# SASO ISO 18481:2019
# ISO 18481:2017

# Hydrometry — Liquid flow measurement using end depth method in channels with a free overfall



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**ICS 17.120.20**

## Foreword

The Saudi Standards ,Metrology and Quality Organization (SASO)has adopted the International standard No. ISO 18481:2017 “Hydrometry — Liquid flow measurement using end depth method in channels with a free overfall” issued by (OIML). The text of this international standard has been translated into Arabic so as to be approved as a Saudi standard without introducing any technical modification.

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# Hydrometry — Liquid flow measurement using end depth method in channels with a free overfall

## 1 Scope

This document specifies a method for the estimation of the sub-critical flow of clear water in a smooth, essentially horizontal channel (or a gently sloping channel), abruptly discontinued at bottom by a hydraulic structure, with a vertical drop and discharging freely. Such an overfall forms a control section and offers a means for the estimation of flow using the end depth measurement method. A wide variety of channel cross-sections with overfall have been studied, but only those which have received general acceptance after adequate research and testing, and therefore do not require in situ calibration, are considered. This document covers channels with the following types of cross-sections:

a) rectangular with confined and unconfined nappe;

b) trapezoidal;

c) triangular;

d) circular;

e) parabolic.

The flow at the brink is curvilinear; therefore, the measured depth at the drop is not equal to the critical depth as computed by the principle based on assumption of parallel flow. However, the end depth and the critical depth (as in the case of the assumption of parallel flow) have unique relation, which is used to estimate the flow through these structures.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

# 4 Symbols and abbreviated terms

| Symbol | Unit | Definition |
|---|---|---|
| $A$ | $m^2$ | area of approach channel |
| $2a$ | m | semi-latus rectum of parabola |
| $A_c$ | $m^2$ | area of flow at critical depth |
| $b$ | m | width of rectangular channel |
| $C$ | — | coefficient of discharge |
| $d$ | m | diameter of the circle |
| $h_e$ | m | end depth corresponding to the maximum anticipated discharge |
| $z$ | — | side slope 1 vertical to $z$ horizontal |
| $Q$ | $m^3/s$ | total discharge |
| $m_t$ | m | top width of flow |
| $D_c$ | m | critical depth |
| $D_e$ | m | end depth |
| $\theta$ | radian | apex angles subtended by the top width of flow at the centre of the circle |
| $\propto$ | radian | semi-vertex angle of triangular channel |

# 5 Principle

The un-submerged flow at an abrupt end of a long channel can be referred to as free overfall. In many cases, the measurement of flow depth at the free overfall is possible and could be used for discharge estimation. Such a discharge measurement method does not generally require any obtrusive structure to be built. Many available overfall structures constructed for other reasons could also be used for the discharge measurement with minor modifications.

There is a unique relationship between the flow discharge and the critical depth in an open channel. The ratio of end depth to the critical depth (EDR) established theoretically and verified experimentally offers an easy method to measure the discharge using end depth method.

# 6 Installation

## 6.1 General

General requirements of overfall discharge measurement installation are described in the following clauses. Special requirements of different types are described in clauses which deal with specific types.

## 6.2 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. The potential application of this method of flow measurement is at proposed or existing water and waste water treatment plants, where flumes and channels form part of such installations. The discharge measurement using end depth can be installed on existing flumes and channels after verification that they conform to the requirements necessary for measurement by the end depth method or they can be modified to make them conform to the requirements. 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 $20h_e$, 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) 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 satisfactory flow in smooth, straight channels. Baffles and flow straighteners can be used to simulate satisfactory velocity distribution, but their location with respect to the measuring section shall be not less than the minimum length prescribed for the approach channel.

c) The channel bottom should be horizontal. Gentle positive slopes not greater than 1 in 2 000 are admissible; the flow shall be sub-critical, practically uniform upstream of the drop, and the water surface shall be relatively stable and free from perturbations at even during low velocities.

d) The side walls, as well as the bottom, shall be smooth as far as possible (in this document, a smooth surface shall correspond to a neat cement finish). The finish of the structure shall be well maintained; changes in wall roughness due to various forms of deposition will change the discharge relationship.

e) The end (face) of channel shall be normal to its longitudinal centre line and water shall be allowed to fall freely beyond this point.

f) In the case of a confined nappe, the downstream side walls shall be extended to a distance not less than six times the maximum end depth.

g) In the case of unconfined nappe, the side walls shall end at the drop and nappe should be completely free at the sides to permit unrestricted spreading.

h) The nappe bottom shall be fully aerated in all the cases.

## 7 Measurement of end depth

### 7.1 General

The end depth is computed by deducting the bed level (gauge datum) from water surface level, both measured at the end or at the fall. The depth shall be measured exactly at the end (drop) of the channel. The flow at the drop is fully curvilinear and any small error in the location of the gauge will result in large error in measurement of discharge.

### 7.2 Head measuring devices

The water surface at the fall or end may be measured using a point gauge or other suitable measuring device. The pointer shall be at the centre of the channel width. The use of hook gauge or any other measuring device requiring insertion inside water is not advised and is discouraged. The flow would drag the pointer and displace it away from the point of measurement or the pointer will vibrate leading to inaccurate measurement. The device selected should not disturb the flow conditions at the free fall. Stilling well or float well cannot be used for the measurement of the end depth.

### 7.3 Gauge datum

Accuracy of end depth measurement is critically dependent upon the determination of the gauge datum or gauge zero, which is defined as the gauge reading corresponding to the channel bed (bottom) at the end (drop) in case of rectangular or trapezoidal channels, or the lowest point of the triangular or circular channel at the end (drop).

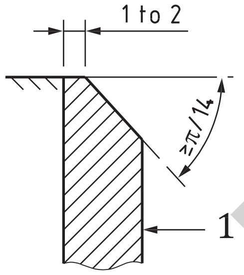
## 8 Maintenance

### 8.1 General

Maintenance of the drop structure is necessary to achieve the accuracy in measurement. 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 drop structure shall be kept clean. In the process of cleaning, care shall be taken to avoid damage to the surface of the drop structure, particularly brink edge and upstream bed and side surface. The head measuring devices like point gauge shall be checked periodically to ensure accuracy.

Dimensions in millimetres




**Key**

1 downstream face

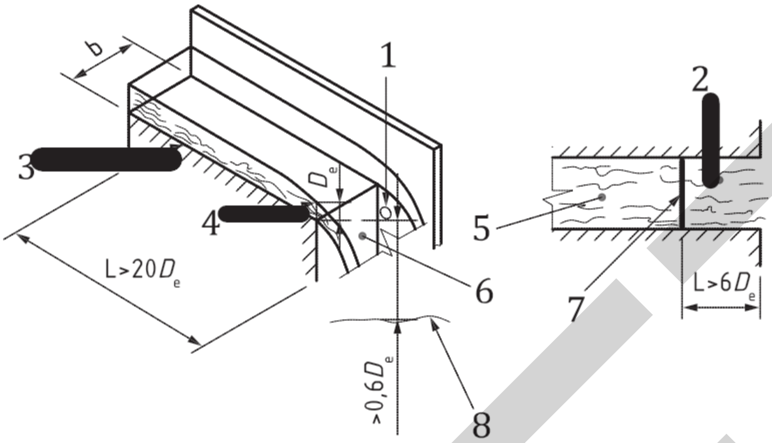
**Figure 1 — Drop edge of overfall**

The drop edge shall be sharp at its intersection without any burrs. To ensure that the brink edge and sides are sharp, a machined metallic rim could be fitted at the end of the channel. The thickness of the metallic rim should be uniform and it should be between 1 mm and 2 mm along the flow. The metallic rim shall be fitted flush with the vertical face of the overfall structure to ensure that no gaps exist between the rim and the channel. The downstream edges of the metallic rim shall be chamfered if the rim plate is thicker than the maximum allowable width along the flow. The surface of the chamfer shall make an angle of not less than π/4 radians (45°) with a line extending along the horizontal channel bed or side surfaces of the fall (see detail, Figure 1). The metallic rim shall be made of corrosion-resistant metal; but if it is not, all the smooth surfaces and sharp edges shall be kept coated with a thin, protective film (for example, oil, wax, silicone) applied with a soft cloth. If a flow straightener is used in the approach channel, perforated plates shall be kept clean so that the percentage open area remains greater than 40 %.

## 8.2 Types

The free overfall structures in rectangular channels are further classified into two types: confined nappe and unconfined nappe.

The confined nappe is the jet formed by the flow where the guide walls of the structure extend to at least six times the end depth at maximum flow beyond the brink edge and where the bottom of nappe is sufficiently ventilated to ensure atmospheric pressure below the nappe (see Figure 2).

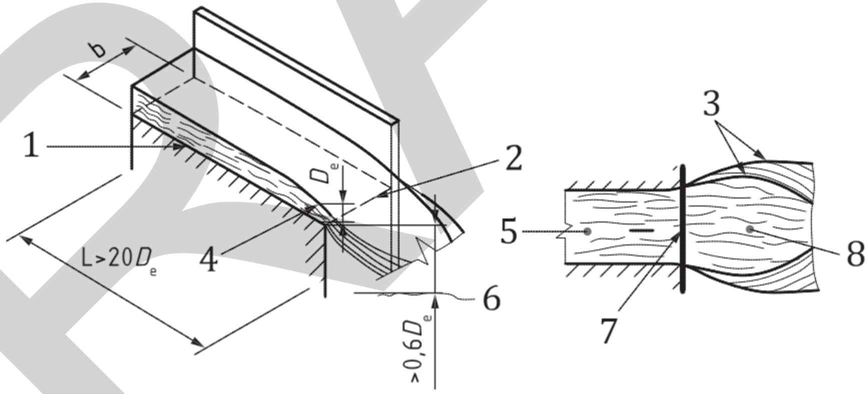



**Key**

| | | | |
|---|---|---|---|
| 1 | aeration hole in side wall | 5 | flow |
| 2 | nappe width same as channel | 6 | overfall at the end of the channel |
| 3 | horizontal bottom | 7 | fall |
| 4 | point of measurement exactly at the drop | 8 | tail water level (TWL) |

**Figure 2 — Rectangular channel with confined nappe (bottom nappe aerated)**

The unconfined nappe is the jet formed by the flow where the guide walls of the structure end at the edge of the drop structure and permit free lateral expansion of flow and where the nappe is sufficiently ventilated to ensure atmospheric pressure below the nappe (see Figure 3).




**Key**

| | | | |
|---|---|---|---|
| 1 | horizontal bottom | 5 | flow |
| 2 | overfall (at the end of channel) | 6 | tail water level |
| 3 | two alternative forms of nappe | 7 | fall |
| 4 | point of measurement exactly at the drop | 8 | nappe |

**Figure 3 — Rectangular channel with unconfined nappe**

## 8.3 Specifications for the drop structure

The basic overfall structure consists of an abrupt drop or discontinuity in the bed at the end of a rectangular channel. The overfall shall be plane, rigid and perpendicular to the walls and the floor of the approach channel. The surface finish along the bed and sides shall be the same until the drop. The side walls of the rectangular channel shall be parallel to each other and the distance between them (width of channel) shall be the same for the specified length of the channel. The brink (overfall edge) line shall be horizontal and perpendicular to the longitudinal axis of the rectangular channel.

## 8.4 Specifications for installation

The specifications stated in 6.2 shall apply. In general, the overfall structure used for end depth discharge measurement shall be located in a straight, horizontal, rectangular approach channel. The full width of the approach channel shall be used as the drop structure. The flow in the approach channel shall be uniform and steady, as specified in 6.2.

## 8.5 Determination of gauge zero

The hook gauge is lowered to the edge of the channel and its reading is recorded. The reading taken at any point over the width shall be same.

## 8.6 Discharge relationship

In terms of end depth, the basic discharge formula for a rectangular overfall is given by Formula (1):

$$Q = Cb\sqrt{g}\, D_e^{3/2} \tag{1}$$

where

| | |
|---|---|
| $Q$ | is the total discharge expressed in cubic metres per second ($m^3/s$); |
| $C$ | is the effective coefficient of discharge for subcritical flow in the upstream channel; |
| $b$ | is the width of the channel expressed in m; |
| $g$ | is the gravitational acceleration (standard value) expressed in $m/s^2$; |
| $D$ | is the end depth exactly at the overfall, measured at the centre of the edge width. |

## 8.7 Coefficient of discharge

### 8.7.1 Confined nappe

The coefficient of discharge $C$ for horizontal channel with confined nappe on the sides and aerated bottom is given by

$$C = 1{,}654\,2$$

### 8.7.2 Unconfined nappe

The coefficient of discharge $C$ for horizontal channel with unconfined nappe and aerated bottom is given by

$$C = 1{,}706\,42$$

## 8.8 Practical limitations

For the application of method, the following limitations shall apply.

— The vertical distance from channel bottom to the downstream water surface shall be greater than $0{,}6h_e$.

— The end depth ($D_e$) shall be greater than 0,04 m.

### 8.9 Uncertainty of measurement

The overall uncertainty of flow measurement by this method depends on the uncertainty of the depth measurement, of the measurement of width of the channel and of the coefficient of discharge.

With reasonable care and skill in the construction and installation of the structure, the tolerance in the coefficient of discharge for horizontal channel may be of the order of ±2 %.

The method by which the errors in the coefficient shall be combined with other sources of error is given in Clause 13.

## 9 Triangular channel drop structure

### 9.1 Specifications for the drop structure

The triangular channel drop structure consists of a V-shaped horizontal channel with abrupt discontinuity leading to overfall of the jet issuing out of the channel as shown in Figure 4. The drop face shall be plane, rigid and perpendicular to the floor of the channel. The downstream face of the channel shall be smooth.

The bisector of triangular channel and the drop structure shall be vertical and equidistant from the two sides of the channel. The triangle formed by the flow cross-section shall always be a vertical isosceles triangle.

### 9.2 Specifications for installation

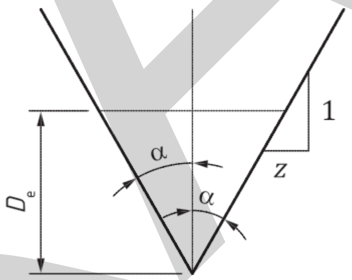



**Figure 4 — Triangular channel overfall**

The specifications stated in 6.2 shall apply. In general, the overfall structure used for end depth discharge measurement shall be located in a straight, horizontal, triangular approach channel. The f low in the approach channel shall be uniform and steady, as specified in 6.2.

### 9.3 Specifications for head measurement

#### 9.3.1 General

The conditions specified in Clause 7 shall apply.

#### 9.3.2 Determination of channel angle

Precise head measurements for triangular channel drop structure require that the vertex angle (angle included between sides of the channel) be measured accurately. One of the satisfactory methods is described as follows.

Two true disks of different, micrometered diameters are placed in the triangular channel at the brink with their edges tangent to the sides of the triangle.

The vertical distance between the centres (or two corresponding edges) of the two disks is measured with a micrometre caliper.

The vertex angle, α, is twice the angle whose sine is equal to the differences between the radii of the disks divided by the distance between the centres of the disks.

#### 9.3.3 Determination of gauge zero

The head-gauge datum or gauge zero shall be determined with great care, and it shall be checked when necessary. The pointer gauge mounted vertically over the vertex of the triangular channel at the brink shall be lowered until it just touches the vertex and the reading of the gauge is recorded as gauge zero. This can also be done by marking a horizontal line passing through the vertex extending on either side of the vertex. The pointer gauge reading, when it touches the horizontal line passing through the vertex, is taken as zero.

### 9.4 Discharge formula — Unconfined

Recommended discharge formula for triangular channel drop structure for semi-vertex angle between 25° to 45° is given by Formula (2):

$$Q = 1{,}359\,4\sqrt{g}\,zD_e^{5/2} \tag{2}$$

where

- $Q$ is the total discharge expressed in cubic metres per second ($m^3/s$);
- $g$ is the gravitational acceleration (standard value) expressed in $m/s^2$;
- $z$ is the side slope 1 vertical to $z$ horizontal;
- $D_e$ is the end depth exactly at the overfall, measured over the vertex.

### 9.5 Practical limitations

For the application of method, the following limitations shall apply.

- — The semi-vertex angle, α, shall be between 25° and 45°.
- — The vertical distance from channel vertex (bottom) to the downstream water surface shall be greater than $0{,}6h_e$.
- — The end depth ($D_e$) shall be greater than 0,05 m.

### 9.6 Uncertainty of measurement

The overall uncertainty of flow measurement by this method depends on the uncertainty of the depth measurement, of the measurement of side slope of the channel and of the coefficient of discharge.

With reasonable care and skill in the construction and installation of the structure, the tolerance in the coefficient of discharge for horizontal channel may be of the order of ±2 %.

The method by which the errors in the coefficient shall be combined with other sources of error is given in Clause 13.

# 10 Trapezoidal channel drop structure

## 10.1 Specifications for the drop structure

The specifications stated in 6.2 shall apply. In general, the overfall structure used for end depth discharge measurement shall be located in a straight, horizontal, trapezoidal approach channel. The f low in the approach channel shall be uniform and steady, as specified in 6.2 (see Figure 5).

## 10.2 Specifications for head measurement

### 10.2.1 General

The conditions specified in Clause 7 shall apply.

### 10.2.2 Determination of gauge zero

The head-gauge datum or gauge zero shall be determined with great care, and it shall be checked when necessary. The pointer gauge mounted vertically over the bed of the trapezoidal channel at the brink shall be lowered until it just touches the bed and the reading of the gauge is recorded.

## 10.3 Discharge formula — Unconfined

Recommended discharge formula for trapezoidal channel drop structure with side slopes of (Vertical):0(Horizontal) to 1(Vertical):1,5(Horizontal) is given by Formula (3):

$$Q=b^{5/2}g^{1/2}\left[1{,}654\,2\left(\frac{D_e}{b}\right)^{3/2}+1{,}359\,4z\left(\frac{D_e}{b}\right)^{5/2}\right] \quad (3)$$

where

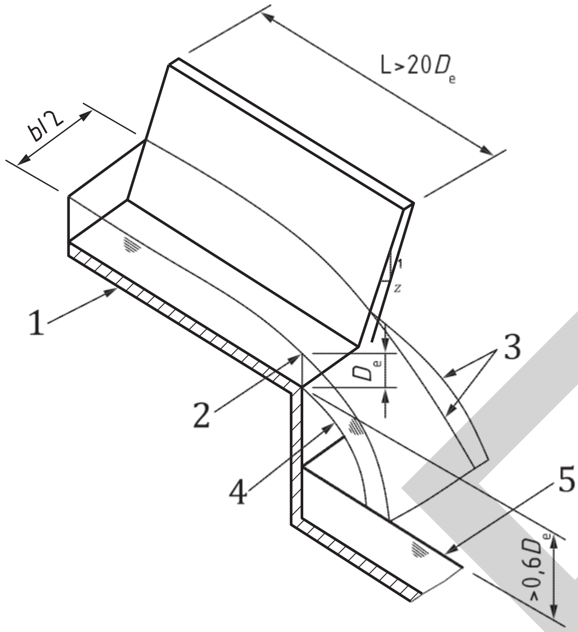
$Q$ is the total discharge expressed in cubic metres per second ($m^3/s$);

$g$ is the gravitational acceleration (standard value) expressed in $m/s^2$;

$z$ is the side slope 1 vertical to $z$ horizontal;

$D_e$ is the end depth exactly at the overfall, measured over the vertex;

$b$ is the bed width of the trapezoidal channel.




**Key**

1 centreline of channel (horizontal)

2 point of measurement exactly at the drop

3 two alternative forms of nappe

4 unconfined nappe

5 tail water level

**Figure 5 — Overfall in trapezoidal channel**

## 10.4 Practical limitations

For the application of method, the following limitations shall apply.

— The side slope of the trapezoidal channel shall be in the range of "*z*" varying from zero to a maximum of 1,5.

— The vertical distance from channel vertex (bottom) to the downstream water surface shall be greater than 0,6$h_e$.

— The end depth ($D_e$) shall be greater than 0,05 m.

## 10.5 Uncertainty of measurement

The overall uncertainty of flow measurement by this method depends on the uncertainty of the depth measurement, of the measurement of width of the channel, of the measurement of side slope of the channel and of the coefficient of discharge.

With reasonable care and skill in the construction and installation of the structure, the tolerance in the coefficient of discharge for horizontal channel may be of the order of ±2 %.

The method by which the errors in the coefficient shall be combined with other sources of error is given in Clause 13.

# 11 Circular channel drop structure

## 11.1 Specifications for the drop structure

The specifications stated in 6.2 shall apply. In general, the overfall structure used for end depth discharge measurement shall be located in a straight, horizontal, circular approach channel (see Figure 6). The flow in approach channel shall be uniform and steady, as specified in 6.2.

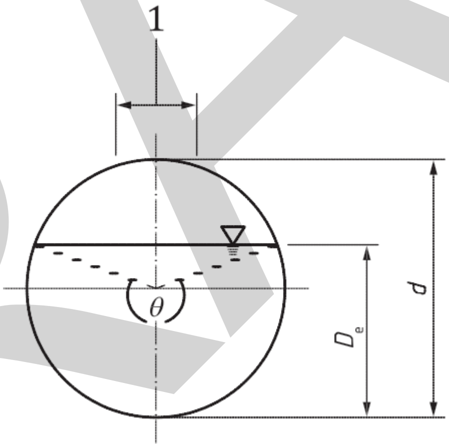
## 11.2 Specifications for head measurement

### 11.2.1 General

The conditions specified in Clause 7 shall apply.

### 11.2.2 Determination of gauge zero

The head-gauge datum or gauge zero shall be determined with great care, and it shall be checked when necessary. The pointer gauge shall be mounted vertically over the lowest point of the circular channel bed at the brink. The pointer gauge is lowered until it just touches the lowest point and the reading of the gauge is recorded. The readings taken at the adjacent points on either side shall indicate rise in the bed level. Alternatively, it is better done by marking a horizontal line passing through the bottom most point (tangentially) extending on either side. The pointer gauge reading, when it touches the horizontal line marked, is taken as zero.




**Key**

1 pointer gauge access slot

**Figure 6 — Overfall in circular channel**

## 11.3 Discharge formula — Unconfined

Recommended discharge formula for circular channel drop structure involves computation of critical depth, $D_c$, of flow from end depth, $D_e$, using critical depth to compute discharge as given below:

The critical depth

$$D_c = \frac{D_e}{0{,}75} \quad (4)$$

The apex angle subtended by the top width of flow at the centre of the circle

$$\theta = 2\cos^{-1}\left(1 - 2\frac{D_c}{d}\right) \quad (5)$$

The top width of flow

$$m_t = d\sin\left(\frac{\theta}{2}\right) \quad (6)$$

and area of cross-section of flow at critical depth, $D_c$, is

$$A_c = \frac{d^2}{8}(\theta - \sin\theta) \quad (7)$$

where $\theta$ is in radian.

The discharge

$$Q = \sqrt{\frac{gA_c^3}{m_t}} \quad (8)$$

where

$Q$ is the total discharge expressed in cubic metres per second ($m^3/s$);

$g$ is the gravitational acceleration (standard value) expressed in $m/s^2$;

$A_c$ is the area of flow at critical depth expressed in $m^2$;

$m_t$ is the top width of flow expressed in m.

Table 1 may be used for the estimation of discharge.

**Table 1 — Discharge for circular channel**

| $D_e/d$ | $D_c/d$ | $\theta$ radian | $m_t/d$ | $A_c/d^2$ | $Q/d^{2,5}$ |
|---|---|---|---|---|---|
| 0,08 | 0,106 7 | 1,330 8 | 0,617 4 | 0,044 9 | 0,038 0 |
| 0,09 | 0,120 0 | 1,415 0 | 0,649 9 | 0,053 4 | 0,047 9 |
| 0,1 | 0,133 3 | 1,495 2 | 0,679 9 | 0,062 3 | 0,059 0 |
| 0,11 | 0,146 7 | 1,572 0 | 0,707 5 | 0,071 5 | 0,071 2 |
| 0,12 | 0,160 0 | 1,646 1 | 0,733 2 | 0,081 1 | 0,084 5 |
| 0,13 | 0,173 3 | 1,717 6 | 0,757 1 | 0,091 0 | 0,098 9 |
| 0,14 | 0,186 7 | 1,787 1 | 0,779 3 | 0,101 3 | 0,114 4 |
| 0,15 | 0,200 0 | 1,854 6 | 0,800 0 | 0,111 8 | 0,130 9 |
| 0,16 | 0,213 3 | 1,920 5 | 0,819 3 | 0,122 6 | 0,148 6 |
| 0,17 | 0,226 7 | 1,984 8 | 0,837 4 | 0,133 7 | 0,167 3 |
| 0,18 | 0,240 0 | 2,047 9 | 0,854 2 | 0,144 9 | 0,187 0 |
| For the definitions of the variables in this table, see Clause 4. | | | | | |

**Table 1** *(continued)*

| $D_e/d$ | $D_c/d$ | $\theta$ radian | $m_t/d$ | $A_c/d^2$ | $Q/d^{2,5}$ |
|---|---|---|---|---|---|
| 0,19 | 0,253 3 | 2,109 8 | 0,869 8 | 0,156 4 | 0,207 8 |
| 0,2 | 0,266 7 | 2,170 6 | 0,884 4 | 0,168 1 | 0,229 6 |
| 0,21 | 0,280 0 | 2,230 4 | 0,898 0 | 0,180 0 | 0,252 5 |
| 0,22 | 0,293 3 | 2,289 4 | 0,910 6 | 0,192 1 | 0,276 3 |
| 0,23 | 0,306 7 | 2,347 6 | 0,922 2 | 0,204 3 | 0,301 2 |
| 0,24 | 0,320 0 | 2,405 1 | 0,933 0 | 0,216 7 | 0,327 0 |
| 0,25 | 0,333 3 | 2,461 9 | 0,942 8 | 0,229 2 | 0,353 9 |
| 0,26 | 0,346 7 | 2,518 2 | 0,951 8 | 0,241 8 | 0,381 7 |
| 0,27 | 0,360 0 | 2,574 0 | 0,960 0 | 0,254 6 | 0,410 5 |
| 0,28 | 0,373 3 | 2,629 3 | 0,967 4 | 0,267 4 | 0,440 3 |
| 0,29 | 0,386 7 | 2,684 3 | 0,974 0 | 0,280 3 | 0,471 1 |
| 0,3 | 0,400 0 | 2,738 9 | 0,979 8 | 0,293 4 | 0,502 8 |
| 0,31 | 0,413 3 | 2,793 2 | 0,984 9 | 0,306 5 | 0,535 5 |
| 0,32 | 0,426 7 | 2,847 2 | 0,989 2 | 0,319 6 | 0,569 1 |
| 0,33 | 0,440 0 | 2,901 0 | 0,992 8 | 0,332 8 | 0,603 6 |
| 0,34 | 0,453 3 | 2,954 7 | 0,995 6 | 0,346 1 | 0,639 1 |
| 0,35 | 0,466 7 | 3,008 2 | 0,997 8 | 0,359 4 | 0,675 6 |
| 0,36 | 0,480 0 | 3,061 6 | 0,999 2 | 0,372 7 | 0,712 9 |
| 0,37 | 0,493 3 | 3,114 9 | 0,999 9 | 0,386 0 | 0,751 3 |
| 0,38 | 0,506 7 | 3,168 3 | 0,999 9 | 0,399 4 | 0,790 5 |
| 0,39 | 0,520 0 | 3,221 6 | 0,999 2 | 0,412 7 | 0,830 7 |
| 0,4 | 0,533 3 | 3,275 0 | 0,997 8 | 0,426 0 | 0,871 9 |
| 0,41 | 0,546 7 | 3,328 5 | 0,995 6 | 0,439 3 | 0,914 0 |
| 0,42 | 0,560 0 | 3,382 2 | 0,992 8 | 0,452 6 | 0,957 0 |
| 0,43 | 0,573 3 | 3,436 0 | 0,989 2 | 0,465 8 | 1,001 0 |
| 0,44 | 0,586 7 | 3,490 0 | 0,984 9 | 0,478 9 | 1,046 1 |
| 0,45 | 0,600 0 | 3,544 3 | 0,979 8 | 0,492 0 | 1,092 1 |
| For the definitions of the variables in this table, see Clause 4. | | | | | |

## 11.4 Practical limitations

For the application of method, the following limitations shall apply.

— The discharge formula is applicable for the case of flow having a ratio of $0{,}1 \leq \frac{D_e}{d} \leq 0{,}45$.

— The vertical distance from channel vertex (bottom) to the downstream water surface shall be greater than $0{,}6h_e$.

— The end depth ($D_e$) shall be greater than 0,05 m.

## 11.5 Uncertainty of measurement

The overall uncertainty of flow measurement by this method depends on the uncertainty of the depth measurement, of the measurement of diameter of the channel and of the coefficient of discharge.

With reasonable care and skill in the construction and installation of the structure, the tolerance in the coefficient of discharge for horizontal channel may be of the order of ±3 %.

The method by which the errors in the coefficient shall be combined with other sources of error is given in Clause 13.

## 12 Parabolic channel drop structure

### 12.1 Specifications for the drop structure

The specifications stated in 6.2 shall apply. In general, the overfall structure used for end depth discharge measurement shall be located in a straight, horizontal, parabolic approach channel (see Figure 7). The flow in approach channel shall be uniform and steady, as specified in 6.2.

### 12.2 Specifications for head measurement

#### 12.2.1 General

The conditions specified in Clause 7 shall apply.

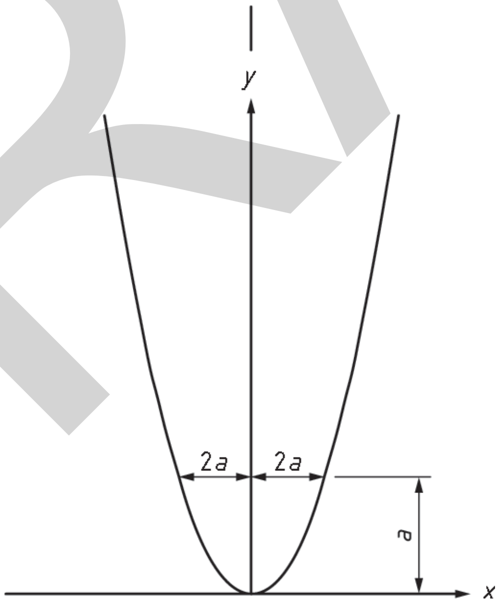
#### 12.2.2 Geometry

The geometry of channel cross-section is shown in Figure 7. The equation of the channel cross-section is given by Formula (9):

$$x^2 = 4ay \quad (9)$$

#### 12.2.3 Determination of gauge zero

The head-gauge datum or gauge zero shall be determined with great care, and it shall be checked when necessary. The pointer gauge shall be mounted vertically over the lowest point of the parabolic channel bed at the brink. The pointer gauge is lowered until it just touches the lowest point and the reading of the gauge is recorded. The readings taken at the adjacent points on either side shall indicate a rise in the bed level.




NOTE The formula of parabola is $x^2 = 4ay$.

**Figure 7 — Overfall in parabolic channel**

### 12.3 Discharge formula — Unconfined

Recommended discharge formula for parabolic channel drop structure involves computation of critical depth, $D_c$, of flow from end depth, $D_e$, using critical depth to compute discharge as given below.

The critical depth is given by Formula (10):

$$D_c = 1{,}295 D_e \qquad (10)$$

The discharge in terms of critical depth is given by Formula (11):

$$Q = 2{,}175\sqrt{ga}\, D_c^2 \qquad (11)$$

where

$Q$ is the total discharge expressed in cubic metres per second ($m^3/s$);

$g$ is the gravitational acceleration (standard value) expressed in $m/s^2$;

$D_c$ is the critical depth, expressed in metres, computed using Formula 10 by substituting measured end depth;

$2a$ is the semi-latus rectum of the parabolic channel, expressed in metres. The chord through a focus parallel to the directrix of a conic section is called the latus rectum, and half this length is called the semi-latus rectum.

### 12.4 Practical limitations

For the application of method, the following limitations shall apply.

— The semi-latus rectum $2a$ shall lie between 0,019 m and 0,033 m.

— The vertical distance from channel vertex (bottom) to the downstream water surface shall be greater than $0{,}6D_e$.

— The end depth ($D_e$) shall be greater than 0,05 m.

## 13 Uncertainties of flow measurement

### 13.1 General

**13.1.1** 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 document to estimate the uncertainty in a measurement of discharge.

**13.1.2** The error may be defined as the difference between the true rate of flow and that calculated in accordance with the formula of the type of channel at a site selected in accordance with this document. The term “uncertainty” is used to denote the deviation from the true rate of flow within which the measurement is expected to lie some 19 times out of 20 (95 % confidence limits).

### 13.2 Sources of error

**13.2.1** The sources of error in discharge measurement may be identified by considering the appropriate discharge formula.

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

a) the discharge coefficient, $C$, or the ratio $D_e/D_c$;

b) the dimensional measurement of the channel (for example, $b$ in the case of rectangular and trapezoidal channels, diameter, $d$, in circular channels, $\alpha$ in the case of triangular channels and $a$ in the case of parabolic channels);

c) the measured end depth, $D_e$.

**13.2.3** The uncertainties in dimensional measurements and in $D_e$ 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.

### 13.3 Kinds of error

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

**13.3.2** The standard deviation of a set of $n$ measurements of a quantity $Y$ under steady conditions may be estimated using Formula (12):

$$S_Y = \left( \frac{\sum_{i=1}^{n} \left(Y_i - \bar{Y}\right)^2}{n-1} \right)^{1/2} \qquad (12)$$

where $\bar{Y}$ is the arithmetic mean of $n$ measurements. The standard deviation of the mean is then given by Formula (13):

$$S_{\bar{Y}} = \frac{S_Y}{\sqrt{n}} \qquad (13)$$

and the uncertainty of the mean $2S_{\bar{Y}}$ (to 95 % confidence level). This uncertainty is the contribution of the observations of $Y$ to the total uncertainty.

The factor of 2 assumes that $n$ is large. For $n = 6$, the factor should be 2,6; $n = 8$ requires a factor of 2,4; $n = 10$ requires a factor of 2,3; $n = 15$ requires a factor of 2,1.

**13.3.3** A measurement may also be subject to systematic error; the mean of 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.

### 13.4 Uncertainties in coefficient values

**13.4.1** The values of the discharge coefficient, $C$, quoted in this document 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.

**13.4.2** The uncertainty in the discharge coefficients, quoted in the preceding clauses of this document, is based on a consideration of the deviation of experimental data from the formulae given. The suggested uncertainties thus represent the accumulation of evidence and experience available.

**13.4.3** The maximum systematic uncertainty in the discharge coefficient, *C*, is likely to be ± 5 % from the specified values, with 95 % confidence limits.

### 13.5 Uncertainties in measurements made by the user

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

**13.5.2** Since neither the methods of measurement nor the way in which they are to be made is 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.

**13.5.3** The uncertainty of the gauge depth shall be determined from an assessment of the individual sources of error; for example, the zero setting, the gauge sensitivity, backlash in the indication mechanism (where appropriate), 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.

### 13.6 Combination of uncertainties to give total uncertainty on discharge

**13.6.1** The total systematic random uncertainty is the resultant of several contributory uncertainties, which may 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.

**13.6.2** It should be realized that the uncertainty in discharge, $U_D$, 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.

### 13.7 Example

The following is an example of uncertainty computation of a single determination of discharge using the end depth method in a rectangular channel, under subcritical flow in the channel. The bottom width, *b*, is equal to 1 m with a random uncertainty of $\Delta b$ = ±1 mm and the end depth, $D_e$, is equal to 0,3 m, measured with a random uncertainty of $\Delta' D_e$ = ±12 mm. So the percentage random uncertainties are:

$U_c = \pm 2\%$

$U_b = \pm 0.1\ \%$

$U_{De} = \pm 4\ \%$

The formula used is

$$Q = Cb\sqrt{g}D_e^{3/2}$$

The random uncertainty in $Q$ can be calculated as follows:

$$U_Q = \pm\left[(U_c)^2 + (U_b)^2 + \left(\frac{3}{2}U_{D_e}\right)^2\right]^{1/2}$$

$$U_Q = \pm\left[(2{,}0)^2 + (0{,}1)^2 + \left(\frac{3}{2} * 4\right)^2\right]^{1/2}$$

$U_Q = \pm\ 6.33\ \%$

The systematic uncertainty in $Q$ is calculated in a similar way. It is assumed that the only source of systematic uncertainty is in the coefficient of discharge $C$.

According to 13.4.3,

$U_Q = \pm\ 5\ \%$

$U_b = \pm\ 0.1\ \%$

$U_{De} = \pm\ 4\ \%$

The formula used is

$$Q = Cb\sqrt{g}D_e^{3/2}$$

The systematic uncertainty in $Q$ can be calculated as follows:

$$u_Q = \pm\left[(U_c)^2 + (U_b)^2 + \left(\frac{3}{2}U_{D_e}\right)^2\right]^{1/2}$$

$$u_Q = \pm\left[(5{,}0)^2 + (0{,}1)^2 + \left(\frac{3}{2} * 4\right)^2\right]^{1/2}$$

$U_Q = \pm\ 7.81\%$

In order to obtain an overall value for the uncertainty in $Q$, the random and systematic uncertainty may be combined by the root sum of squares rule as follows:

$$U = \pm (U^2{}_Q + u^2{}_Q)^{1/2}$$

$$= \pm (6.33^2 + 7.81^2)^{1/2}$$

$$= \pm 10.05\ \%$$

# Bibliography

[1] ISO 4373, *Hydrometry — Water level measuring devices*

[2] Ferro V Theoretical end depth discharge relationship for free overfall. *Journal of Irrigation and Drainage Engineering, ASCE*, January/February 1999, **125** (1), for rectangular, triangular and trapezoidal cases

[3] Dey S End depth in circular channels. *Journal of Hydraulics Engineering, ASCE*, August 1998, **124**, (8)