International Standard 1438/1

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Water flow measurement in open channels using weirs and venturi flumes — Part 1 : Thin-plate weirs

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FOREWORD

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 1438/1 was developed by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, and was circulated to the member bodies in November 1977.

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

USSR

This International Standard covers only thin-plate weirs and supersedes the relevant portions of ISO 1438-1975. A separate International Standard on flumes is under preparation and when it is available will become ISO 1438/2. ISO 1438-1975 will then be fully withdrawn.

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Water flow measurement in open channels using weirs and venturi flumes — Part 1 : Thin-plate weirs

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies methods for the measurement of water flow in open channels using rectangular and triangular-notch (V-notch) thin-plate weirs. The flow conditions considered are limited to steady, free and fully ventilated discharge. Recommended discharge coefficients are applicable to water only in the approximate range of temperatures from 5 to 30 °C. Using the coefficients for water temperatures several degrees outside this range will result in negligible error except at very small heads. Limitations of applicability related to weir and flow geometry are specified for the recommended formulae.

2 REFERENCES

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

ISO 4373, *Measurement of liquid flow in open channels — Water level measuring devices.*

3 DEFINITIONS

For the purpose of this International Standard the definitions given in ISO 772 shall apply. Terms which have special significance in this standard are defined where they first occur.

4 UNITS OF MEASUREMENT

Units used in this International Standard are SI units.

5 PRINCIPLE

The discharge over thin-plate weirs is a function of the head on the weir, the size and shape of the discharge area, and an experimentally determined coefficient which takes into account the head on the weir, the geometrical properties of the weir and approach channel and the dynamical properties of the water.

6 INSTALLATION

6.1 General

General requirements of weir installations are described in the following clauses. Special requirements of different types of weirs are described in clauses which deal with specific weirs (see clauses 9 and 10).

6.2 Selection of site

The type of weir to be used for discharge measurement is determined in part by the nature of the proposed measuring site. Under some conditions of design and use, weirs shall be located in rectangular flumes or in weir boxes which simulate flow conditions in rectangular flumes. Under other conditions, weirs may be located in natural channels as well as flumes or weir boxes, with no significant difference in measurement accuracy. Specific site-related requirements of the installation are described in 6.3.

6.3 Installation conditions

6.3.1 *General*

Weir discharge is critically influenced by the physical characteristics of the weir and the weir channel. Thin-plate weirs are especially dependent on installation features which control the velocity distribution in the approach channel and on the construction and maintenance of the weir crest in meticulous conformance with standard specifications.

6.3.2 *Weir*

Thin plate weirs shall be vertical and perpendicular to the walls of the channel. The intersection of the weir plate with the walls and floor of the channel shall be watertight and firm, and the weir shall be capable of withstanding the maximum flow without distortion or damage.

Stated practical limits associated with different discharge formulae such as minimum width, minimum weir height, minimum head, and maximum values of h/p and b/B (where h is the measured head, p is the height of crest relative to floor, b is the measured width of the notch and B is the width of the approach channel), are factors which influence both the selection of weir type and the installation.

6.3.3 *Approach channel*

For the purposes of this International Standard the approach channel is that portion of the weir channel which extends upstream from the weir a distance not less than ten times

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the width of the nappe at maximum head. If the weir is located in a weir box, the length of the box shall be equal to the specified length of the approach channel.

The flow in the approach channel shall be uniform and steady, with the velocity distribution approximating that in a channel of sufficient length to develop normal (resistance-controlled) flow in smooth, straight channels. Figure 1 shows measured normal velocity distributions in rectangular channels, upstream from the influence of a weir. Baffles and flow straighteners can be used to simulate normal velocity distribution, but their location with respect to the weir shall be not less than the minimum length prescribed for the approach channel.

The influence of approach-channel velocity distribution on weir flow increases as h/p and b/B increase in magnitude. If a weir installation unavoidably results in a velocity distribution which is appreciably non-uniform, the possibility of error in calculated discharge should be checked by means of an alternative discharge-measuring method for a representative range of discharges.

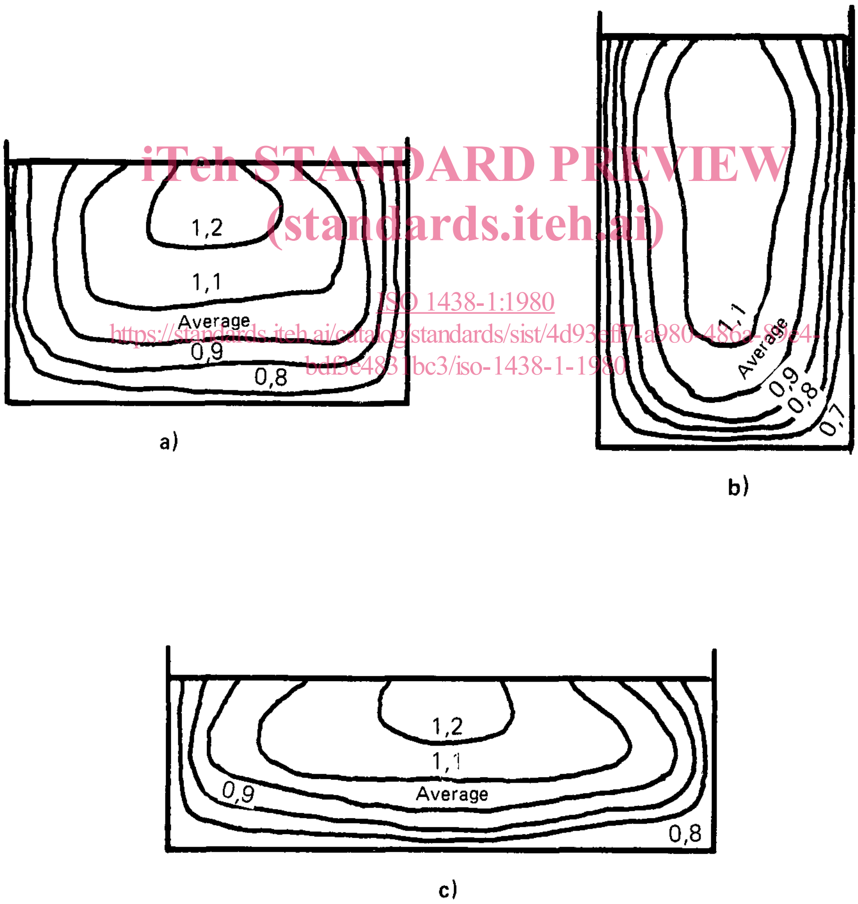

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FIGURE 1 – **Examples of normal velocity distribution in rectangular channels**

6.3.4 *Downstream channel*

The shape and size of the channel downstream from the weir is of no significance, but the level of the water in the downstream channel shall be a sufficient vertical distance below the crest to ensure free, fully ventilated discharges. Free (non-submerged) discharge is ensured when the discharge is independent of the downstream water level. Fully ventilated discharge is ensured when the air pressure on the lower surface of the nappe is fully atmospheric.

7 MEASUREMENT OF HEAD

7.1 Head measuring devices

In order to obtain discharge measurement accuracies specified for the standard weirs, the head on the weir shall be measured with a laboratory-grade hook gauge, point gauge, manometer, or other gauge of equivalent accuracy. For a continuous record of head variations, precise float gauges and servo-operated point gauges can be used. Staff and tape gauges can be used when less accurate measurements are acceptable.

Additional specifications for head-measuring devices are given in ISO 4373.

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7.2 Stilling well

For the exceptional case where surface velocities and disturbances in the approach channel are negligible, the headwater level can be measured directly (for example, by means of a point gauge mounted over the headwater surface). Generally, however, to avoid water-level variations caused by waves, turbulence or vibration, the headwater level should be measured in a stilling well.

Stilling wells are connected to the approach channel by means of a suitable conduit, equipped if necessary with a throttle valve to damp oscillations. At the channel end of the conduit, the connection is made to floor or wall piezometers or a static tube located at the head-measurement section.

Additional specifications for stilling wells are given in ISO 4373.

7.3 Head-measurement section

The head-measurement section shall be located a sufficient distance upstream from the weir to avoid the region of surface drawdown caused by the formation of the nappe. On the other hand, it shall be sufficiently close to the weir that the energy loss between the head-measurement section and the weir is negligible. For the weirs included in this International Standard the location of the head-measurement section will be satisfactory if it is at a distance equal to 4 to 5 times the maximum head (4 to 5 h_{max}) upstream from the weir.

If high velocities occur in the approach channel or if water-surface disturbances or irregularities occur at the head-measurement section because of high values of h/p or b/B, it may be necessary to install several pressure intakes to ensure that the head measured in the stilling well is the average of the heads at the several measurement points.

7.4 Head-gauge datum (gauge zero)

Accuracy of head measurements is critically dependent upon the determination of the head-gauge datum or gauge zero, which is defined as the gauge reading corresponding to the level of the weir crest (rectangular weirs) or the level of the vertex of the notch (triangular-notch weirs). When necessary, the gauge zero shall be checked. Numerous acceptable methods of determining the gauge zero are in use. Typical methods are described in subsequent clauses dealing specifically with rectangular and triangular weirs. (See clauses 9 and 10.)

Because of surface tension, the gauge zero cannot be determined with sufficient accuracy by reading the head gauge with the water in the approach channel drawn down to the apparent crest (or notch) level.

8 MAINTENANCE

Maintenance of the weir and the weir channel is necessary to ensure accurate measurements.

The approach channel shall be kept free of silt, vegetation and obstructions which might have deleterious effects on the flow conditions specified for the standard installation. The downstream channel shall be kept free of obstructions which might cause submergence or inhibit full ventilation of the nappe under all conditions of flow.

The weir plate shall be kept clean and firmly secured. In the process of cleaning, care shall be taken to avoid damage to the crest or notch, particularly the upstream edges and surfaces. Construction specifications for these most sensitive features should be reviewed before maintenance is undertaken.

Head-measurement piezometers, connecting conduits and the stilling well shall be cleaned and checked for leakage. The hook or point gauge, manometer, float or other instrument used to measure the head shall be checked periodically to ensure accuracy.

9 RECTANGULAR THIN-PLATE WEIR

9.1 Types

The rectangular thin-plate weir is a general classification in which the rectangular-notch weir is the basic form and the full-width weir is a limiting case. A diagrammatic illustration of the basic weir form is shown in figure 2 with intermediate values of b/B and h/p. When $b/B = 1{,}0$ that is when the width of the weir (b) is equal to the width of the channel at the weir section (B), the weir is of full-width type (also referred to as a "suppressed" weir, because its nappe lacks side contractions).

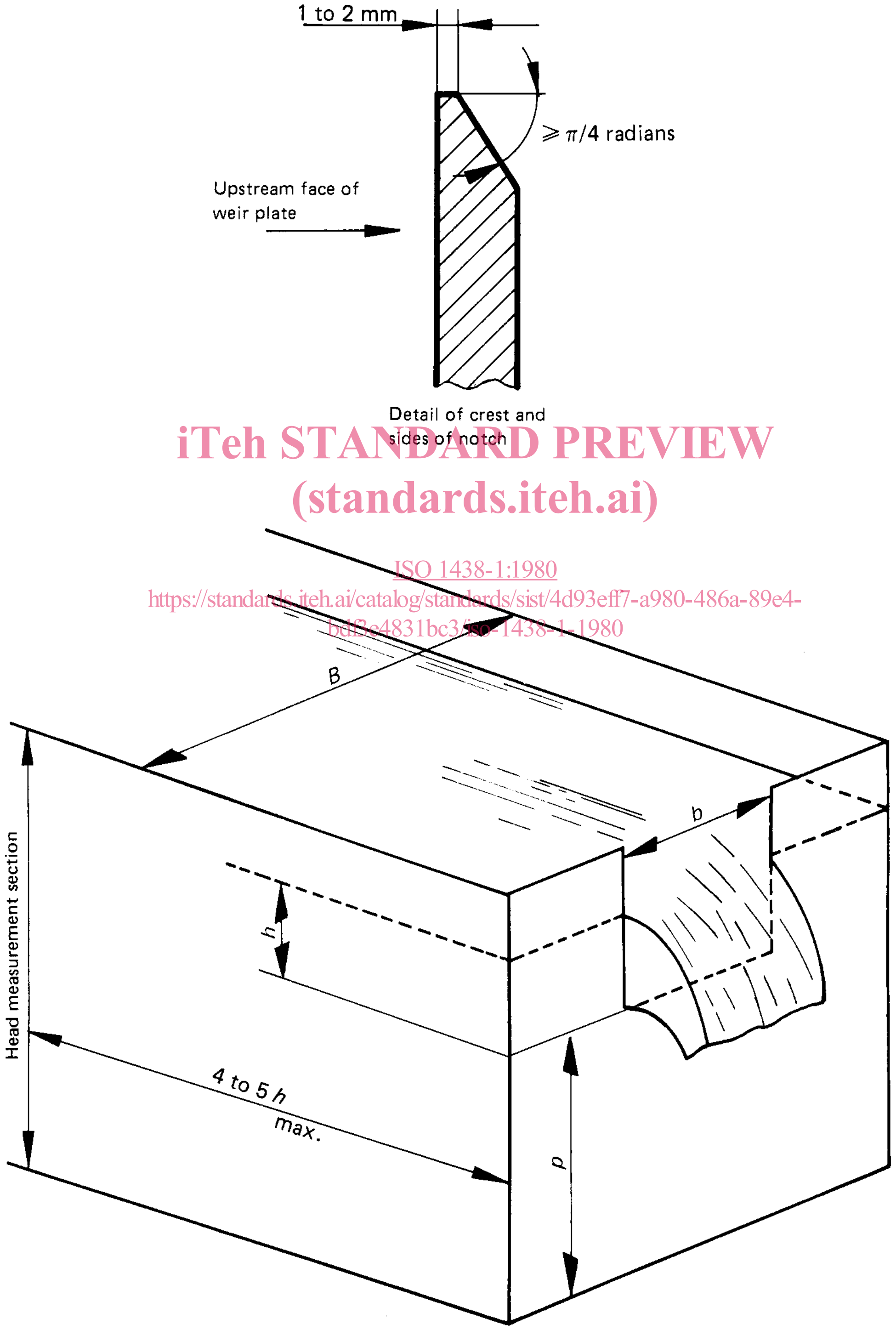

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FIGURE 2 — **Rectangular-notch, thin-plate weir**

9.2 Specifications for the standard weir

The basic weir form consists of a rectangular notch in a vertical, thin plate. The plate shall be plane and rigid and perpendicular to the walls and the floor of the approach channel. The upstream face of the plate shall be smooth (in the vicinity of the notch it shall be equivalent in surface finish to that of rolled sheet-metal).

The vertical bisector of the notch shall be equidistant from the two walls of the channel. The crest surface of the notch shall be a horizontal, plane surface, which shall form a sharp edge at its intersection with the upstream face of the weir plate. The width of the crest surface, measured perpendicular to the face of the plate, shall be between 1 and 2 mm. The side surfaces of the notch shall be vertical, plane surfaces which shall make sharp edges at their intersection with the upstream face of the weir plate. For the limiting case of the full-width weir, the crest of the weir shall extend to the walls of the channel, which in the vicinity of the crest shall be plane and smooth (see also 9.3).

To ensure that the upstream edges of the crest and the sides of the notch are sharp, they shall be machined or filed, perpendicular to the upstream face of the weir plate, free of burrs or scratches and untouched by abrasive cloth or paper. The downstream edges of the notch shall be chamfered if the weir plate is thicker than the maximum allowable width of the notch surface. The surface of the chamfer shall make an angle of not less than $\pi/4$ radians (45°) with the crest and side surfaces of the notch (see detail, figure 2). The weir plate in the vicinity of the notch preferably shall be made of corrosion-resistant metal; but if it is not, all specified smooth surfaces and sharp edges shall be kept coated with a thin, protective film (for example, oil, wax, silicone) applied with a soft cloth.

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9.3 Specifications for installation

The specifications stated in 6.3 shall apply. In general, the weir shall be located in a straight, horizontal, rectangular approach channel if possible. However, if the effective opening of the notch is so small in comparison with the area of the upstream channel that the approach velocity is negligible, the shape of the channel is not significant. In any case, the flow in the approach channel shall be uniform and steady, as specified in 6.3.3.

If the width of the weir is equal to the width of the channel at the weir section (i.e., a full-width weir), the sides of the channel upstream from the plane of the weir shall be vertical, plane, parallel and smooth (equivalent in surface finish to that of rolled sheet-metal). The sides of the channel above the level of the crest of a full-width weir shall extend at least 0,3 h_{max} downstream from the plane of the weir. Fully ventilated discharge shall be ensured as specified in 6.3.4.

The approach channel floor shall be smooth, flat and horizontal when the height of the crest relative to the floor (p) is small and/or h/p is large. For rectangular weirs, the floor should be smooth, flat and horizontal, particularly when p is less than 0,1 m and/or h_{max}/p is greater than 1. Additional conditions are specified in connection with the recommended discharge formulae.

9.4 Specifications for head measurement

9.4.1 *General*

The conditions specified in 7.1, 7.2 and 7.3 shall apply without exception.

9.4.2 *Determination of gauge zero*

The head-gauge datum or gauge zero shall be determined with great care, and it shall be checked when necessary. A typical, acceptable method of determining the gauge zero for rectangular weirs is described as follows :

a) still water in the approach channel is drawn to a level below the weir crest;

b) a temporary hook gauge is mounted over the approach channel, a short distance upstream from the weir crest;

c) a precise machinists' level is placed with its axis horizontal, with one end lying on the weir crest and the other end on the point of the temporary hook gauge (the gauge having been adjusted to hold the level in this position). The reading of the temporary gauge is recorded;

d) the temporary hook gauge is lowered to the water surface in the approach channel and its reading is recorded. The permanent gauge is adjusted to read the level in the stilling well, and this reading is recorded;

e) the computed difference between the two readings of the temporary gauge is added to the reading of the permanent gauge. The sum is the gauge zero for the permanent gauge.

Figure 3 illustrates the use of this procedure with a form of temporary hook gauge which is conveniently mounted on the weir plate.

9.5 Discharge formulae — General

Recommended discharge formulae for rectangular thin-plate weirs are presented in two categories :

a) formulae for the basic weir form (all values of b/B);

b) formulae for full-width weirs (b/B = 1,0).

Common symbols used in the formulae are defined as follows :

Q is the volume rate of flow, in cubic metres per second;

C is the coefficient of discharge (non-dimensional);

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

b is the measured width of the notch, in metres;

B is the width of the approach channel, in metres;

h is the measured head, in metres;

p is the height of the crest relative to the floor, in metres.

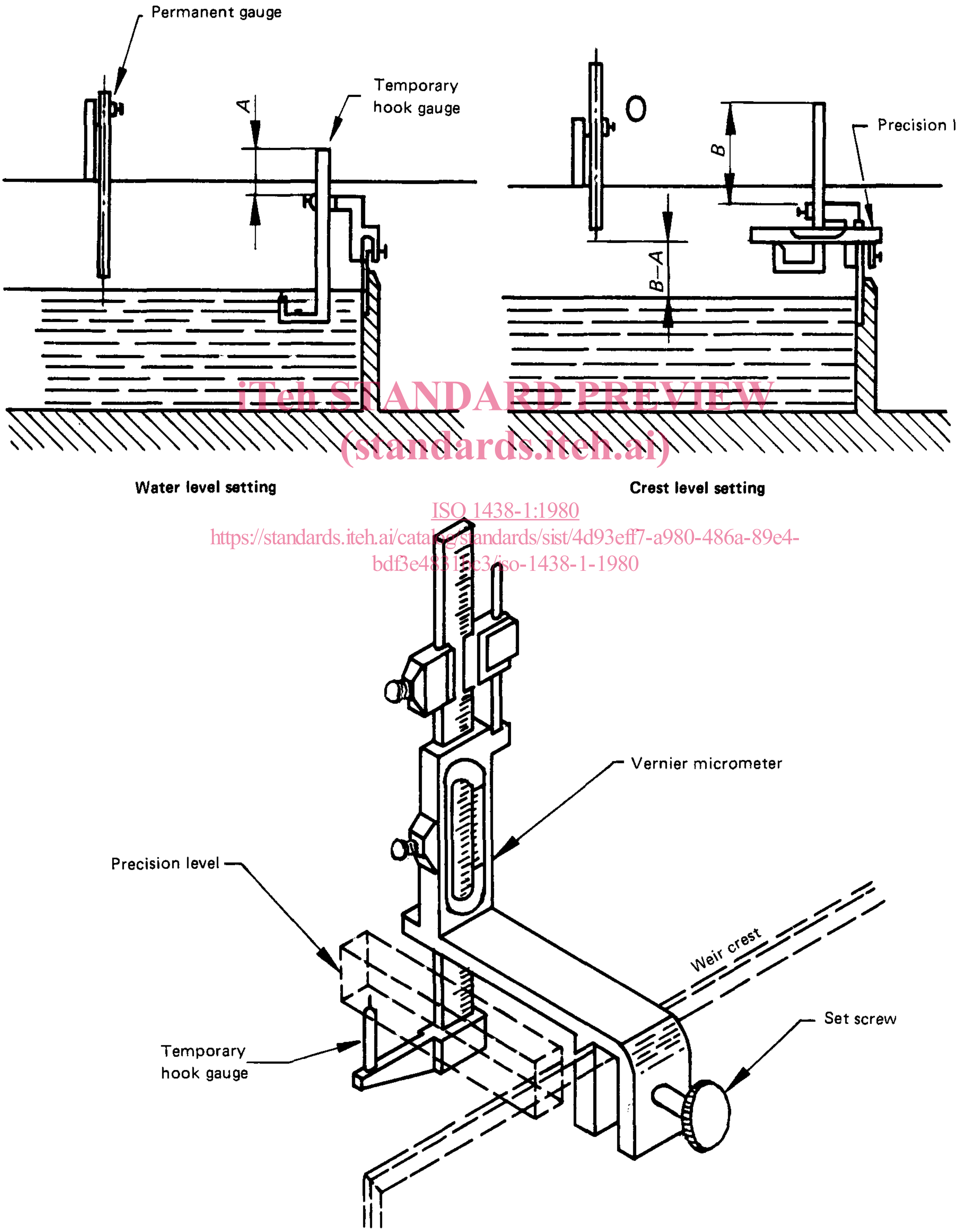

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FIGURE 3 — **Determination of gauge zero for rectangular weir**

Additional, special symbols are defined following their first occurrence in a formula.

9.6 Formulae for the basic weir form (all values of b/B)

9.6.1 *Kindsvater-Carter formula*

The Kindsvater-Carter formula for the basic weir form is

$$Q = C_e \frac{2}{3} \sqrt{2g}\, b_e h_e^{3/2} \qquad \ldots (1)$$

in which

C_e is the coefficient of discharge;

b_e is the effective width;

h_e is the effective head.

9.6.1.1 EVALUATION OF C_e, k_b AND k_h

Figure 4 shows experimentally determined values of C_e as a function of h/p for representative values of b/B. Values of C_e for intermediate values of b/B can be determined by interpolation.

The coefficient of discharge C_e has been determined by experiment as a function of two variables from the formula

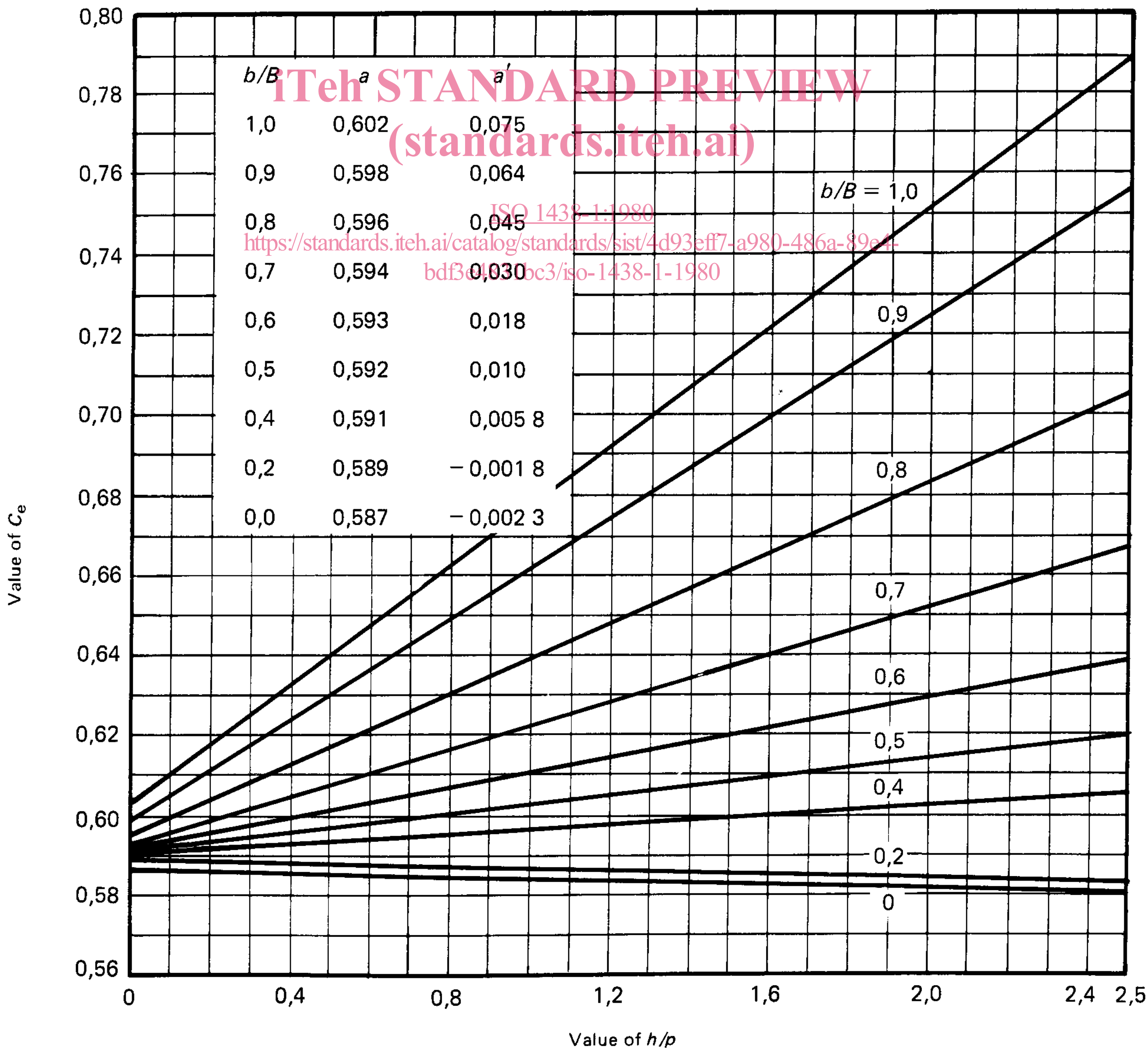
$$C_e = f\left(\frac{b}{B}, \frac{h}{p}\right) \qquad \ldots (2)$$

The effective width and head are defined by the equations

$$b_e = b + k_b \qquad \ldots (3)$$

$$h_e = h + k_h \qquad \ldots (4)$$

in which k_b and k_h are experimentally determined quantities, in metres, which compensate for the combined effects of viscosity and surface tension.



b/B	a	a'
1,0	0,602	0,075
0,9	0,598	0,064
0,8	0,596	0,045
0,7	0,594	0,030
0,6	0,593	0,018
0,5	0,592	0,010
0,4	0,591	0,005 8
0,2	0,589	− 0,001 8
0,0	0,587	− 0,002 3

FIGURE 4 — **Coefficient of discharge** $C_e = a + a' (h/p)$

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Figure 5 shows values of k_b, which have been experimentally determined as a function of b/B.

Experiments have shown that k_h can be taken to have a constant value of 0,001 m for weirs constructed in strict conformance with recommended specifications.

9.6.1.2 Formulae for C_e

For specific values of b/B the relationship between C_e and h/p has been shown by experiment (see figure 4) to be of the linear form,

$$C_e = a + a' \left(\frac{h}{p}\right)$$

Thus, for the values of b/B shown on figure 4, formulae for C_e can be written as follows :

$$(b/B = 1{,}0) : C_e = 0{,}602 + 0{,}075 \frac{h}{p} \qquad \ldots (5)$$

$$(b/B = 0{,}9) : C_e = 0{,}598 + 0{,}064 \frac{h}{p} \qquad \ldots (6)$$

$$(b/B = 0{,}8) : C_e = 0{,}596 + 0{,}045 \frac{h}{p} \qquad \ldots (7)$$

$$(b/B = 0{,}7) : C_e = 0{,}594 + 0{,}030 \frac{h}{p} \qquad \ldots (8)$$

$$(b/B = 0{,}6) : C_e = 0{,}593 + 0{,}018 \frac{h}{p} \qquad \ldots (9)$$

$$(b/B = 0{,}4) : C_e = 0{,}591 + 0{,}005\,8 \frac{h}{p} \qquad \ldots (10)$$

$$(b/B = 0{,}2) : C_e = 0{,}589 - 0{,}001\,8 \frac{h}{p} \qquad \ldots (11)$$

$$(b/B = 0) : C_e = 0{,}587 - 0{,}002\,3 \frac{h}{p} \qquad \ldots (12)$$

For intermediate values of b/B, formulae for C_e can be determined satisfactorily by interpolation.

9.6.1.3 Practical limitations on h/p, h, b and p

Practical limits are placed on h/p because head-measurement difficulties and errors result from surges and waves which occur in the approach channel at larger values of h/p. Limits are placed on h to avoid the "clinging nappe" phenomenon which occurs at very low heads. Limits are placed on b because of uncertainties regarding the combined effects of viscosity and surface tension represented by the quantity of k_b at very small values of b. Limits are placed on p and $B-b$ to avoid the instabilities which result from eddies that form in the corners between the channel boundaries and the weir when values of p and $B-b$ are small.

For conservative practice, limitations applicable to the use of the Kindsvater-Carter formula are :

a) h/p shall be not greater than 2,5;

b) h shall be not less than 0,03 m;

c) b shall be not less than 0,15 m;

d) p shall be not less than 0,10 m;

e) either $(B-b)/2 = 0$ (full width weir) or $(B-b)/2$ shall not be less than 0,10 m (contracted weir).

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9.6.2 *SIA*[1] *formula*

The SIA formula for the basic weir form is :

$$Q = C \frac{2}{3} \sqrt{2\,g}\, b\, h^{3/2} \qquad \ldots (13)$$

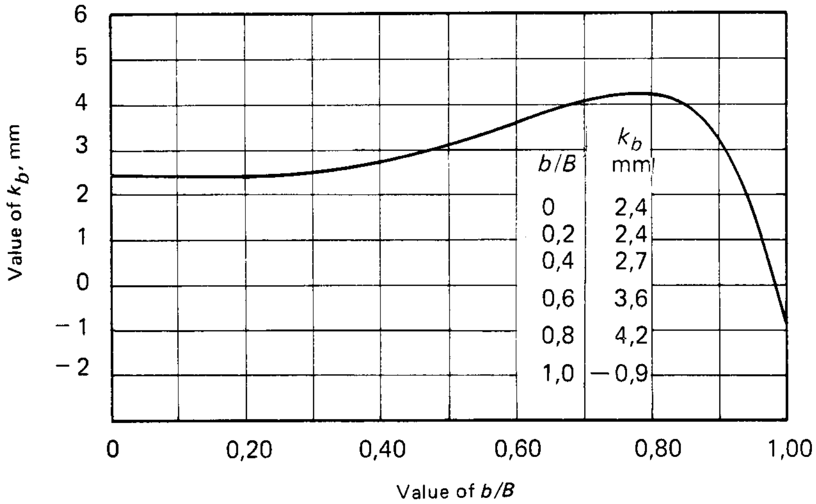

FIGURE 5 — **Value of k_b related to b/B**

1) Société suisse des ingénieurs et architectes.