

Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs

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National foreword

This British Standard reproduces verbatim ISO 4377:2002 and implements it as the UK national standard. It supersedes BS 3680-4G:1999 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee CPI/113, Hydrometry, to Subcommittee CPI/113/2, Notches, weirs and flumes, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

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Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs

*Déterminations hydrométriques — Mesure de débit dans les canaux
découverts au moyen de structures — Déversoirs en V ouvert*



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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.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 4377 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 2, *Notches, weirs and flumes*.

This third edition cancels and replaces the second edition (ISO 4377:1990), which has been technically revised to give a rigorous version of the basic discharge equation for a weir operating under drowned flow conditions. The successive approximation method for calculating discharges is reintroduced.

Annex A forms a normative part of this International Standard.

Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs

1 Scope

This International Standard describes the methods of measurement of flow in rivers and artificial channels under steady or slowly varying conditions using flat-V weirs (see Figure 1).

Annex A gives guidance on acceptable velocity distribution.

2 Normative references

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

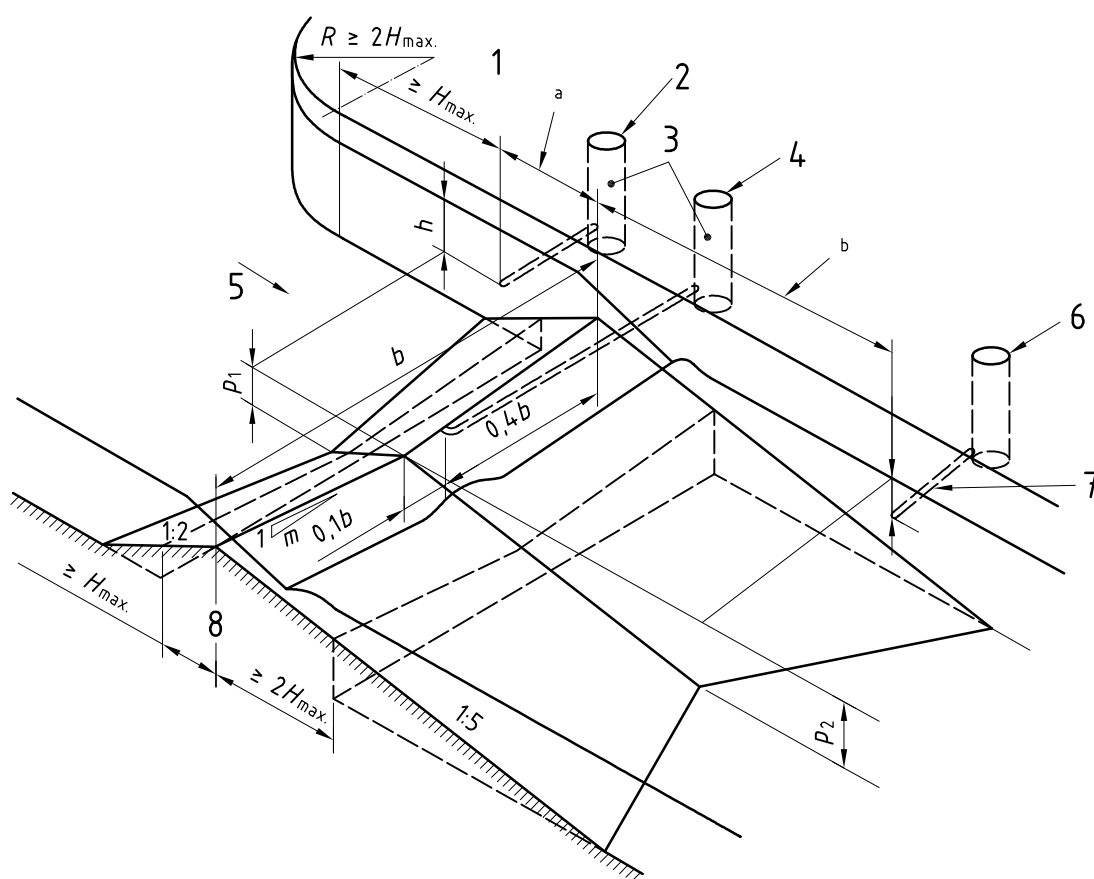
ISO 772, *Hydrometric determinations — Vocabulary and symbols*

ISO/TR 5168, *Measurement of fluid flow — Evaluation of uncertainties*

Guide to the expression of uncertainty in measurement (GUM), BIPM, IEC, IFCC, ISO, IUPAC, INPAP and OIML

3 Terms and definitions

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

**Key**

- 1 Head gauging section
- 2 Upstream tapping
- 3 Stilling wells
- 4 Crest tapping
- 5 Flow
- 6 Downstream tapping
- 7 100 mm above stilling basin level
- 8 Permissible truncation

^a $10 H'$ but equal or greater than $3H_{\max}$

^b $25 H'$ but equal or greater than $3H_{\max}$

Figure 1 — Triangular profile flat-V weir

4 Symbols

The following is a list of symbols used, with the corresponding units of measurement.

Symbol ^a	Meaning	Units
A	Area of cross-section of flow	m^2
B	Width of approach channel	m
b	Crest width	m
C_D	Coefficient of discharge	Non-dimensional
C_{dr}	Drowned flow reduction factor	Non-dimensional
C_v	Coefficient of approach velocity	Non-dimensional
e_h	Uncertainty in head measurement	m
$e_{h,0}$	Uncertainty in gauge zero	m
$e_{k,h}$	Uncertainty in head correction factor	m
g	Gravitational acceleration (standard value)	m/s^2
H	Total head above lowest crest elevation	m
H_{max}	Maximum total head above crest elevation	m
h	Gauged head above lowest crest elevation	m
h_p	Separation pocket head	m
h_{pe}	Effective separation pocket head relative to lowest crest elevation	m
h', H'	Difference between lowest and highest crest elevations	m
K_1, K_2	Constants	Non-dimensional
k_h	Head correction factor	m
m	Crest cross-slope (1 vertical: m horizontal)	Non-dimensional
n	Number of measurements in a set	Non-dimensional
p	Difference between mean bed level and lowest crest elevation	m
Q	Discharge	m^3/s
$s_{\overline{h}}$	Standard deviation of the mean of several head readings	m
$\overline{v}$	Mean velocity at cross-section	m/s
$\overline{v}_a$	Mean velocity in approach channel	m/s
$X_{C,D}$	Percentage uncertainty in discharge coefficient	Non-dimensional
$X_{C,v}$	Percentage uncertainty in coefficient of velocity	Non-dimensional
$X_{C,dr}$	Percentage uncertainty in drowned flow reduction factor	Non-dimensional
X_h	Percentage uncertainty in head measurement	Non-dimensional
X_Q	Percentage uncertainty in discharge measurement	Non-dimensional
Z_h, Z_H	Shape factors	Non-dimensional
α	Coriolis energy coefficient	Non-dimensional

Subscript

1	denotes upstream value
2	denotes downstream value
e	denotes “effective” and implies that corrections for fluid effects have been made to the quantity

^a In cases where the subscript of a symbol also contains a subscript, it is house style to write the second subscript on the same line after a comma.

Thus e_{k_h} is written $e_{k,h}$, and $X_{C_{dr}}$ is written $X_{C,dr}$

5 Characteristics of flat-V weirs

The standard flat-V weir is a control structure the crest of which takes the form of a shallow V when viewed in the direction of flow.

The standard weir is of a triangular profile with an upstream slope of 1 (vertical): 2 (horizontal) and a downstream slope of 1:5. The cross-slope of the crest line shall not be steeper than 1:10. The cross-slope shall lie in the range of 0 to 1:10 and, at the limit when the cross-slope is zero, the weir becomes a two dimensional triangular profile weir.

The weir can be used in both the modular and drowned ranges of flow. In the modular flow range, discharges depend solely on upstream water levels and a single measurement of upstream head is sufficient. In the drowned flow range, discharges depend on both upstream and downstream water levels, and two independent head measurements are required. For the standard flat-V weir, these are:

- the upstream head;
- the head developed within the separation pocket which forms just downstream of the crest or, as a less accurate alternative, the head measured just downstream of the structure.

The flat-V weir will measure a wide range of flows and has the advantage of high sensitivity at low flows.

Operation in the drowned flow range minimizes afflux at very high flows. Flat-V weirs shall not be used in steep rivers, particularly where there is a high sediment load.

There is no specified upper limit for the size of this structure. Table 1 gives the ranges of discharges for three typical weirs.

The flat-V weir can be designed to minimize the obstruction to the passage of fish in the appropriate flow range. Flow is concentrated towards the centre of the downstream face and this provides the depth of water required by migratory fish.

Table 1 — Ranges of discharge

Elevation of crest above bed m	Crest/cross-slope ratio	Width m	Range of discharge m ³ /s
0,2	1:10	4	0,015 to 5
0,5	1:20	20	0,030 to 180 (within maximum head of 3 m)
1,0	1:40	80	0,055 to 630 (within maximum head of 3 m)

6 Installation

6.1 Selection of site

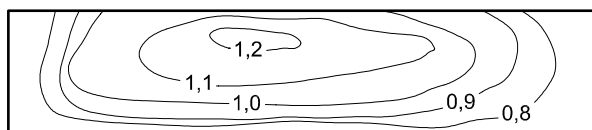
6.1.1 The weir shall be located in a straight section of the channel, avoiding local obstructions, roughness or unevenness of the bed.

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

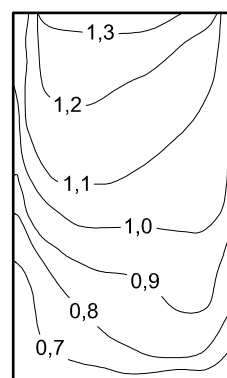
- a) the adequacy of the length of channel of regular cross-section available (see 6.2.2.2);
- b) the uniformity of the existing velocity distribution (see annex A);
- c) the avoidance of a steep channel (see 6.2.2.6);
- d) the effects of increased upstream water levels due to the measuring structure;
- e) the conditions downstream (including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features, such as seasonal weed growth, 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;
- i) the uniformity of the approach channel section;
- j) the effect of wind on the flow over the weir, especially when it is wide and the head is small and when the prevailing wind is in a transverse direction.

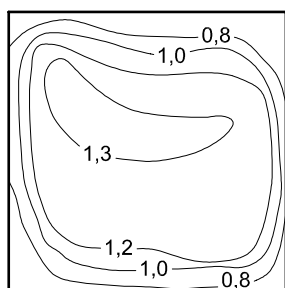
6.1.3 If the site does not possess the characteristics necessary for satisfactory measurements, or if an inspection of the stream shows that the velocity distribution in the approach channel deviates appreciably from the examples shown in Figure 2, the site shall not be used unless suitable improvements are practicable.



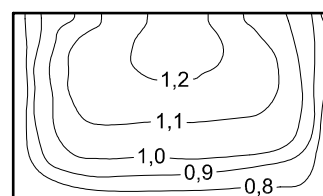
a) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 6,9 \%$



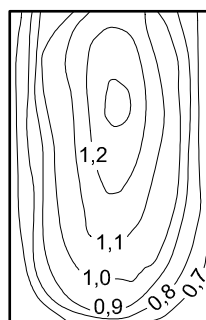
b) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 9,0 \%$



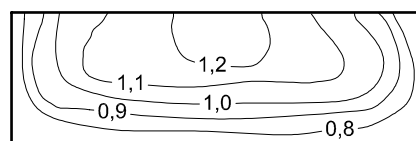
c) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 12,3 \%$



d) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 1,2 \%$



e) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 0,6 \%$



f) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}} - 1 \right) \times 100 = 0,9 \%$

Figure 2 — Examples of velocity profiles in the approach channel

6.2 Installation conditions

6.2.1 General requirements

The complete measuring installation consists of an approach channel, a weir structure and a downstream channel.

NOTE 1 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, the cross-sectional shape of the channel, channel roughness and the influence of control devices upstream or downstream of the gauging structure.

NOTE 2 The distribution and direction of velocity can have an important influence on the performance of a weir (see 6.2.2 and annex A).

NOTE 3 Once a weir has been installed, any physical changes in the installation will change the discharge characteristics; recalibration will then be necessary.

6.2.2 Approach channel

6.2.2.1 If the flow in the approach channel is disturbed by irregularities in the boundary, e.g. 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 shall have a symmetrical velocity distribution (see annex A.) This can be achieved by providing a long, straight approach channel of uniform cross-section.

6.2.2.2 A minimum required length of straight approach channel shall be five times the width of the water surface at maximum flow, provided flow does not enter the approach channel with high velocity via a sharp bend or angled sluice gate.

NOTE 1 This figure refers to the distance upstream of the head-measuring position.

NOTE 2 A greater length of uniform approach channel is desirable if it can be readily provided.

6.2.2.3 In a natural channel where it is uneconomic to line the bed and banks with concrete for this distance, and if where the width between the vertical walls of the lined approach to the weir is less than the approach width of the natural channel, the banks shall be profiled to give a smooth transition from the approach channel width to the width between the vertical side walls. The unlined channel upstream of the contraction shall nevertheless conform to 6.2.2.1 and 6.2.2.2.

6.2.2.4 Vertical side walls constructed to effect a narrowing of the natural channel shall be symmetrically aligned with the centre line of the channel and curved to a radius not less than $2 H_{\max}$ as shown in Figure 1. The tangent point of this radius nearest to the weir crest shall be at least $H_{\max}$ upstream of the head measurement section. The height of the side walls shall be chosen to contain the design maximum discharge.

6.2.2.5 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. No baffle shall be nearer to the point at which the head is measured than 10 times the maximum upstream head.

6.2.2.6 Under certain conditions, a hydraulic jump may occur upstream of the measuring structure, for example if the approach channel is steep. Provided the wave created by the hydraulic jump is at a distance upstream of no less than 20 times the maximum upstream depth, flow measurement is feasible, subject to confirmation that an even velocity distribution exists at the gauging station.

6.2.2.7 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 can be made by means of a current meter. The velocity distribution shall comply with the requirements of annex A, clause A.5.

6.3 Weir structure

6.3.1 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 straight when viewed from above and at right angles to the direction of flow in the upstream channel. The geometry shall conform to the dimensions given in clause 5 and Figure 1.

The weir shall be contained within vertical side walls, and the crest width shall not exceed the width of the approach channel (see Figure 1). Weir blocks may be truncated but their horizontal dimensions shall not be reduced in the direction of flow to less than $H_{1\max}$ and $2 H_{1\max}$, upstream and downstream of the crest line respectively, where $H_{1\max}$ is the maximum upstream total head, expressed in metres, relative to the lowest crest elevation.

6.3.2 The weir and the approach channel as far as the upstream tapping point shall be constructed with a smooth non-corrodible material. A good surface finish is important near the crest but can be relaxed a distance along the profile of $0,5 H_{\max}$ upstream and downstream of the crest line.

The crest shall be formed by an embedded stainless steel insert with bevelled edges to conform with the surface of the weir block. The insert shall be in the form of a removable bar-section, typically 15 mm by 100 mm lying along the downstream face of the weir with its 15 mm edge bevelled at $52,1^\circ$ to align it with the upstream face at a gradient of 1:2.

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

- a) crest width $\pm 0,2 \%$ (with a maximum of 0,01 m);
- b) upstream slope $\pm 1,0 \%$;
- c) downstream slope $\pm 1,0 \%$;
- d) crest cross-slope $\pm 1,0 \%$;
- e) point deviations from the mean crest line $\pm 0,2 \%$ of the crest width.

NOTE Laboratory installations will normally require higher accuracy.

6.3.4 The structure shall be measured upon completion and mean dimensional values and their standard deviations at 95 % confidence limits computed. The former are used for computation of discharge and the latter are used to obtain the overall uncertainty of a single determination of discharge (see 11.6).

6.4 Downstream conditions

Conditions downstream of the structure are an important factor controlling 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 light of this evidence.

7 Maintenance

Maintenance of the measuring structure and the approach channel is important to enable accurate measurements to be made. The approach channel shall be kept clean and free from silt and vegetation for at least the distance specified in 6.2.2.2. The float wells, tappings and connecting pipework 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.

The weir crest shall be inspected for erosion damage regularly. If the mean effective radius of the crest exceeds 5 mm then refurbishment shall be considered.