INTERNATIONAL STANDARD

ISO 4377

Third edition
2002-10-01

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

Reference number
ISO 4377:2002(E)

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

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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.

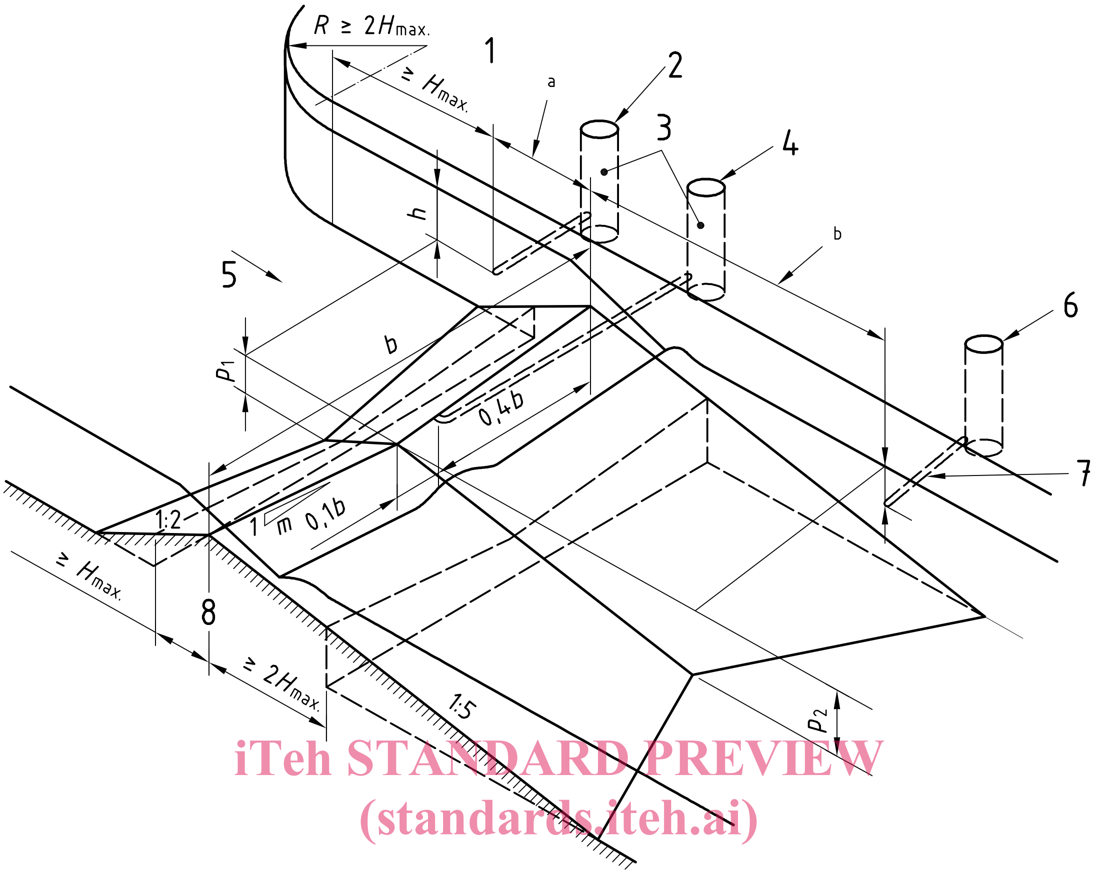
ISO 772, *Hydrometric determinations — Vocabulary and symbols*

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
$e_{\mathrm{k},h}$	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
$\overline{v}_\mathrm{a}$	Mean velocity in approach channel	m/s
$X_{C,\mathrm{D}}$	Percentage uncertainty in discharge coefficient	Non-dimensional
$X_{C,v}$	Percentage uncertainty in coefficient of velocity	Non-dimensional
$X_{C,\mathrm{dr}}$	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 $e_{\mathrm{k},h}$, and X_{C_dr} is written $X_{C,\mathrm{dr}}$

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;

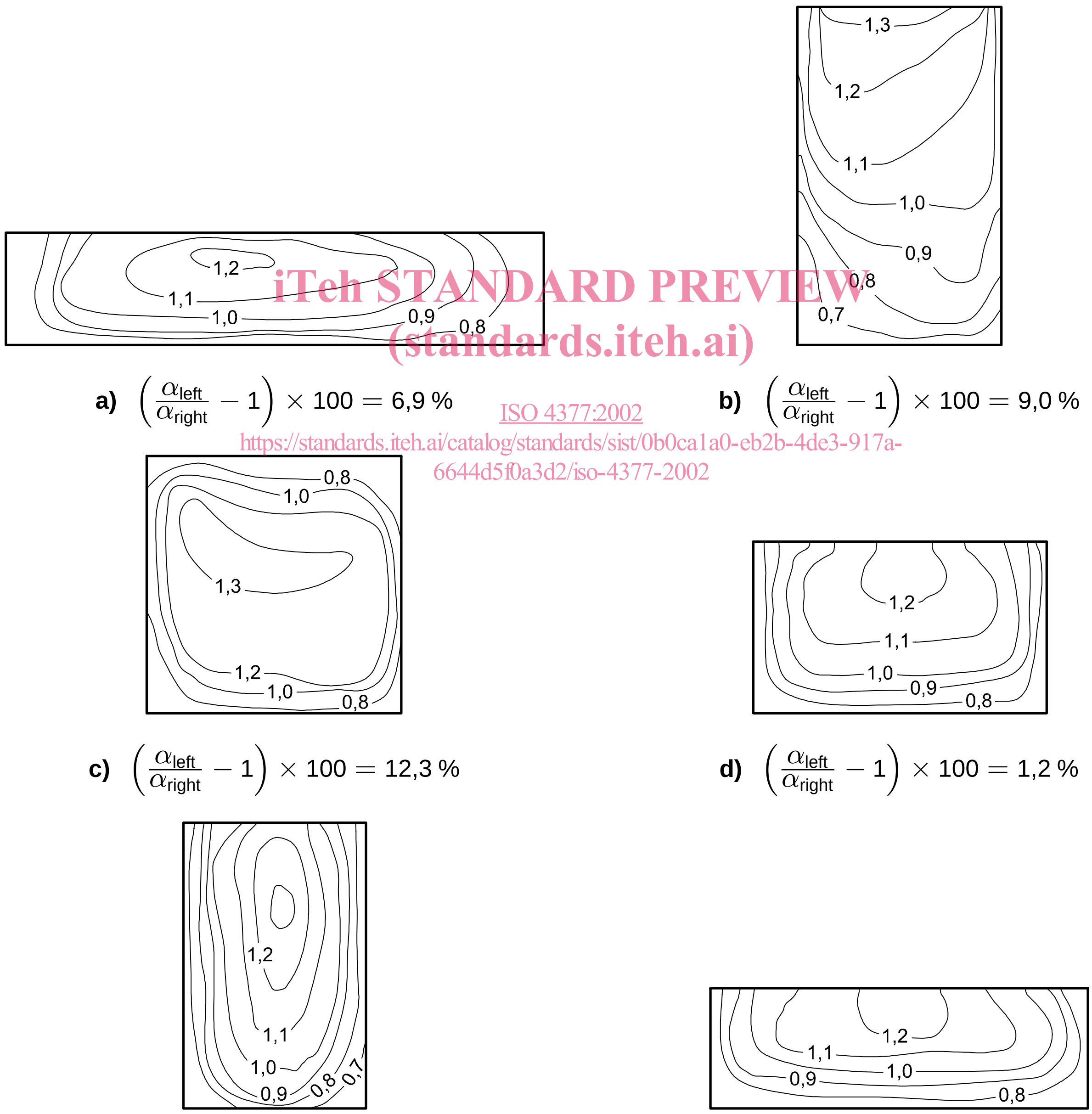
g) the necessity for flood banks, to confine the maximum discharge to the channel;

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 $H_{1\text{max}}$ and 2 $H_{1\text{max}}$, upstream and downstream of the crest line respectively, where $H_{1\text{max}}$ 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° 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.

Erosion lowers the zero datum and affects the coefficient of discharge at low flows (see 8.3 and clause 9). In such cases, the metal crest shall be removed, dressed and refitted.

If conditions are modular when maintenance is carried out, a useful check on the satisfactory operation of a crest tapping is to ensure that the readings accord with the specification given in 9.5.

8 Measurement of head(s)

8.1 General

Where spot measurements are required, the heads can be measured by vertical gauges, hooks, points, wires or tape gauges. Where continuous records are required, recording gauges shall be used.

NOTE As the size of the weir and head decreases, small discrepancies in construction and in the zero setting and reading of the head measuring device become of greater relative importance.

8.2 Gauge wells

8.2.1 It is common practice to measure the upstream head in a gauge well to reduce the effects of water surface irregularities.

Periodic checks on the measurement of the head in the approach channel shall be made.

Where the weir is designed to operate in the drowned flow range, a separate gauge well shall be used to record the piezometric head. This develops within the separation pocket which forms immediately downstream of the crest or in the channel downstream of the structure.

8.2.2 Gauge wells shall be vertical and of sufficient height and depth to cover the full range of water levels. In field installations they shall have a minimum height of 0,3 m above the maximum water levels expected. Gauge wells shall be connected to the appropriate head measurement positions by means of pipes.

8.2.3 Both the well and the connecting pipe shall be watertight. Where the well is provided for the accommodation of the float of a level recorder, it shall be of adequate size and depth.

8.2.4 The invert of the pipe shall be positioned at a distance of no less than 0,06 m below the lowest level to be gauged.

8.2.5 Pipe connections to the upstream and downstream head measurement positions shall terminate either flush with, or at right angles to the boundary of the approach and downstream channels. The channel boundary shall be plain and smooth (equivalent to carefully finished concrete) within a distance 10 times the diameter of the pipes from the centreline of the connection. The pipes may be oblique to the wall only if it is fitted with a removable cap or plate, set flush with the wall, through which a number of holes are drilled. The edges of these holes shall not be rounded or burred. Perforated cover plates are not recommended where weed or silt are likely to be present.

8.2.6 The static head at the separation pocket behind the crest of the weir shall be transmitted to its gauge well by one of the following:

a) an array of tapping holes set into a plate covering a cavity in the crest of the weir block;

b) the underside of the plate supporting a manifold into which the static head is communicated via an array of feed tubes;

c) a horizontal conduit leading from the cavity through the weir block beneath the crest and terminating at the gauge well;

d) a flexible transmission tube to communicate static head within the manifold to the gauge well;

e) a watertight seal around the transmission tube to prevent static head within the cavity from influencing the static head transmitted from within the manifold.

The static head within the manifold may be at a different pressure because of leakage around the periphery of the cover plate.

These arrangements minimize the occurrence of silting within the communication path between the separation pocket and the gauge well and provide for the effective purging of the pipework by the occasional backflushing of the system. For this purpose a volume of water shall periodically be introduced into the gauge well.

Figure 3 shows the general arrangement for the crest-tapping installation. The size and disposition of the crest-tapping holes is given in Table 2.

8.2.7 Adequate additional depth shall be provided in wells to avoid the danger of floats, if used, grounding either on the bottom or on any accumulation of silt or debris.

The gauge well arrangement may include an intermediate chamber of similar size and proportions as the approach channel, to enable silt and other debris to settle out where it may be readily seen and removed.

8.2.8 The diameter of the connecting pipe or width of slot to the upstream well shall be sufficient to permit the water level in the well to follow the rise and fall of head without appreciable delay. Care should be taken however not to oversize the pipe, in order to ensure ease of maintenance and to damp out oscillations due to short period waves.

NOTE No firm rule can be laid down for determining the size of the connecting pipe to the upstream well, because this is dependent on a particular installation, e.g. whether the site is exposed and thus subject to waves, and whether a larger diameter well is required to house the floats of recorders.

Table 2 — Arrangements for crest tappings

Crest tapping holes	Crest width b m			
	0,30 to 0,99	1,00 to 1,99	2,00 to 3,99	> 4,00
Hole diameter (mm)	5	5	10	10
Hole pitch (mm)	25	25	40	50
Number of tapping holes	3	5	7	9
Offset of centre hole from centre line of weir	$0,1b$	$0,1b$	$0,1b$	$0,1b$
Distance of the array of holes downstream of the crest (mm)	10	15	20	20
Bore diameter of manifold feeder tubes (mm)	5	5	10	10
Bore diameter of transmission tube (mm)	15	20	25	30

8.3 Zero setting

8.3.1 Accurate initial setting of the zeros of the head measuring devices with reference to the level of the crest and subsequent regular checks of these settings is essential.

8.3.2 An accurate means of checking the zero at frequent intervals shall be provided. Bench marks, in the form of horizontal metal plates, shall be set up on the top of the vertical side walls and in the gauge wells. These shall be accurately levelled to ensure their elevation relative to crest level is known.

Instrument zeros can be checked with respect to these bench marks without the necessity of re-surveying the crest each time. Any settlement of the structure may, however, affect the relationships between crest and bench mark levels and it is advisable to make occasional checks on these relationships.

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