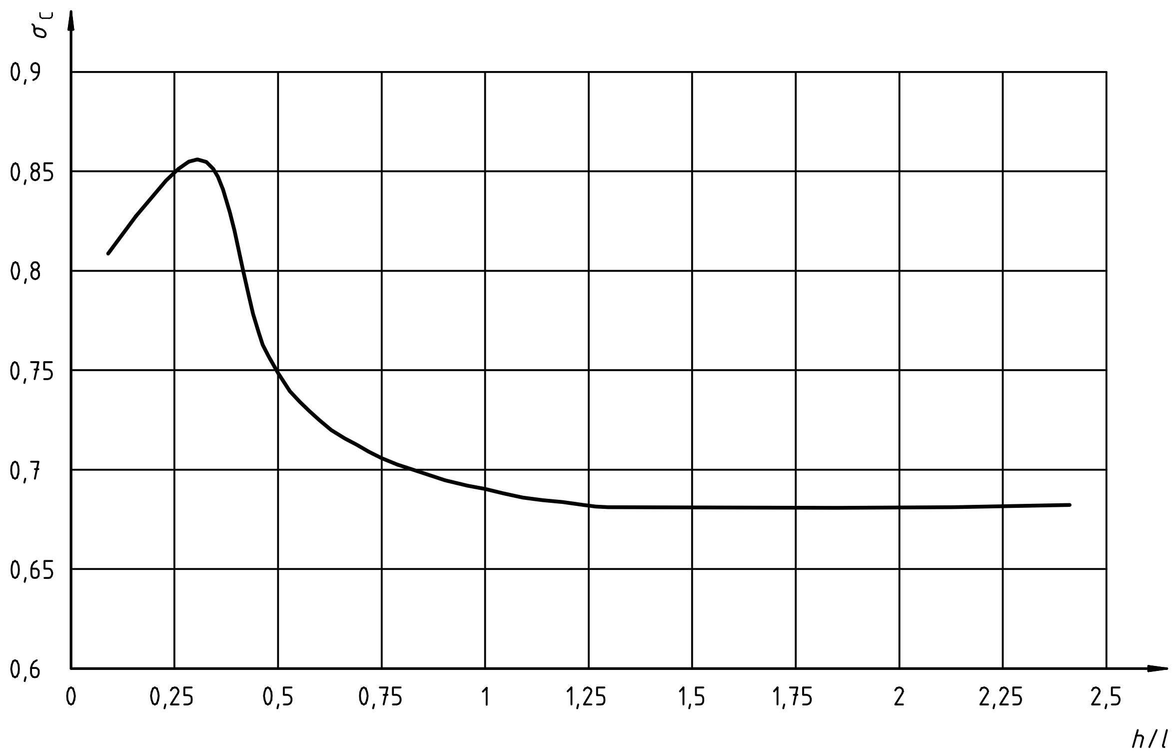


Figure 6 — Variation in the modular limit σ_c for Z_1 = 2 and Z_2 = 2

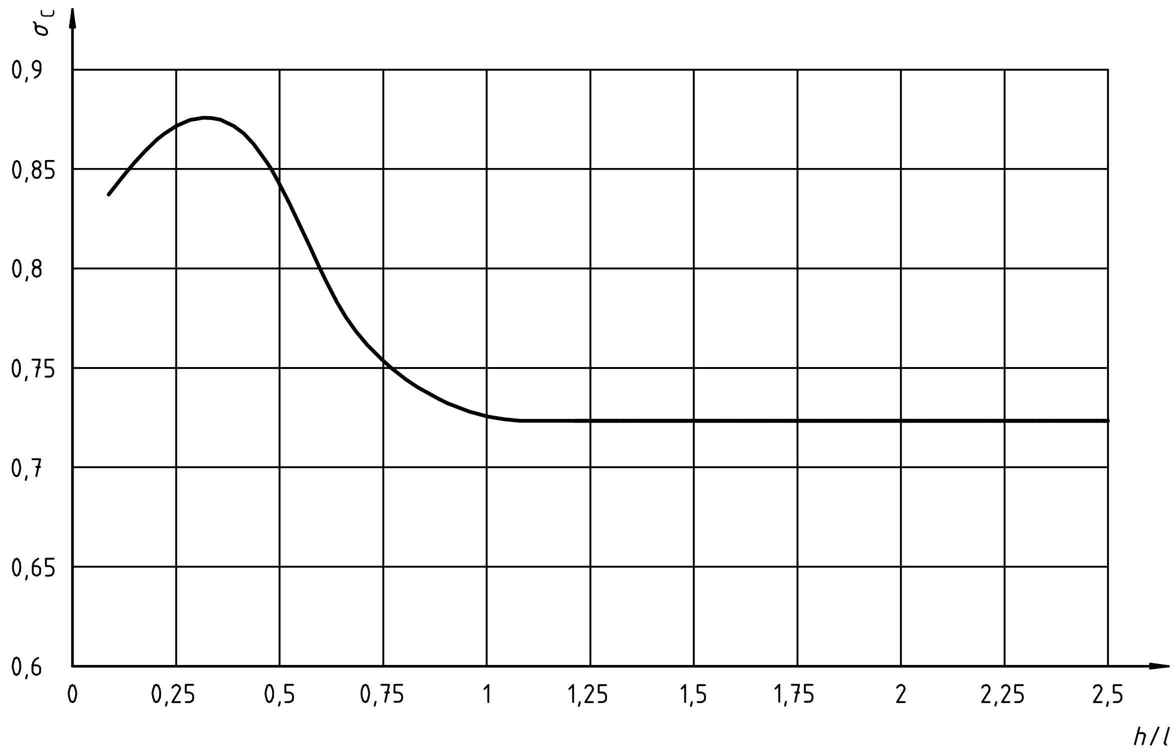


Figure 7 — Variation in the modular limit σ_c for Z_1 = 2 and Z_2 = 3

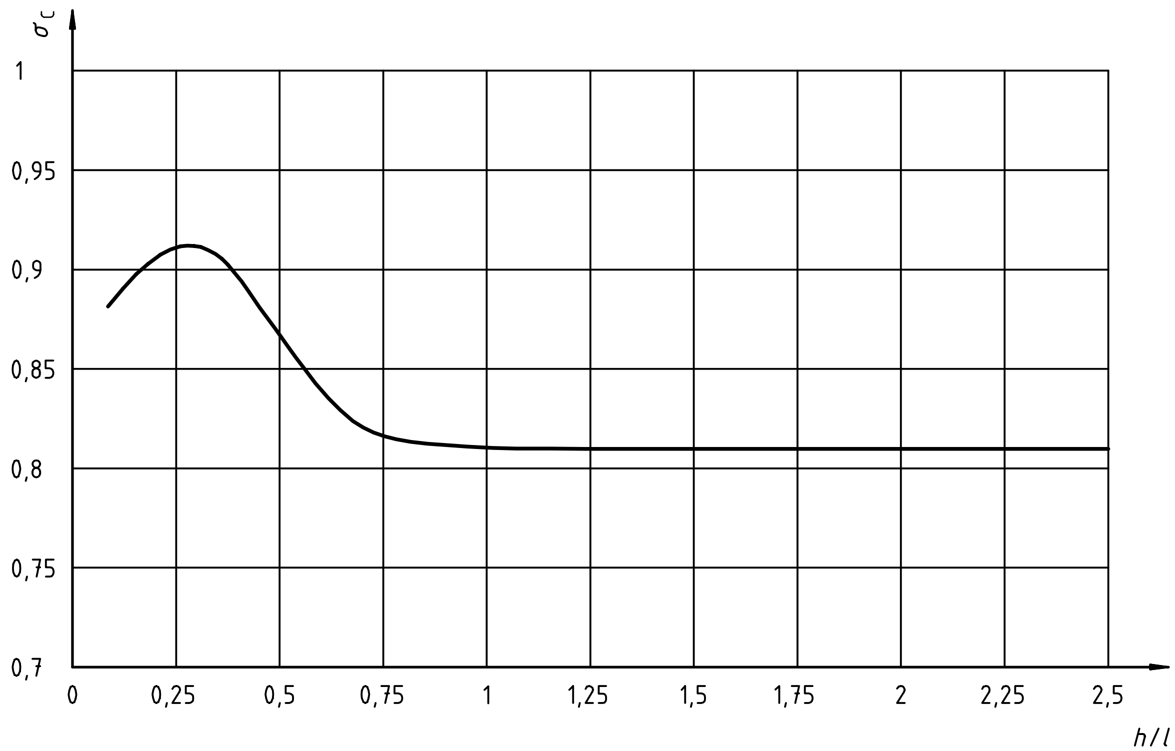


Figure 8 — Variation in the modular limit σ_c for Z_1 = 2 and Z_2 = 5

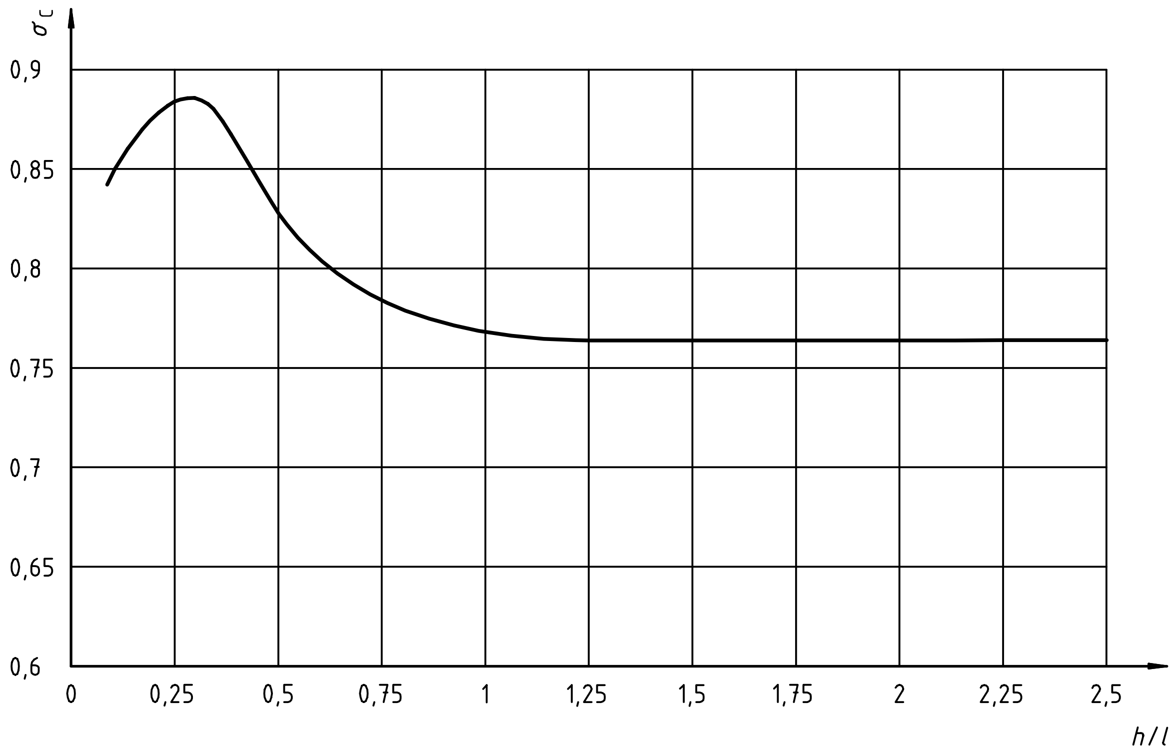


Figure 9 — Variation in the modular limit σ_c for Z_1 = 3 and Z_2 = 3

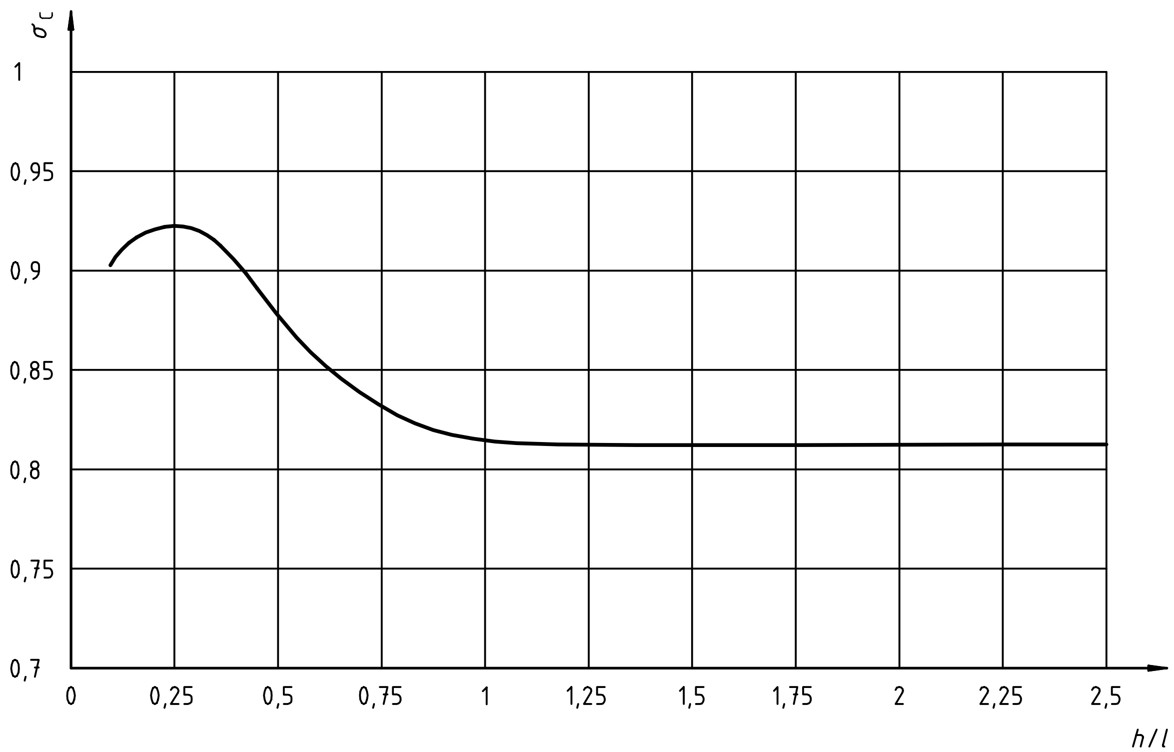
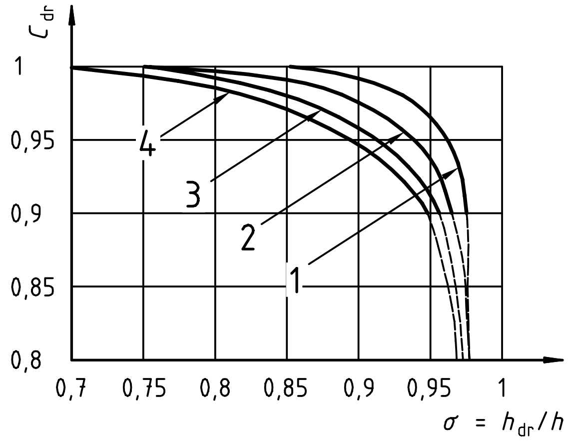


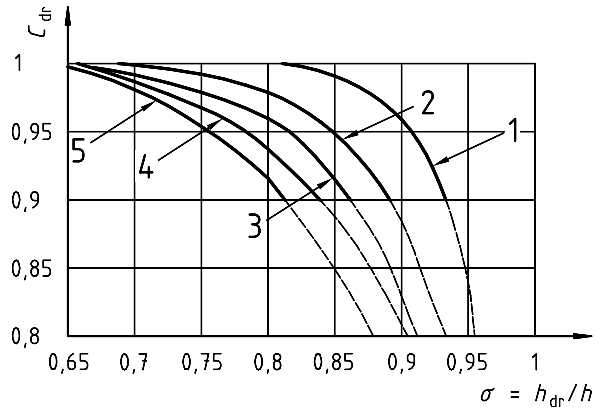
Figure 10 — Variation in the modular limit σ_c for Z_1 = 3 and Z_2 = 5



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 1
4 h/l = 2

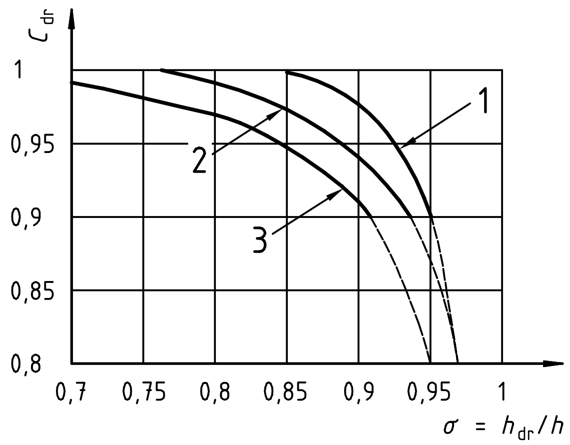
Figure 11 — Variation in the drowned-flow coefficient for Z_1 = 1 and Z_2 = 5



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 1
4 h/l = 1,5
5 h/l = 2

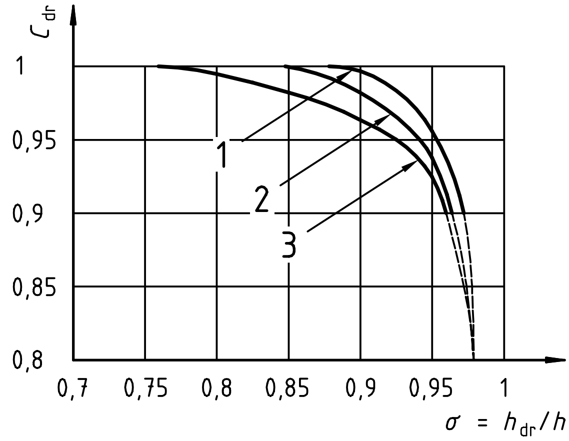
Figure 12 — Variation in the drowned-flow coefficient for Z_1 = 2 and Z_2 = 2



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 2

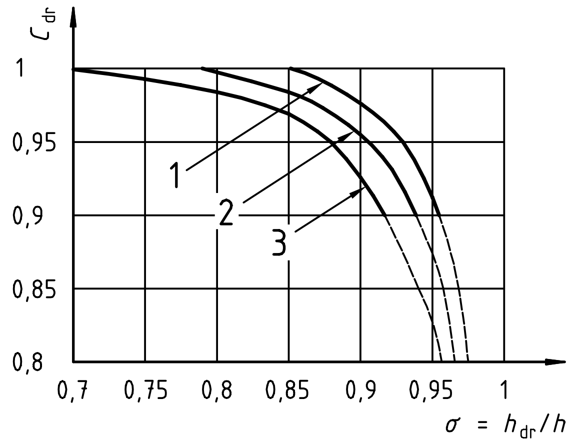
Figure 13 — Variation in the drowned-flow coefficient for Z_1 = 2 and Z_2 = 3



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 2

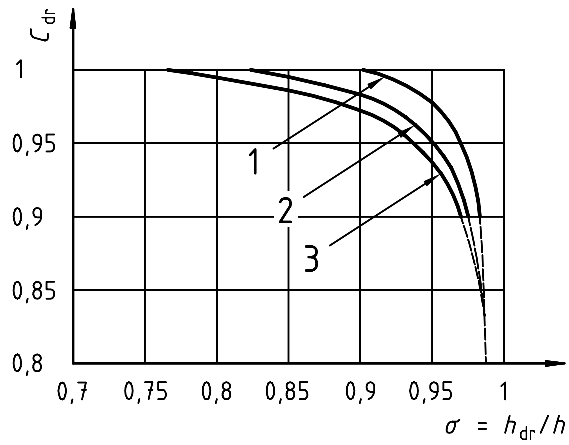
Figure 14 — Variation in the drowned-flow coefficient for Z_1 = 2 and Z_2 = 5



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 2

Figure 15 — Variation in the drowned-flow coefficient for Z_1 = 3 and Z_2 = 3



Key

1 h/l = 0,3
2 h/l = 0,6
3 h/l = 1,5

Figure 16 — Variation in the drowned-flow coefficient for Z_1 = 3 and Z_2 = 5

7.6 Limitations

The discharge relationships specified in this International Standard are subject to the following limitations. To avoid surface tension and viscous effects, the following general limitations are recommended:

$h \geqslant 0{,}05$ m

$h_p \geqslant 0{,}15$ m

$b \geqslant 0{,}3$ m

On the basis of the experimental data currently available, the following specific limitations are recommended for free and submerged flows.

a) Free flow

$$0{,}2 \leqslant \frac{l}{h_p} \leqslant 2$$

$$\frac{h}{h_p} \leqslant 1{,}3$$

$$0{,}1 \leqslant \frac{h}{l} \leqslant 3$$

b) Submerged flow

$$0{,}2 \leqslant \frac{l}{h_p} \leqslant 2$$

$$\frac{h}{h_p} \leqslant 1{,}3$$

$$0{,}1 \leqslant \frac{h}{l} \leqslant x$$

where x, the upper limit for h/l, is the limit up to which correlations are given in Figures 11 to 16, i.e. x = 1,5 for Z_1 = 3, Z_2 = 5 and x = 2 for all other pairs of Z_1 and Z_2 given in Table 1.

In addition, σ should not exceed a value such that C_{dr} becomes less than 0,9.

7.7 Uncertainty in measurement

7.7.1 The overall uncertainty in flow measurements made using trapezoidal broad-crested weirs in rectangular channels depends on the uncertainties in the head measurements, in the measurements of the dimensions of weir and in the coefficients as they apply to the weir in use.

7.7.2 With reasonable care and skill in the construction and installation of a trapezoidal broad-crested weir, the systematic uncertainty in the combined coefficient $C_D C_v$ is within ± 4 %. There is no uncertainty in the coefficient C_{dr} for free flow. For submerged 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 $C_D C_v C_{dr}$ is within ± 6 %.

The random uncertainty in the coefficient of discharge C_D reflects the real but marginal differences in coefficient values for different discharges, and may be taken as ± 0,5 %. The random uncertainty in the coefficients C_v and C_{dr} may be ignored.

7.7.3 The method by which the uncertainties in the coefficients shall be combined with other sources of uncertainty is given in clause 9.

In general, the discharge coefficients quoted in this International Standard have been determined using calibration experiments on small-scale model structures. It should be borne in mind that these coefficients will not be identical for larger structures, owing to scale effects.

8 Trapezoidal broad-crested weirs in trapezoidal channels

8.1 Specification for the standard weir

The weir comprises an upstream slope of $1{:}Z_1$, a horizontal crest, and a vertical or a sloping downstream face $1{:}Z_2$, constructed in a trapezoidal channel section (see Figure 17).

The values of Z_1 and Z_2 for standard trapezoidal broad-crested weirs in trapezoidal channel sections, specified in this International Standard are as follows:

$2 \leqslant Z_1 \leqslant 4$ and $0 \leqslant Z_2 \leqslant 5$ for free-flow conditions

$2 \leqslant Z_1 \leqslant 4$ and $Z_2 = 0$ for submerged flow conditions

The intersection of the surface of the upstream and downstream slopes with the horizontal crest shall form a well-defined straight sharp corner which shall be horizontal and at right angles to the direction of flow in the approach channel. The crest shall be horizontal and shall have a rectangular plane surface. The surfaces of the crest and the slopes shall be smooth. The width b_c of the crest perpendicular to the direction of flow follows from the channel's bottom-width b, the side slope m and the apex height h_p:

$$b_c = b + 2mh_p$$

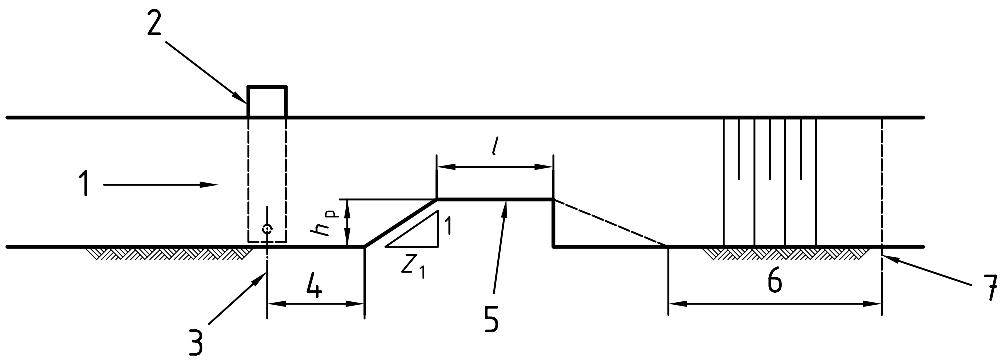
The weir width b_c shall be checked after construction of the weir.

A sketch of the trapezoidal broad-crested weir in a trapezoidal channel is given in Figure 17.

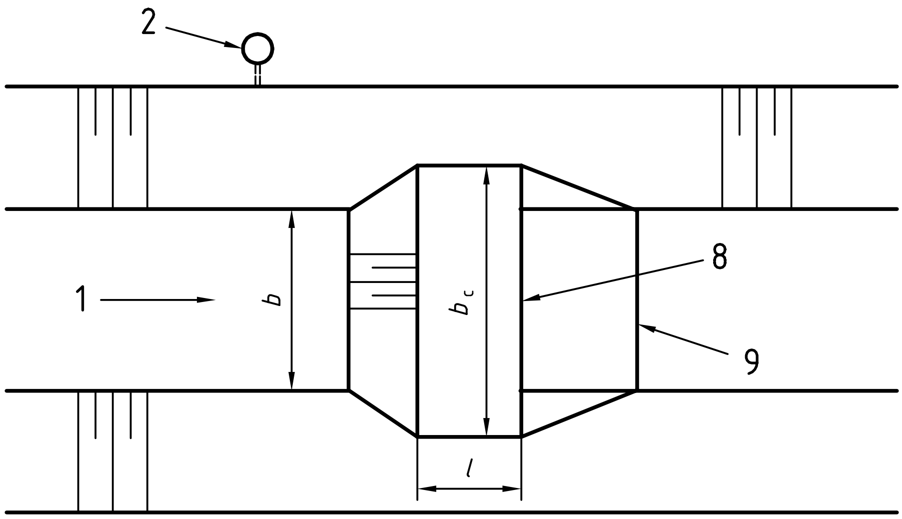
8.2 Location of head measurement section

Piezometers or a point-gauge station for the measurement of the head on the weir shall be located at a sufficient distance upstream from the weir to avoid the region of surface drawdown. However, they (it) 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.

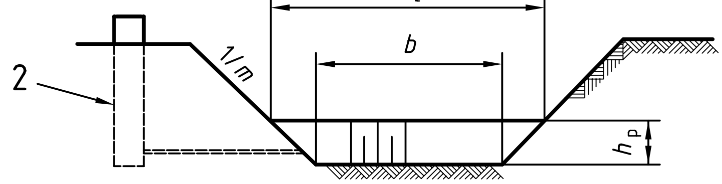
It is recommended that the head measurement section be located at a distance equal to three to four times the maximum head (i.e. $3h_{max}$ to $4h_{max}$) upstream from the toe of the upstream face of the weir.



a) Longitudinal section



b) Plan view



c) Cross-section

Key

1 Direction of flow
2 Stilling well
3 Head measurement section
4 $3h_{max}$ to $4h_{max}$
5 Horizontal crest
6 $5h_{max}$ to $6h_{max}$
7 Tailwater level measurement section
8 Vertical backface, $Z_2 = 0$
9 Sloping backface

Figure 17 — Trapezoidal broad-crested weir in a trapezoidal channel

8.3 Location of tailwater level measurement section

Piezometers or a point-gauge station for the measurement of the tailwater level shall be located at a sufficient distance downstream from the weir to avoid regions of fluctuation.

Generally, it is recommended that the tailwater level measurement section be located at a distance of five to six times the maximum head (i.e. $5h_{max}$ to $6h_{max}$) downstream from the toe of the downstream face of the weir, so that the measurement is downstream of any unstable water surface or jump.

8.4 Conditions for free flow

Flow is free flow when it is independent of variations in the tailwater level. For each upstream and downstream slope combination of the weir, correlations for the modular limit σ_c are given in 8.5.2. The tailwater head shall not rise more than σ_c times the upstream head above the crest level, if the flow is not to be affected by more than 1 % for subcritical conditions in the tailwater.

8.5 Determination of discharge

8.5.1 Determination of discharge under free-flow conditions

The discharge equation for trapezoidal broad-crested weirs in trapezoidal channels is expressed in terms of the total upstream energy head H_1 over the weir. Bernoulli's equation, applied for the H_1-section upstream of the weir and the control section above the weir gives:

$$Q = A_c\{2g(H_1 - y_c)\}^{0,5} \text{ for ideal flow}$$

The effects of non-ideal flow are accounted for by the introduction of a discharge coefficient C_D, which depends on the shape and type of the structure and a drowned flow coefficient C_{dr} for submerged flow conditions.

In a trapezoidal control section, the cross-sectional area is $A_c = b_c y_c + m y_c{}^2$.

The discharge equation for trapezoidal broad-crested weirs in trapezoidal channels is as follows:

$$Q = C_D C_{dr}\left(b_c y_c + m y_c^2\right)\left[2g(H_1 - y_c)\right]^{0,5}$$

where

b_c is the width of the weir-crest perpendicular to the direction of flow, in metres;

y_c is the critical depth in the control section, in metres;

m is the channel side slope in the control section, which is dimensionless;

C_D is the coefficient of discharge, which is dimensionless;

C_{dr} is the drowned-flow coefficient, which is dimensionless;

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

H_1 is the total upstream energy-head, in metres.

The critical depth y_c can be calculated using Table 3, giving the ratio y_c/H_1 as a function of m and H_1/b_c for trapezoidal control sections.

The coefficient of discharge C_D is given in Figure 18 and Table 4 as a function of H_1/l.

Under free flow conditions C_{dr} = 1.

After calculation of the rating curve Q versus H_1, this relation shall be converted into the head-discharge relation Q versus h_1, where h_1 is the measured head, in metres.

8.5.2 Modular limit σ_c

The modular limit σ_c is a function of H_1/l and the downstream slope. It is taken to be equal to the value of the submergence ratio $\sigma = h_{dr}/h$ (where h_{dr} is the tailwater head above the crest) above which the reduction in discharge exceeds 1 % of the free-flow (or modular flow) discharge. Values of σ_c as a function of H_1/l are given in Figure 19 for weirs with a vertical downstream face.

8.5.3 Determination of discharge under submerged flow conditions

C_{dr} is a function of H_1/l and the downstream slope Z_2.

For free flow and submerged flow conditions where the submergence ratio is less than the modular limit specified in 8.5.2, the drowned flow coefficient C_{dr} may be taken to be unity.

For flow conditions where the submergence ratio is greater than the modular limit, the value of C_{dr} may be determined from Table 5, where C_{dr} is given for a weir with a vertical downstream face, $Z_2 = 0$, and as a function of H_1/l and the submergence ratio H_2/H_1.

Table 3 — Values of y_c/H_1 as a function of H_1/b_c and m for trapezoidal control sections

	Values of y_c/H_1							
	Channel side slope m							
H_1/b_c	Vertical	0,50	0,75	1	1,5	2	2,5	3
0,00	0,667	0,667	0,667	0,667	0,667	0,667	0,667	0,667
0,01	0,667	0,667	0,668	0,668	0,669	0,670	0,670	0,671
0,02	0,667	0,668	0,669	0,670	0,671	0,672	0,674	0,675
0,03	0,667	0,669	0,670	0,671	0,673	0,675	0,677	0,679
0,04	0,667	0,670	0,671	0,672	0,675	0,677	0,680	0,683
0,05	0,667	0,670	0,672	0,674	0,677	0,680	0,683	0,686
0,06	0,667	0,671	0,673	0,675	0,679	0,683	0,686	0,690
0,07	0,667	0,672	0,674	0,676	0,681	0,685	0,689	0,693
0,08	0,667	0,672	0,675	0,678	0,683	0,687	0,692	0,696
0,09	0,667	0,673	0,676	0,679	0,684	0,690	0,695	0,698
0,10	0,667	0,674	0,677	0,680	0,686	0,692	0,697	0,701
0,12	0,667	0,675	0,679	0,684	0,690	0,692	0,701	0,706
0,14	0,667	0,676	0,681	0,686	0,693	0,699	0,705	0,711
0,16	0,667	0,678	0,683	0,688	0,696	0,703	0,709	0,715
0,18	0,667	0,679	0,684	0,690	0,698	0,706	0,713	0,719
0,20	0,667	0,680	0,686	0,692	0,701	0,709	0,717	0,723
0,22	0,667	0,681	0,688	0,694	0,704	0,712	0,720	0,726
0,24	0,667	0,683	0,689	0,696	0,706	0,715	0,723	0,729
0,26	0,667	0,684	0,691	0,698	0,709	0,718	0,725	0,732
0,28	0,667	0,685	0,693	0,699	0,711	0,720	0,728	0,734
0,30	0,667	0,686	0,694	0,701	0,713	0,723	0,730	0,737
0,32	0,667	0,687	0,696	0,703	0,715	0,725	0,733	0,739
0,34	0,667	0,689	0,697	0,705	0,717	0,727	0,735	0,741
0,36	0,667	0,690	0,699	0,706	0,719	0,729	0,737	0,743
0,38	0,667	0,691	0,700	0,708	0,721	0,731	0,738	0,745
0,40	0,667	0,692	0,701	0,709	0,723	0,733	0,740	0,747
0,42	0,667	0,693	0,703	0,711	0,725	0,734	0,742	0,748
0,44	0,667	0,694	0,704	0,712	0,727	0,736	0,744	0,750
0,46	0,667	0,695	0,705	0,714	0,728	0,737	0,745	0,751
0,48	0,667	0,696	0,706	0,715	0,729	0,739	0,747	0,752
0,5	0,667	0,697	0,708	0,717	0,730	0,740	0,748	0,754
0,6	0,667	0,701	0,713	0,723	0,737	0,747	0,754	0,759
0,7	0,667	0,706	0,718	0,728	0,742	0,752	0,758	0,764
0,8	0,667	0,709	0,723	0,732	0,746	0,756	0,762	0,767
0,9	0,667	0,713	0,727	0,737	0,750	0,759	0,766	0,770
1,0	0,667	0,717	0,730	0,740	0,754	0,762	0,768	0,773
1,2	0,667	0,723	0,737	0,747	0,759	0,767	0,772	0,776
1,4	0,667	0,729	0,742	0,752	0,764	0,771	0,776	0,779
1,6	0,667	0,733	0,747	0,756	0,767	0,774	0,778	0,781
1,8	0,667	0,737	0,750	0,759	0,770	0,776	0,781	0,783
2	0,667	0,740	0,754	0,762	0,773	0,778	0,782	0,785
3	0,667	0,753	0,766	0,773	0,781	0,785	0,787	0,790
4	0,667	0,762	0,773	0,778	0,785	0,788	0,790	0,792
5	0,667	0,768	0,777	0,782	0,788	0,791	0,792	0,794
10	0,667	0,782	0,788	0,791	0,794	0,795	0,796	0,797
∞		0,800	0,800	0,800	0,800	0,800	0,800	0,800

Table 4 — Variation in the coefficient of discharge C_D for a trapezoidal broad-crested weir, 2 ⩽ Z_1 ⩽ 4 and 0 ⩽ Z_2 ⩽ 5 in a trapezoidal channel, m = 1 to 1,5

H_1/l	C_D
0,10	0,937
0,15	0,963
0,20	0,979
0,25	0,988
0,30	0,994
0,35	0,997
0,40	0,999
0,45	1,002
0,50	1,007
0,55	1,014
0,60	1,021
0,65	1,029
0,70	1,037
0,75	1,044
0,80	1,051
0,85	1,058
0,90	1,064
0,95	1,069
1,00	1,074
1,05	1,079
1,10	1,084
1,15	1,087
1,20	1,090

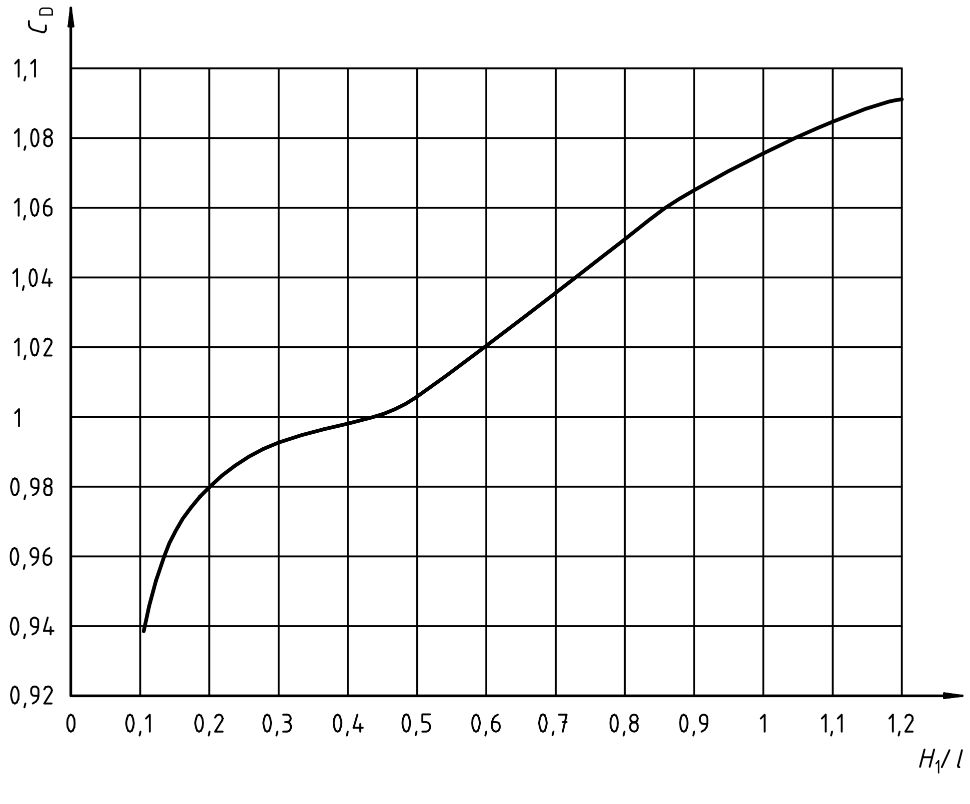


Figure 18 — Variation in the coefficient of discharge for a trapezoidal broad-crested weir 2 ⩽ Z_1 ⩽ 4 and 0 ⩽ Z_2 ⩽ 5 in a trapezoidal channel, m = 1 to 1,5

8.6 Limitations

The discharge relationships specified in this International Standard are subject to the following limitations. To avoid surface tension and viscous effects, the following general limitations are recommended:

$h_1 \geqslant 0{,}05$ m

$h_p \geqslant 0{,}15$ m

$b \geqslant 0{,}3$ m

On the basis of the experimental data currently available, the following specific limitations are recommended for free and submerged flows.

a) Free flow

$$0{,}2 \leqslant \frac{l}{h_p} \leqslant 2$$

$$\frac{h_1}{h_p} \leqslant 1{,}3$$

$$0{,}1 \leqslant \frac{H_1}{l} \leqslant 1{,}2$$

$2 \leqslant Z_1 \leqslant 4$ and $0 \leqslant Z_2 \leqslant 5$

b) Submerged flow

$$0{,}2 \leqslant \frac{l}{h_p} \leqslant 2$$

$$\frac{h_1}{h_p} \leqslant 1{,}3$$

$$0{,}1 \leqslant \frac{H_1}{l} \leqslant 1{,}2$$

$2 \leqslant Z_1 \leqslant 4$ and $Z_2 = 0$

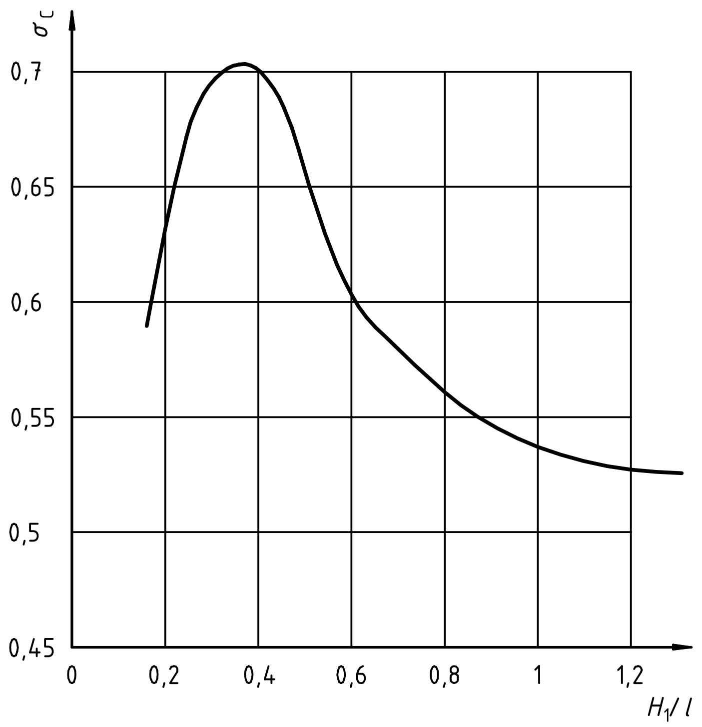


Figure 19 — Modular limit σ_c for trapezoidal broad-crested weirs with a vertical downstream face (Z_2 = 0) as a function of H_1/l

Table 5 — The drowned-flow coefficient C_{dr} as a function of H_1/l and H_2/H_1

	Values of the drowned-flow coefficient C_{dr}										
	H_1/l										
H_2/H_1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,95	0,60[a]	0,62[a]	0,64[a]	0,67	0,69	0,70	0,71	0,74	0,75	0,75	0,75
0,94	0,63[a]	0,66	0,69	0,72	0,74	0,75	0,76	0,78	0,79	0,79	0,79
0,93	0,67	0,70	0,74	0,76	0,78	0,80	0,80	0,81	0,81	0,82	0,82
0,92	0,70	0,75	0,78	0,80	0,82	0,82	0,83	0,83	0,84	0,84	0,84
0,91	0,74	0,78	0,81	0,83	0,85	0,85	0,85	0,86	0,85	0,85	0,85
0,90	0,77	0,81	0,84	0,86	0,87	0,87	0,87	0,87	0,87	0,87	0,86
0,89	0,80	0,85	0,87	0,88	0,89	0,89	0,89	0,88	0,88	0,88	0,87
0,88	0,83	0,87	0,89	0,90	0,90	0,90	0,90	0,89	0,90	0,88	0,88
0,87	0,85	0,88	0,90	0,91	0,91	0,91	0,91	0,90	0,91	0,89	0,89
0,86	0,87	0,89	0,92	0,92	0,92	0,92	0,91	0,91	0,91	0,90	0,90
0,85	0,88	0,91	0,94	0,93	0,93	0,92	0,92	0,92	0,92	0,91	0,90
0,84	0,90	0,93	0,95	0,94	0,94	0,93	0,92	0,92	0,92	0,92	0,91
0,83	0,91	0,95	0,96	0,95	0,94	0,94	0,93	0,93	0,93	0,92	0,92
0,82	0,92	0,96	0,97	0,96	0,95	0,94	0,93	0,93	0,93	0,93	0,92
0,81	0,93	0,96	0,97	0,96	0,95	0,95	0,94	0,94	0,94	0,93	0,93
0,80	0,94	0,97	0,98	0,97	0,96	0,95	0,94	0,94	0,94	0,94	0,93
0,79	0,94	0,97	0,98	0,97	0,96	0,95	0,95	0,94	0,94	0,94	0,94
0,78	0,95	0,97	0,98	0,97	0,96	0,96	0,95	0,95	0,95	0,94	0,94
0,77	0,95	0,98	0,98	0,98	0,97	0,96	0,95	0,95	0,95	0,95	0,94
0,76	0,96	0,98	0,98	0,98	0,97	0,96	0,96	0,95	0,95	0,95	0,95
0,75	0,96	0,98	0,99	0,98	0,97	0,97	0,96	0,96	0,95	0,95	0,95
0,74	0,97	0,98	0,99	0,98	0,97	0,97	0,96	0,96	0,96	0,96	0,95
0,73	0,97	0,99	0,99	0,98	0,98	0,97	0,97	0,96	0,96	0,96	0,95
0,72	0,97	0,99	0,99	0,99	0,98	0,97	0,97	0,96	0,96	0,96	0,96
0,71	0,97	0,99	0,99	0,99	0,98	0,98	0,97	0,97	0,96	0,96	0,96
0,70	0,98	0,99	FF	0,99	0,98	0,98	0,97	0,97	0,97	0,97	0,96
0,69	0,98	FF		0,99	0,98	0,98	0,98	0,97	0,97	0,97	0,96
0,68	0,98			0,99	0,98	0,98	0,98	0,97	0,97	0,97	0,97
0,67	0,98			0,99	0,98	0,98	0,98	0,98	0,97	0,97	0,97
0,66	0,99			0,99	0,99	0,98	0,98	0,98	0,97	0,97	0,97
0,65	0,99			FF	0,99	0,98	0,98	0,98	0,98	0,98	0,97
0,64	FF				0,99	0,99	0,98	0,98	0,98	0,98	0,98
0,63					0,99	0,99	0,98	0,98	0,98	0,98	0,98
0,62					0,99	0,99	0,99	0,98	0,98	0,98	0,98
0,61					0,99	0,99	0,99	0,99	0,98	0,98	0,98
0,60					FF	0,99	0,99	0,99	0,98	0,98	0,98
0,59						0,99	0,99	0,99	0,98	0,98	0,98
0,58						0,99	0,99	0,99	0,99	0,99	0,99
0,57						FF	0,99	0,99	0,99	0,99	0,99
0,56							0,99	0,99	0,99	0,99	0,99
0,55							FF	0,99	0,99	0,99	0,99
0,54								FF	0,99	0,99	0,99
0,53									FF	FF	0,99
0,52											FF

[a] Extrapolated.

8.7 Uncertainty in measurement

8.7.1 The overall uncertainty in flow measurements made using trapezoidal broad-crested weirs in trapezoidal channels depends on the uncertainties in the head measurements, in the measurements of the dimensions of the weir and in the coefficients as they apply to the weir in use.

8.7.2 With reasonable care and skill in the construction and installation of a trapezoidal broad-crested weir, the systematic uncertainty in the discharge coefficient C_D is within ± 3 %. There is no uncertainty in the coefficient C_{dr} for free flow. For submerged 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 $C_D \cdot C_{dr}$ is within ± 5 %.

The random uncertainty in the coefficient of discharge C_D reflects the real but marginal differences in coefficient values for different discharges, and may be taken as ± 0,5 %. The random uncertainty in the coefficient C_{dr} may be ignored.

8.7.3 The method by which the uncertainties in the coefficients shall be combined with other sources of uncertainty is given in clause 9.

In general, the discharge coefficients quoted in this International Standard have been determined using calibration experiments on small-scale model structures. It should be borne in mind that these coefficients will not be identical for larger structures, owing to scale effects.

9 Uncertainties in flow measurement

9.1 General

9.1.1 For general information, reference should be made to ISO/TR 5168.

9.1.2 In general, the component uncertainties arising from various sources of error may be assessed (see 9.4 and 9.5) and combined (see 9.6) to obtain an estimation of the total uncertainty in the discharge measurement. This total uncertainty allows judgement of whether the discharge can be measured with sufficient accuracy for the purpose in hand.

Clause 9 is intended to provide sufficient information for the user of this International Standard to estimate the uncertainty in a measurement of discharge.

9.1.3 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 range of values, around the measured value, within which the true rate of flow is expected to lie 19 times out of 20 (i.e. 95 % confidence limits).

9.2 Sources of error

9.2.1 The sources of error in the discharge measurement may be identified by considering the generalized form of the discharge equations as given in 7.5.1 and 8.5.1

For rectangular channels:

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

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.

For trapezoidal channels:

$$Q = C_D C_{dr} \left(b_c y_c + m y_c^2 \right) \left[2g (H_1 - y_c) \right]^{0,5}$$

9.2.2 The only sources of error which need to be considered are

a) the discharge coefficient C_D, the velocity of approach coefficient C_v and the drowned-flow coefficient C_{dr}, for which numerical estimates of uncertainty (in the combined coefficient $C_D C_v C_{dr}$) are given in 7.7 and 8.7.

b) the dimensional measurement of the structure, e.g. the width of weir b, and

c) the measured head h.

9.3 Types of error

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

9.3.2 The standard deviation of a set of n measurements of a quantity y under steady conditions may be estimated using the equation

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

where

$\bar{y}$ is the arithmetic mean of n measurements;

y_i is the result of the ith measurement.

The standard deviation of the mean is then given by

$$s_{\bar{y}} = \frac{s_y}{\sqrt{n}}$$

and the uncertainty of the mean [1)] is 2 $s_{\bar{y}}$ (at the 95 % probability level). This uncertainty is the contribution of random errors in any series of experimental measurements to the total uncertainty.

9.3.3 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. For example, an error in setting the zero of a water-level gauge to the crest level produces a systematic error between the true mean of the measured head and the actual value. As repetition of the measurement does not eliminate systematic error, the actual value can only be determined by an independent measurement known to be more accurate.

9.4 Uncertainties in coefficient values

9.4.1 All errors in this category are systematic.

[1)] The factor of 2 is applicable where n is large. For n = 6 the factor is 2,6; for n = 8 it is 2,4: for n = 10 it is 2,3; for n = 15 it is 2,1.

9.4.2 The values of the coefficients C_D and C_{dr} quoted in this International Standard are based on an appraisal of experiments which 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, owing to variations in the surface finish of the device, its installation, the approach flow conditions, the scale effect between model and site structure, etc.

9.4.3 The uncertainties in the coefficients quoted in this International Standard are calculated on the basis of the deviation of experimental data from various sources from the theoretical equations given. The uncertainty values suggested thus represent the accumulation of evidence and experience available.

9.5 Uncertainties in measurements made by the user

9.5.1 Both random and systematic uncertainties will occur in measurements made by the user; these uncertainties shall be estimated by the user according to the methods used and the conditions of measurement. Since neither the method of measurement nor the procedure is specified in this International Standard, no numerical values for uncertainties in this category can be given here.

9.5.2 The uncertainty in dimensional measurement of the weir (essentially the width b) depends on the accuracy to which the device as constructed can be measured. In practice, this uncertainty may often prove to be insignificant in comparison with other uncertainties.

9.5.3 The uncertainty in the gauged head shall be determined from an assessment of the individual sources of error, e.g. the uncertainty in the determination of the gauge zero, the freedom from bias and the repeatability of the measuring device (of which any mechanical backlash is an important element), the fluctuations of the level to be measured, etc. The uncertainty in the gauged head is the square root of the sum of the squares of the individual uncertainties. This uncertainty may be small if a vernier or micrometer instrument is used, with a zero determination of comparable accuracy.

9.6 Combination of uncertainties

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

9.6.2 All sources contributing uncertainties will have both random and systematic components. However, in some cases, either the random or the systematic component may be predominant and the other component can be neglected by comparison.

9.6.3 Because of the different nature of random and systematic uncertainties, they should not normally be combined with each other. However, if the proviso of 9.6.1 is taken into account, random uncertainties from different sources may be combined together by the root-sum-of-squares rule; systematic uncertainties from different sources may be similarly combined.

9.6.4 The percentage random uncertainty X'_Q in the discharge may be calculated from the following equation:

$$X'_Q = \pm \left(X'^2_C + X'^2_b + 2{,}25\, X'^2_h \right)^{1/2}$$

where

X'_C is the percentage random uncertainty in $C_D C_v C_{dr}$;

X'_b is the percentage random uncertainty in b;

X'_h is the percentage random uncertainty in h;

and

$$X'_b = \frac{e_b}{b} \times 100$$

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

where

e_b	is the random uncertainty in the width measurement;
${}_1X'_h$, ${}_2X'_h$, etc.	are percentage random uncertainties in the head measurement (see 9.5.3);
X'_m	is the percentage random uncertainty in the mean if a series of readings of head measurement are taken at constant water level.

The term X'_m is easily estimated if, for example, a point gauge is used for water level measurement. For continuous or digital recording equipment, the random uncertainty in reading a given water level can be assessed by laboratory tests on the equipment.

9.6.5 The percentage systematic uncertainty X''_Q in the discharge may be calculated from the following equation:

$$X''_Q = \pm (X''^2_C + X''^2_b + 2{,}25 X''^2_h)^{1/2}$$

where

X''_C is the percentage systematic uncertainty in $C_D C_V C_{dr}$;

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

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

and

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

where ${}_1X''_h$, ${}_2X''_h$, etc. are percentage systematic uncertainties in the head measurement (see 9.5.3).

9.6.6 It should be noted that the uncertainties in the discharge are not constant for a given device, but vary with the rate of flow. It may therefore be necessary to consider the uncertainties for several rates of flow covering the required range of measurement.

9.7 Presentation of results

Although it is desirable, and frequently necessary, to list total random and total systematic uncertainties separately, it is appreciated that a simpler presentation of results may be required. (For this purpose, random and systematic uncertainties may be combined as described in ISO/TR 5168.) If so, the random and systematic uncertainties may be combined to yield a total uncertainty X_Q:

$$X_Q = \pm (X'^2_Q + X''^2_Q)^{1/2}$$

10 Example

10.1 The following is an example of the computation of the discharge and associated uncertainty in a single measurement of flow using a trapezoidal broad-crested weir in a rectangular channel operating under free-flow conditions. The upstream slope of the weir Z_1 is 2 and the downstream slope of the weir Z_2 is 3. The crest height h_p above the bed of the approach channel is 1 m and the gauged head h is 0,67 m. The width of the weir crest b and the width of the approach channel b_1 are both equal to 10 m. The length of the weir l in the direction of flow is 0,67 m. A float operated recorder is used.

10.2 The value of the coefficient of discharge C_D for the weir with Z_1 = 2 and Z_2 = 3 and an h/l value of 1 is obtained from Figure 3 or Table 2 as 1,054. The value of the approach velocity coefficient C_v is obtained from 7.5.1.2 as 1,041. For free flow, the value of the drowned-flow coefficient C_{dr} is 1.

10.3 Using the equation given in 7.5.1.1,

$$Q = \left(\frac{2}{3}\right)^{3/2} \times 1{,}054 \times 1{,}041 \times 1 \times \sqrt{g} \times 10 \times 0{,}67^{3/2} = 10{,}26 \text{ m}^3/\text{s}$$

10.4 The percentage uncertainties in the coefficient value $C = C_D C_v C_{dr}$ are

$$X'_C = \pm 0{,}5\ \%$$

(see 7.7.2)

$$X''_C = \pm 4\ \%$$

(see 7.7.2)

10.5 If it is assumed that several measurements of width are taken, the random component of uncertainty in width measurement is likely to be negligible. The systematic uncertainty in width measurement is assumed in this case to be 0,01 m.

Accordingly,

$$X'_b = 0$$

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

$$= \pm 0{,}1\ \%$$

10.6 The magnitude of the uncertainty associated with the head measuring device is related to the particular equipment used. It has been demonstrated that the gauge zero could be set to within ± 0,003 m. This is a systematic uncertainty. There is no random uncertainty associated with the zero setting because until the zero is reset the true zero will have the same magnitude and sign.

Therefore,

$${}_1X'_h = 0$$

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

$$= \pm 0{,}45\ \%$$

10.7 Uncertainties associated with different types of water level observation equipment can be determined by using careful tests under controlled conditions. The random component of uncertainty can be determined by taking a series of readings at a given water level. However, to distinguish this uncertainty from other sources of uncertainty, it is necessary that these tests be carried out with the water level always rising (or falling). For the equipment used in this example the random component of uncertainty in water level measurement is approximately ± 0,001 m. Systematic uncertainties in water level measurement occur owing to backlash, tape stretching, etc. Where possible, corrections should be applied, but controlled tests for given types of equipment will indicate the magnitude of the residual systematic uncertainty. In this case, where a float operated recorder is used, this value is approximately ± 0,002 5 m.

Accordingly,

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

$$= \pm\ 0{,}15\ \%$$

$${}_2X''_h = \pm \frac{0{,}002\ 5}{0{,}67} \times 100$$

$$= \pm\ 0{,}37\ \%$$

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

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

$$X'_h = \pm \left({}_1X'^2_h + {}_2X'^2_h\right)^{1/2}$$

$$= \pm \left(0 + 0{,}15^2\right)^{1/2}$$

$$= \pm\ 0{,}15\ \%$$

$$X''_h = \pm \left({}_1X''^2_h + {}_2X''^2_h\right)^{1/2}$$

$$= \pm \left(0{,}45^2 + 0{,}37^2\right)^{1/2}$$

$$= \pm\ 0{,}58\ \%$$

The total percentage random uncertainty in the discharge measurement is

$$X'_Q = \pm \left(X'^2_C + X'^2_b + 2{,}25X'^2_h\right)^{1/2}$$

$$= \pm \left(0{,}5^2 + 0 + 2{,}25 \times 0{,}15^2\right)^{1/2}$$

$$= \pm\ 0{,}55\ \%$$

The total percentage systematic uncertainty in the discharge measurement is

$$X''_Q = \pm \left(X''^2_C + X''^2_b + 2{,}25X''^2_h\right)^{1/2}$$

$$= \pm \left(4^2 + 0{,}1^2 + 2{,}25 \times 0{,}58^2\right)^{1/2}$$

$$= \pm\ 4{,}1\ \%$$

To facilitate a simple presentation, the percentage random and systematic uncertainties can be combined by the root-sum-of-squares rule as follows:

$$X_Q = \pm \left(X'^2_Q + X''^2_Q\right)^{1/2}$$

$$= \pm \left(0{,}55^2 + 4{,}1^2\right)^{1/2}$$

$= \pm 4,14$ %

The discharge Q is therefore 10,26 m^3/s ± 4,1 %, or 10,26 m^3/s ± 0,42 m^3/s.

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