International Standard 4371

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Measurement of liquid flow in open channels by weirs and flumes — End depth method for estimation of flow in non-rectangular channels with a free overfall (approximate method)

Mesure de débit des liquides dans les canaux découverts au moyen de déversoirs et de canaux jaugeurs — Méthode d'évaluation du débit par détermination de la profondeur en bout des chenaux non rectangulaires à déversement dénoyé (méthode approximative)

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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.

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. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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0 Introduction

Free overfall occurs in many hydraulic structures when the bottom of a horizontal channel (or gently sloping channel) is abruptly discontinued. Such an overfall forms a control section and offers an approximate means for the estimation of flow. The flow at the brink is curvilinear and, therefore, the depth at the drop is not equal to the critical depth as computed by the principle based on assumption of parallel flow. However, the ratio between the end depth and the critical depth (as in the case of the assumption of parallel flow) has an almost constant value. Therefore, from the depth measured at the drop, the discharge can be estimated.

1 Scope and field of application

This International Standard specifies a method for the estimation of subcritical flow of clear water in smooth, essentially horizontal, straight open channels with a vertical drop and discharging freely. Gentle positive slopes not greater than 1 in 2 000 are admissible. This International Standard covers channels with the following types of cross-section, the nappe being unconfined:

a) trapezoidal;

b) triangular;

c) parabolic;

d) circular.

Using the measured depth at the end, the flow can be estimated.

2 References

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

ISO 1438/1, *Water flow measurement in open channels using weirs and venturi flumes — Part 1: Thin-plate weirs.*

ISO 3846, *Liquid flow measurements in open channels by weirs and flumes — Free overfall weirs of finite crest width (rectangular broad-crested weirs).*

ISO 3847, *Liquid flow measurement in open channels by weirs and flumes — End-depth method for estimation of flow in rectangular channels with a free overfall.*

3 Definitions

For the purpose of this International Standard, in addition to the definitions given in ISO 772, the following definition shall apply:

unconfined nappe: The jet formed by the flow where the guide walls of the structure end at the crest (or edge) and permit free lateral expansion of flow and where the nappe is sufficiently ventilated to ensure atmospheric pressure below the nappe.

4 Units of measurement

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

5 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) to the requirements necessary for measurement by the end depth method.

Particular attention should be paid to the following features in selecting the site and ensuring the necessary flow conditions:

a) an adequate straight length (at least 20 h_e where h_e is the end depth corresponding to the maximum discharge anticipated) of channel of regular cross-section should be available upstream of the drop;

b) velocity distribution seen by inspection or measurement should be normal;

c) the channel bottom should be horizontal. Gentle positive slopes not greater than 1 in 2 000 are admissible;

d) the side walls as well as the bottom should be smooth as far as possible (in this specification a smooth surface shall correspond to a neat cement finish);

NOTE — The finish of the structure shall be well maintained; changes in wall roughness due to erosion and various forms of deposition will change the discharge relationship.

e) the end of the channel shall be cut off normal to its centreline and the water shall be allowed to fall freely beyond this point;

f) the flow shall be sub-critical and normal upstream of the drop;

g) the nappe should be fully aerated and completely free at the sides to permit unrestricted spreading.

6 Measurement of depth

The depth shall be measured midstream exactly at the end (drop) with a point gauge or other suitable measuring device.

NOTE — The flow at the drop is fully curvilinear and any small error in the location of gauge will result in large errors in measurement of discharge.

7 Computation of discharge

7.1 Critical depth, h_c

From the measured value of the end depth h_e, using the relationship for the respective channel cross-section, the critical depth h_c is computed and the discharge in terms of the critical depth is given by the following equation (for a channel cross-section):

$$\frac{Q^2}{g} = \frac{A_c^3}{B_c} = \frac{f_1(h_c)}{f_2(h_c)} \qquad \ldots (1)$$

where

Q is the discharge;

g is the acceleration due to gravity;

A_c is the cross-sectional area at the critical section;

B_c is the surface width of flow at the critical section.

From a knowledge of the critical depth h_c and the geometry of the channel, A_c and B_c can be obtained and by using equation (1), the discharge can be computed.

7.2 Trapezoidal channels

7.2.1 The geometry of channel cross-section is shown in figure 1.

7.2.2 The ratio h_e/h_c (that is, end depth to critical depth) is a function of the parameter

$$\frac{m\,h_e}{B_o}$$

where

m is the side slope;

B_o is the bottom width;

h_e is the depth of flow at the end;

and the value of h_e/h_c can be obtained from figure 2. Knowing the value of h_e, the value of h_c can be computed and used to compute the discharge from equation (1).

7.2.3 As an alternative to equation (1), the discharge in terms of h_c is given by the following equation:

$$Q = \frac{\sqrt{g/2}}{m^{3/2}} \left(\frac{B_o}{2}\right)^{5/2} \left[\frac{\left\{ \dfrac{h_c^2}{\left(\dfrac{B_o}{2m}\right)^2} + \dfrac{2h_c}{\left(\dfrac{B_o}{2m}\right)} \right\}^{3/2}}{\left\{ 1 + \dfrac{h_c}{\left(\dfrac{B_o}{2m}\right)} \right\}^{1/2}} \right] \qquad \ldots (2)$$

Figure 3 may be used directly for computing the discharge, based on equation (2), in view of the simplicity of calculations.

7.3 Triangular channels

7.3.1 The geometry of channel cross-section is shown in figure 4.

7.3.2 The ratio h_e/h_c (that is, end depth to critical depth) is 0,795.

7.3.3 With a triangular channel of semi-apex angle θ, as an alternative to equation (1), the discharge in terms of h_c is given by:

$$Q = \sqrt{g/2} \times h_c^{5/2} \times \tan\theta \qquad \ldots (3)$$

7.4 Parabolic channels

7.4.1 The geometry of channel cross-section is shown in figure 5.

7.4.2 The ratio h_e/h_c (that is, end depth to critical depth) is 0,772.

7.4.3 With a parabolic channel of the form,

$$x^2 = 4ay \qquad \ldots (4)$$

As an alternative to equation (1), the discharge in terms of h_c is given by:

$$Q = 2{,}175\sqrt{g} \times h_c^2 \times \sqrt{a} \qquad \ldots (5)$$

7.5 Circular channels

7.5.1 The geometry of channel cross-section is shown in figure 6.

7.5.2 The ratio h_e/h_c (that is, end depth to critical depth) is 0,756.

7.5.3 With the circular channel of the form shown in figure 6, as an alternative to equation (1), the discharge in terms of h_c is given by:

$$Q = 1/4\sqrt{g}\, r^{5/2} \frac{\left\{2\cos^{-1}(1-\alpha) - 2(2\alpha-\alpha^2)^{1/2}(1-\alpha)\right\}^{3/2}}{(2\alpha-\alpha^2)^{1/4}} \qquad \ldots (6)$$

where r is the radius of the channel and $\alpha = h_c/r$.

Equation (6) is given as a dimensionless graph in figure 7 and may be used for computing the discharge in view of the simplicity of calculations.

8 Limitations

For the application of these methods, the following general limitations are applicable:

a) the drop to tailwater level, d, should be equal to or greater than h_e;

b) the following limitations based on experiments should be satisfied:

1) in the case of trapezoidal channels, the ratio $\frac{m\,h_e}{B_o}$ should be between 0,5 and 7,0;

2) in the case of triangular channels, the semi-apex angle θ should be between 25° and 45°;

3) in the case of parabolic channels, the semi-latus rectum "$2a$" should lie between 0,019 and 0,033 m;

4) in the case of circular channels, the ratio h_e/r (that is, the end depth to the radius of the channel) should lie between 0,19 and 1,0;

c) the method is recommended for use when h_e is greater than 0,05 m;

d) the width of flow at the top should be greater than 0,3 m.

9 Uncertainties in flow measurement

9.1 General

9.1.1 The total uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. In general, these contributions to the total uncertainty may be assessed and will indicate whether the rate of flow can be measured with sufficient accuracy for the purpose in hand. This clause is intended to provide information for the user of this International Standard to estimate the uncertainty in a measurement of discharge.

9.1.2 The error may be defined as the difference between the true rate of flow and that calculated in accordance with the equation of the type of channel at a site selected in accordance with this International Standard. The term "uncertainty" will be used to denote the deviation from the true rate of flow within which the measurement is expected to lie some nineteen times out of twenty (95 % confidence limits).

9.2 Sources of error

9.2.1 The sources of error in discharge measurement may be identified by considering the appropriate discharge equation.

9.2.2 The sources of error which need to be considered further are:

a) the ratio h_e/h_c;

b) the dimensional measurement of the channel (for example, B_o in the case of trapezoidal channels, θ in the case of triangular channels, a in the case of parabolic channels and r in the case of circular channels);

c) the measured end depth, h_e.

9.2.3 The uncertainties in dimensional measurements and in h_e shall be estimated by the user. The uncertainties in dimensional measurement will depend on the precision to which the channel as constructed can be measured; in practice, this uncertainty may prove to be insignificant in comparison with other uncertainties. The uncertainty in the end depth will depend upon the accuracy of the depth-measuring device, the determination of the gauge zero, the precise location of the instrument and upon the technique used.

9.3 Kinds 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 from the equation

$$s_Y = \left(\frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{n-1} \right)^{1/2} \qquad \ldots (7)$$

where $\bar{Y}$ is the arithmetic mean of n measurements. The standard deviation of the mean is then given by:

$$s_{\bar{Y}} = \frac{s_Y}{\sqrt{n}} \qquad \ldots (8)$$

and the uncertainty of the mean is $ts_{\bar{Y}}$ (to 95 % confidence level) [1]. This uncertainty is the contribution of the observations of Y 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. An error in setting the zero of a water level gauge to invert level, for example, produces a systematic difference between the true mean measured head and the actual value. As repetition of the measurement does not eliminate systematic errors, the actual value could only be determined by an independent measurement known to be more accurate.

9.4 Uncertainties of the ratio h_e/h_c

9.4.1 The values of the ratio h_e/h_c quoted in this International Standard are based on an appraisal of experiments, which may be presumed to have been carefully carried out, with sufficient repetition of the readings to ensure adequate precision. However, when measurements are made on other installations, systematic discrepancies between coefficients of discharge may well occur, which may be attributed to variations in surface finish, the approach conditions, the scale effect between model and site structures, etc.

9.4.2 The uncertainty in the ratios quoted in the preceding clauses of this International Standard is based on a consideration of the deviation of experimental data from the equations given. The suggested uncertainties thus represent the accumulation of evidence and experience available.

9.4.3 The maximum systematic uncertainty in the ratio h_e/h_c is likely to be ± 5 % from the specified values, with 95 % confidence limits.

9.5 Uncertainties in measurements made by the user

9.5.1 Both random and systematic errors will occur in measurements made by the user.

9.5.2 Since neither the methods of measurement nor the way in which they are to be made are specified, no numerical values for uncertainties in this category can be given; they shall be estimated by the user. For example, consideration of the method of measuring the channel width should permit the user to determine the uncertainty in this quantity.

9.5.3 The uncertainty of the gauged depth shall be determined from an assessment of the individual sources of error, for example the zero error, the gauge sensitivity, backlash in the indication mechanism, the residual random uncertainty in the mean of a series of measurements, etc. The uncertainty on the gauge depth is the square root of the sum of the square of the individual uncertainties.

9.6 Combination of uncertainties to give total uncertainty on discharge

9.6.1 The total uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties.

When partial uncertainties, the combination of which gives the total uncertainty, are independent of one another, are small and numerous and have a Gaussian distribution, there is a probability of 0,95 that the true error is less than the total uncertainty.

9.6.2 It should be realized that the uncertainty in discharge X_Q is not single-valued for a given device, but will vary with discharge. It may, therefore, be necessary to consider the uncertainty at several discharges covering the required range of measurement.

9.7 Example

The following is an example of uncertainty determination of a single determination of discharge using the end depth method in a trapezoidal channel, under subcritical flow in the channel. The bottom width, B_o, is equal to 1 m with a random uncertainty of $\Delta' B_o = \pm$ 1 mm; the side slope, m, is equal to 1 with no uncertainty and the end depth, h_e, is equal to 0,3 m, measured with a random uncertainty of $\Delta' h_e = \pm 12$ mm. So the percentage random uncertainties are:

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

$$X'_m = 0\ \%$$

$$X'_{h_e} = \pm 4\ \%$$

The critical depth, h_c, follows from figure 2; $mh_e/B_o = 0{,}3$ yields $h_e/h_c = 0{,}717$ and so $h_c = 0{,}418$ m, with a random uncertainty $\Delta' h_c = \frac{0{,}418}{0{,}3} \times 12 = 16{,}74$ mm.

1) When n is large, $t = 2$. For $n = 6$, the factor should be 2,6; $n = 8$ requires 2,4; $n = 10$ requires 2,3; $n = 15$ requires 2,1.

The equation used is

$$Q = \sqrt{g}\,\frac{A_c^{3/2}}{B_c^{1/2}}$$

In this case, the numerical values for A_c and B_c are

$$A_c = h_c B_o + m h_c^2 = 0{,}593\,5\ \text{m}^2$$

$$B_c = B_o + 2\,m h_c = 1{,}836\ \text{m}$$

Their percentage random uncertainties are:

$$X'_{A_c} = \frac{1}{A_c}\left[(B_o \Delta' h_c)^2 + (h_c \Delta' B_o)^2 + (2 m h_c \Delta' h_c)^2\right]^{1/2} \times 100$$

$$= \frac{1}{0{,}593\,5}\left[(1 \times 0{,}016\,74)^2 + (0{,}418 \times 0{,}001)^2 - (2 \times 0{,}418 \times 0{,}016\,74)^2\right]^{1/2} \times 100$$

$$= \pm\ 3{,}68\ \%$$

$$X'_{B_c} = \frac{1}{B_c}\left[(\Delta' B_o)^2 + (2\,m \Delta' h_c)^2\right]^{1/2} \times 100$$

$$= \frac{1}{1{,}836}\left[0{,}001^2 + (2 \times 0{,}016\,74)^2\right]^{1/2} \times 100$$

$$= \pm\ 1{,}82\ \%$$

The random uncertainty in Q can be calculated as follows:

$$X'_Q = \left[\left(\frac{3}{2} X'_{A_c}\right)^2 + \left(\frac{1}{2} X'_{B_c}\right)^2\right]^{1/2}$$

$$= \left[\left(\frac{3}{2} \times 3{,}68\right)^2 + \left(\frac{1}{2} \times 1{,}82\right)^2\right]^{1/2}$$

$$= \pm\ 5{,}6\ \%$$

The systematic uncertainty in Q is calculated in a similar way. It is assumed that the only source of systematic uncertainty is in the ratio h_e/h_c. According to 9.4.3, $X''_{h_c} = \pm\ 5\ \%$, so $\Delta'' h_c = 20{,}92$ mm.

The percentage systematic uncertainties of A_c and B_c are

$$X''_{A_c} = \frac{1}{0{,}593\,5}\left[(1 \times 0{,}020\,92)^2 + (2 \times 0{,}418 \times 0{,}029\,2)^2\right]^{1/2} \times 100$$

$$= \pm\ 4{,}59\ \%$$

$$X''_{B_c} = \frac{1}{1{,}836}\left[(2 \times 0{,}029\,2)^2\right]^{1/2} \times 100$$

$$= \pm\ 2{,}28\ \%$$

The percentage systematic uncertainty in Q is

$$X''_Q = \left[\left(\frac{3}{2} \times 4{,}59\right)^2 + \left(\frac{1}{2} \times 2{,}28\right)^2\right]^{1/2}$$

$$= \pm\ 7{,}0\ \%$$

In order to obtain an overall value for the uncertainty in Q, the random and systematic uncertainty may be combined to give

$$X_Q = [X'^2_Q + X''^2_Q]^{1/2}$$

$$= [5{,}6^2 + 7{,}0^2]^{1/2}$$

$$= \pm\ 9{,}0\ \%$$

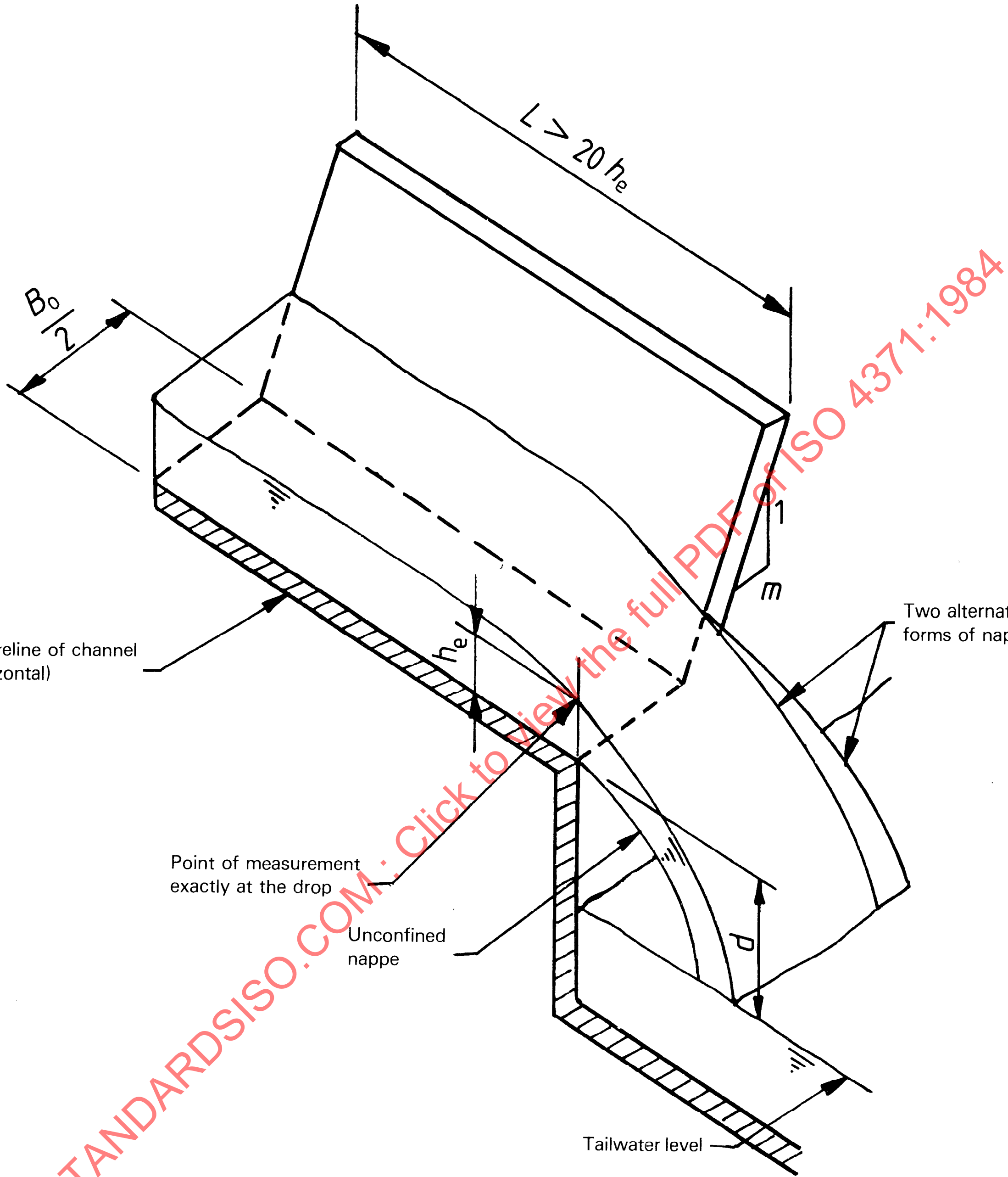

Figure 1 — Definition sketch of trapezoidal channel

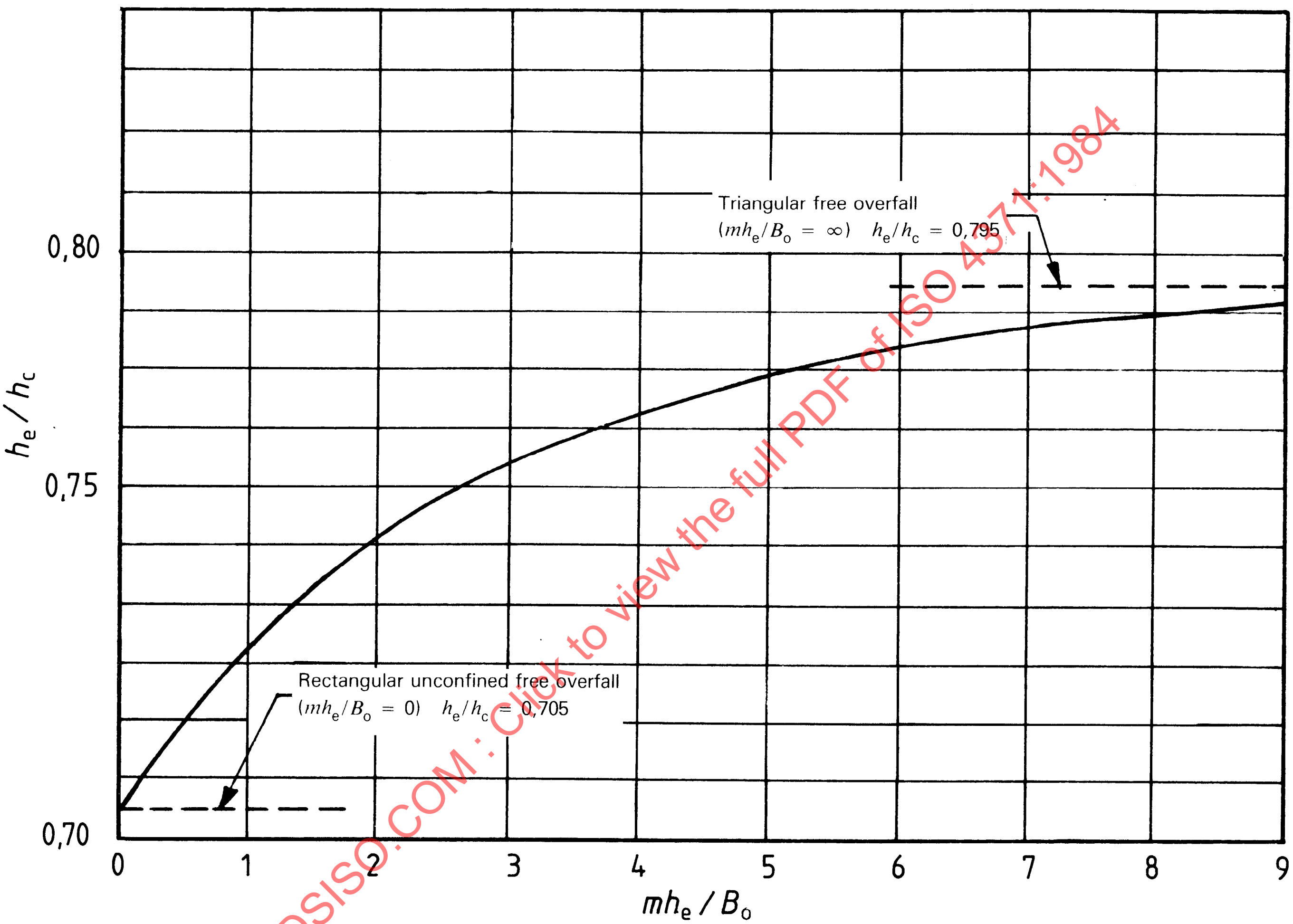

Figure 2 — Values of the ratio of the end depth to critical depth for trapezoidal channels

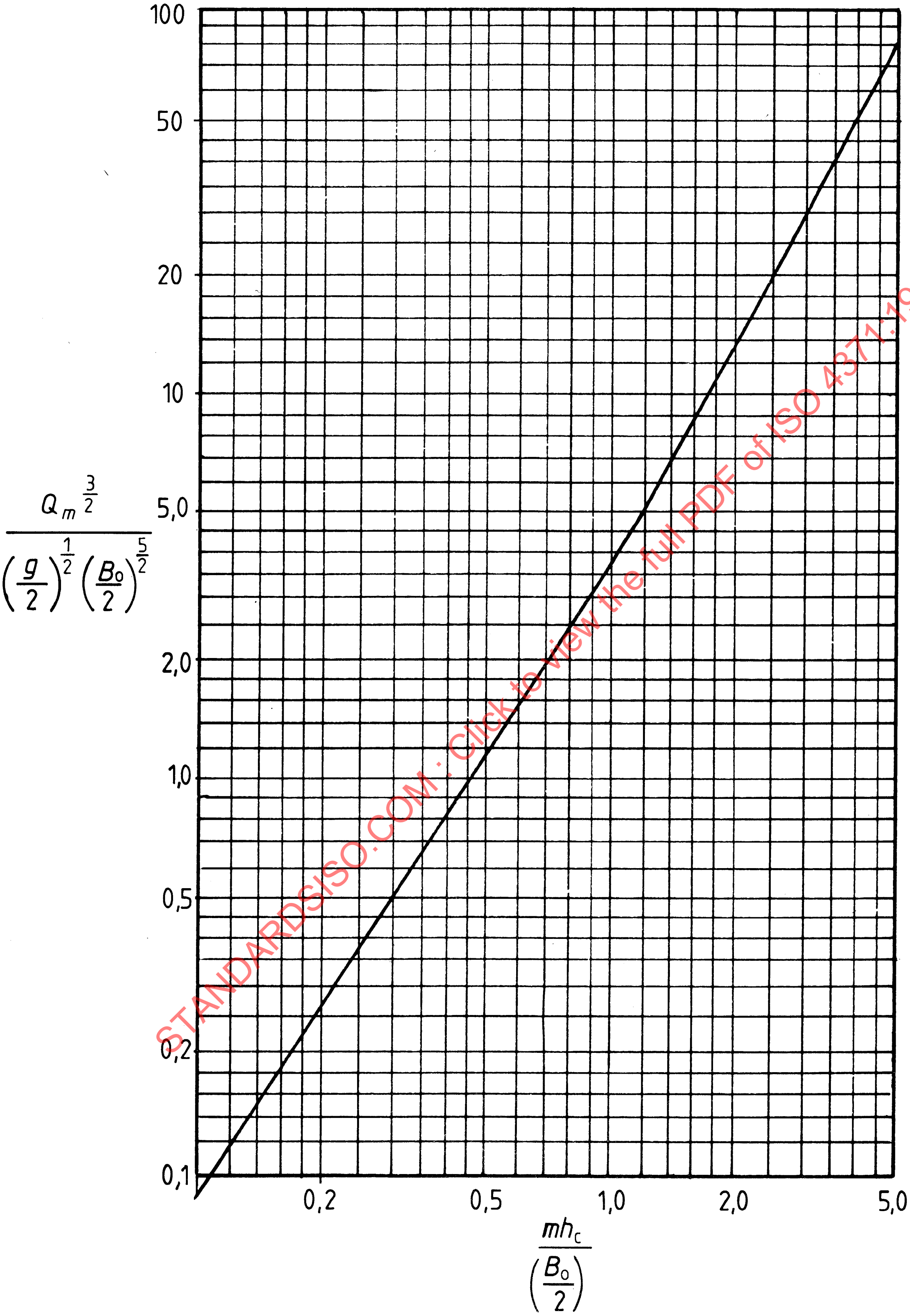

Figure 3 — Relationship between discharge and critical depth (trapezoidal channels)

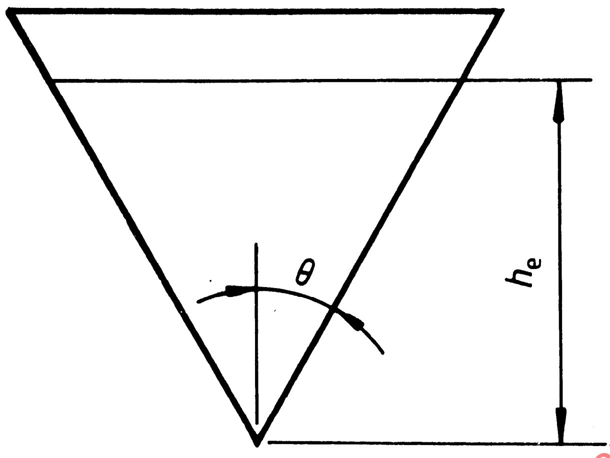

Figure 4 — Definition sketch of the triangular channel

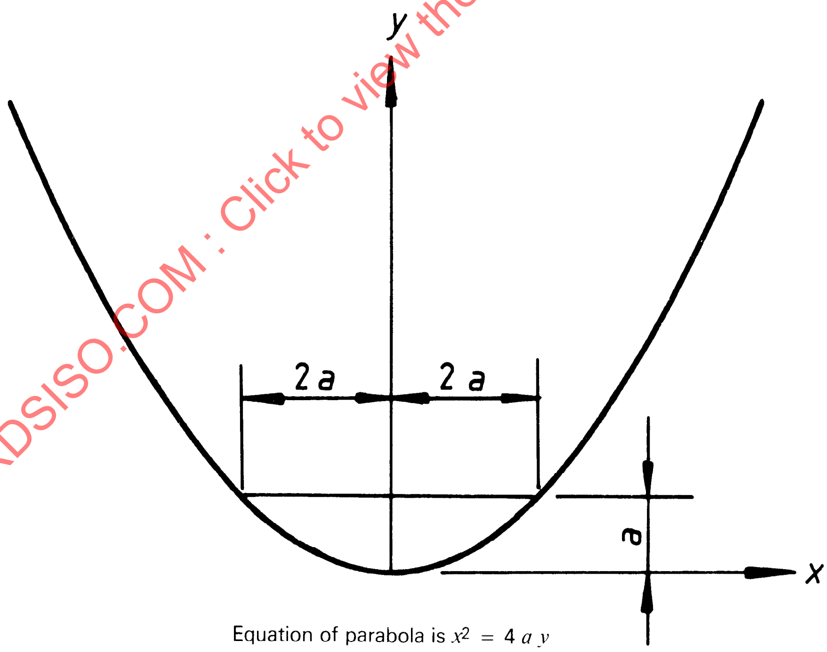

Figure 5 — Definition sketch of the parabolic channel

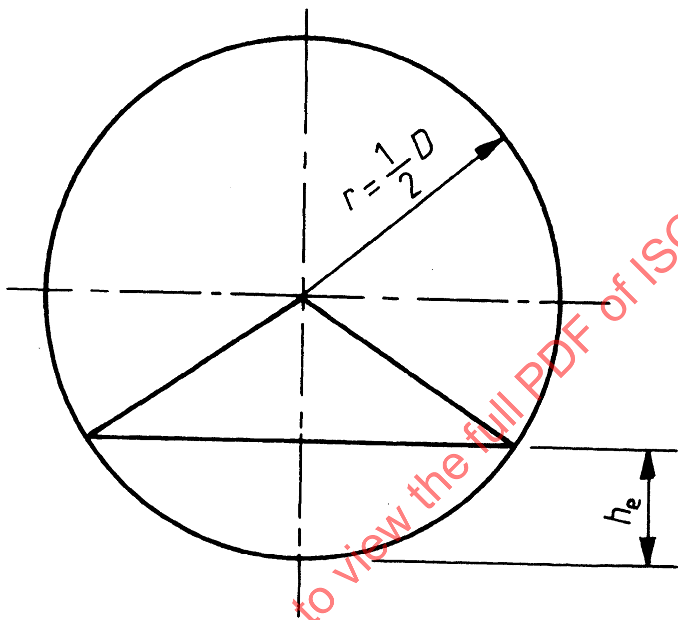

Figure 6 — Definition sketch of circular channels