BRITISH STANDARD

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Measurement of fluid flow in closed conduits —

Part 1: Pressure differential devices —

Section 1.2 Specification for square-edged orifice plates and nozzles (with drain holes, in pipes below 50 mm diameter, as inlet and outlet devices) and other orifice plates

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Committees responsible for this British Standard

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British Compressed Air Society
British Gas plc
Department of Energy (Gas and Oil Measurement Branch)
Department of Trade and Industry (National Engineering Laboratory)
Electricity Supply Industry in England and Wales
Energy Industries Council
GAMBICA (BEAMA Ltd.)
Institute of Measurement and Control
Institute of Petroleum
Institute of Trading Standards Administration
Institution of Gas Engineers
Institution of Mechanical Engineers
Water Authorities' Association

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Engineering Equipment and Materials Users' Association
Institution of Water and Environmental Management (IWEM)
United Kingdom Offshore Operators' Association

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Contents

Foreword

This revision of BS 1042-1.2:1984 has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It supersedes BS 1042-1.2:1984 which is withdrawn. It has the objective of introducing updated data and correcting and improving the text.

This is Section 1.2 of a series of Sections of BS 1042 on pressure differential devices as follows:

— *Section 1.1: Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross section conduits running full;*

— *Section 1.2: Specification for square-edged orifice plates and nozzles (with drain holes, in pipes below 50 mm diameter, as inlet and outlet devices) and other orifice plates;*

— *Section 1.3: Method of use of critical flow venturi nozzles inserted in a closed conduit and calculation of critical flowrates and their associated uncertainties*[1]*;*

— *Section 1.4: Guide to the use of devices specified in Sections 1.1 and 1.2;*

— *Section 1.5: Guide to the effect of departure from the conditions specified in Section 1.1.*

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 14, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1] In preparation

Section 1. General

1 Scope

This Section of BS 1042-1.2 specifies the geometry and method of use for conical entrance orifice plates, quarter circle orifice plates and eccentric orifice plates. Requirements are also specified for square-edged orifice plates and nozzles under conditions outside the scope of BS 1042-1.1.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Symbols

The symbols used in this standard are given in Table 1.

3 Principle of the method of measurement and computation

The principle of the method of measurement and computation is as specified in clause **5** of BS 1042-1.1:1992.

NOTE Sample calculations, physical data and other additional information on using pressure differential devices are given in BS 1042-1.4.

Table 1 — Symbols

Symbols	Represented quantity	Dimensions M: mass L: length T: time	SI unit
a	Pressure tapping hole diameter	L	m
C	Discharge coefficient	dimensionless	
d	Diameter of orifice or throat of primary device at operating conditions	L	m
D	Upstream internal pipe diameter at operating conditions	L	m
e	Thickness of bore	L	m
E, E_1	Thickness of orifice plate	L	m
F_E	Correction factor	dimensionless	
k	Uniform equivalent roughness	L	m
p	Static pressure of the fluid	$ML^{-1}T^{-2}$	Pa
q_m	Mass rate of flow	MT^{-1}	kg/s
r	Radius of profile	L	m
R_a	Roughness criterion	L	m
Re	Reynolds number	dimensionless	
Re_D Re_d	Reynolds number referred to D or d	dimensionless	
β	Diameter ratio, $\beta = \frac{d}{D}$	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
ϵ	Expansibility (expansion) factor	dimensionless	
κ	Isentropic exponent	dimensionless	
ρ	Mass density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio, $\tau = \frac{P_2}{P_1}$	dimensionless	

NOTE 1 Other symbols used in this standard are defined at their place of use.
NOTE 2 Some of the symbols used in this standard are different from those used in BS 1042-1.1.
NOTE 3 Subscript 1 refers to the cross section at the plane of the upstream pressure tapping. Subscript 2 refers to the cross section at the plane of the downstream pressure tapping.

Section 2. Square-edged orifice plates and nozzles with drain holes, in pipes below 50 mm diameter and as inlet and outlet devices

4 Drain holes through the upstream face of the square-edged orifice plate or nozzle

4.1 General

Square-edged orifice plates and nozzles with drain holes shall be used, installed, and manufactured in accordance with clauses **6**, **7**, **8**, **9** and **10** of BS 1042-1.1:1992.

4.2 Square-edged orifice plates

If a drain hole is drilled through the orifice plate the coefficient values specified in BS 1042-1.1 shall not be used unless the following conditions are observed.

a) The pipe diameter shall be larger than 100 mm.

b) The diameter of the drain hole shall not exceed 0.1d and no part of the hole shall lie within a circle, concentric with the orifice, of diameter (D – 0.2d). The outer edge of the drain hole shall be as close to the pipe wall as practicable.

c) The drain hole shall be deburred and the upstream edge shall be sharp.

d) Single pressure tappings shall be orientated so that they are between 90° and 180° to the position of the drain hole.

e) The measured orifice diameter, d_m, shall be corrected to allow for the additional orifice area represented by the drain hole of diameter d_k as shown in the following equations.

$$d \approx d_m \left\{ 1 + 0.55 \left(\frac{d_k}{d_m}\right)^2 \right\}$$

$$d_m \approx d \left\{ 1 - 0.55 \left(\frac{d_k}{d}\right)^2 \right\}$$

NOTE These equations are based on the assumption that the value for $C\epsilon(1 - \beta^4)^{-0.5}$ for flow through the drain hole is 10 % greater than the value for flow through the orifice.

An additional uncertainty equivalent to 100 % of the drain hole correction shall be added arithmetically to the discharge coefficient uncertainty when estimating the overall uncertainty of the flow measurement.

4.3 ISA 1932 nozzles

If a drain hole is drilled through the nozzle upstream face, the coefficient values specified in BS 1042-1.1 shall not be used unless the following conditions are observed.

a) The value of β shall be less than 0.625.

b) The diameter of the drain hole shall not exceed 0.1d and no part of the hole shall lie within a circle, concentric with the throat, of diameter (D – 0.2d).

c) The length of the drain hole shall not exceed 0.1D.

d) The drain hole shall be deburred and the upstream edge shall be sharp.

e) Single pressure tappings shall be orientated so that they are between 90° and 180° to the position of the drain hole.

f) The measured diameter, d_m, shall be corrected to allow for the additional throat area represented by the drain hole of diameter d_k as shown in the following equations.

$$d \approx d_m \left\{ 1 + 0.40 \left(\frac{d_k}{d_m}\right)^2 \right\}$$

$$d_m \approx d \left\{ 1 - 0.40 \left(\frac{d_k}{d}\right)^2 \right\}$$

NOTE These equations are based on the assumption that the value for $C\epsilon\ (1 - \beta^4)^{-0.5}$ for flow through the drain hole is 10 % greater than the value for flow through the throat of the nozzle.

An additional uncertainty equivalent to 100 % of the drain hole correction shall be added arithmetically to the discharge coefficient uncertainty when estimating the overall uncertainty of the flow measurement.

4.4 Long radius nozzles

Drain holes through these primary elements shall not be used.

5 Square-edged orifice plates installed in pipes of diameter 25 mm ⩽ D < 50 mm

5.1 General

Orifice plates shall be installed and manufactured in accordance with clauses **6**, **7** and **8** of BS 1042-1.1:1992.

5.2 Limits of use

When square-edged orifice plates are installed in pipes of bore 25 mm up to 50 mm the following conditions shall be strictly observed.

a) The pipes shall have high quality internal surfaces such as drawn copper or brass tubes, glass or plastics pipes or drawn or fine machined steel tubes. The steel tubes shall be of stainless steel for use with corrosive fluids such as water. The uniform equivalent roughness, k, shall be < 0.03 mm for all β ratios. If the pipe is machined the surface finish shall be better than 0.3 µm.

b) Corner taps shall be used, preferably of the carrier ring type detailed in Figure 6(a) of BS 1042-1.1:1992.

c) The diameter ratio, β, shall be within the range $0.23 \leqslant \beta \leqslant 0.7$ where $0.032 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.350$.

5.3 Discharge coefficients and corresponding uncertainties

The Stolz equation for corner tappings given in **8.3.2.1** of BS 1042-1.1:1992 shall be used for deriving the discharge coefficients provided the minimum pipe Reynolds numbers are above the following values.

$Re_D \geqslant 40\,000\,\beta^2$ for $0.23 \leqslant \beta \leqslant 0.5$

$Re_D \geqslant 10\,000$ for $0.5 \leqslant \beta \leqslant 0.7$

An additional uncertainty of 1.0 % shall be added arithmetically to the uncertainty derived from **8.3.3** of BS 1042-1.1:1992.

6 No upstream or downstream pipeline

6.1 General

This clause shall apply where there is no pipeline on either or both the upstream or downstream sides of the device, that is for flow from a large space into a pipe or vice versa, or flow through a device installed in the partition wall between two large spaces.

6.2 Flow from a large space (no upstream pipeline) into a pipeline or another large space

6.2.1 *Upstream and downstream tappings.* The space on the upstream side of the device shall be considered large if:

a) there is no wall closer than $4d$ to the axis of the device or to the plane of the upstream face of the orifice or nozzle,

b) the velocity of the fluid at any point more than $4d$ from the device is less than 3 % of the velocity in the orifice or throat,

c) the diameter of the downstream pipeline is not less than $2d$.

NOTE 1 The first condition implies, for example, that an upstream pipeline of diameter greater than $8d$ (that is where $\beta < 0.125$) may be regarded as a large space. The second condition, which excludes upstream disturbances due to draughts, swirl and jet effects, implies that the fluid is to enter the space uniformly over an area of not less than 33 times the area of the orifice or throat. For example, if the flow is provided by a fall in level of a liquid in a tank, the area of the liquid surface is not to be less than 33 times the area of the orifice or throat through which the tank is discharged.

The distance of the upstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline shall be greater than $5d$.

NOTE 2 The upstream tapping should preferably be located in a wall perpendicular to the plane of the orifice and be within a distance of $0.5d$ from that plane. The tapping does not necessarily have to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping should be shielded from draughts.

The downstream tapping shall be located as specified for corner tappings in BS 1042-1.1. If the downstream side also consists of a large space, the tapping shall be located as for the upstream tapping, except for venturi nozzles where the throat tap shall be used.

NOTE 3 When the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head.

6.2.2 ***Square-edged orifice plates with corner tappings***

6.2.2.1 Square-edged orifice plates with corner tappings shall be manufactured in accordance with clause **8** of BS 1042-1.1:1992.

6.2.2.2 The limits of use for square-edged orifice plates with corner tappings where there is a flow from a large space shall be as follows.

$d > 6$ mm

upstream: $\beta \leqslant 0.125$

pipeline downstream: $0.2 \leqslant \beta \leqslant 0.5$

large space downstream: $\beta \leqslant 0.125$

$C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.009$

$Re_d \geqslant 50\,000$

6.2.2.3 The discharge coefficient, C, is equal to 0.596 The uncertainty on the value of C is 1 %.

6.2.2.4 The expansibility factor, ϵ, is given by the following equation and is only applicable if $p_1/p_2 > 0.75$:

$$\epsilon = 1 - (0.41 + 0.35\beta^4)\ \frac{\Delta p}{\kappa p_1}$$

When β, $\Delta p/p_1$ and κ are assumed to be known without error, the percentage uncertainty of the value of ϵ is equal to $4\Delta p/p_1$.

Test results for the determination of ϵ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours the isentropic exponent of which is known.

6.2.3 ***ISA nozzle and venturi nozzle***

6.2.3.1 ISA nozzles and venturi nozzles shall be manufactured in accordance with clause **9** or **10.2** of BS 1042-1.1:1992.

6.2.3.2 The limits of use for ISA and venturi nozzles where there is flow from a large space shall be as follows.

$d \geqslant 11.5$ mm

upstream: $\beta \leqslant 0.125$

pipeline downstream: $0.2 \leqslant \beta \leqslant 0.5$

large space downstream: $\beta \leqslant 0.125$

$C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.015$

$Re_d \geqslant 100\ 000$

6.2.3.3 The discharge coefficient, C, is equal to 0.99. The uncertainty in the value of C is 1 %.

6.2.3.4 The expansibility factor, ϵ, is given by the following equation and is only applicable if $p_2/p_1 \geqslant 0.75$:

$$\epsilon = \left\{ \left(\frac{\kappa \tau^{2/\kappa}}{\kappa - 1} \right) \left(\frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau} \right) \right\}^{0.5}$$

The uncertainty on the expansibility factor, in %, is equal to $2\ \Delta p/p_1$.

6.3 Flow into a large space (no downstream pipeline)

6.3.1 The space on the downstream side of the device shall be considered large if there is no wall closer than $4d$ to the axis of the device or to the downstream face of the orifice plate or nozzle.

The diameter of the upstream pipeline shall be greater than $2.5d$ (that is, $\beta < 0.4$).

The upstream tapping shall be located as specified for corner tappings in BS 1042-1.1.

The distance of the downstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline shall be greater than $5d$.

For venturi nozzles, the throat tap shall be used.

NOTE 1 The downstream tapping should preferably be located in a wall perpendicular to the plane of the orifice and be within a distance of $0.5d$ from that plane. The tapping does not necessarily have to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping should be shielded from draughts.

NOTE 2 Where the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head.

6.3.2 ***Square-edged orifice plates with corner tappings***

6.3.2.1 Square-edged orifice plates with corner tappings shall be manufactured in accordance with clause **8** of BS 1042-1.1:1992.

6.3.2.2 Where 25 mm $\leqslant D <$ 50 mm, the limits given in **5.2** shall apply except that:

$0.4 \leqslant \beta \leqslant 0.7$

$0.1 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.35$

Where 50 mm $\leqslant D \leqslant$ 1 000 mm, the limits given in **8.3.1** of BS 1042-1.1:1992 shall apply except that:

$0.4 \leqslant \beta \leqslant 0.8$

$0.1 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.50$

6.3.2.3 Where 25 mm $\leqslant D <$ 50 mm, the coefficients and uncertainties given in **5.3** shall apply.

Where 50 mm $\leqslant D \leqslant$ 1 000 mm, the coefficients and uncertainties given in **8.3.2** and **8.3.3** of BS 1042-1.1:1992 shall apply.

6.3.3 ***ISA nozzle and venturi nozzle***

6.3.3.1 ISA nozzles and venturi nozzles shall be manufactured in accordance with clause **9** or **10.2** of BS 1042-1.1:1992.

6.3.3.2 The limits given in **9.1.6.1** of BS 1042-1.1:1992 shall apply except that:

$0.4 \leqslant \beta \leqslant 0.8$

$0.16 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.75$

6.3.3.3 The coefficients and uncertainties given in **9.1.6.2**, **9.1.6.3** and **9.1.7** of BS 1042-1.1:1992 shall apply.

Section 3. Orifice plates (except square-edged)

7 Conical entrance orifice plates

7.1 General

NOTE A conical entrance orifice plate has the characteristic that its discharge coefficient remains constant down to a low Reynolds number, thus making it suitable for the measurement of flowrate of viscous fluids such as oil. Conical entrance orifice plates are further distinguished from other types of orifice plates in that their discharge coefficient is the same for any β ratio within the limits specified in this standard.

Conical entrance orifice plates shall be used and installed in accordance with clauses **6** and **7** of BS 1042-1.1:1992.

7.2 Limits of use

The limits of use for conical entrance orifice plates shall be as follows:

$d > 6$ mm

$D \leqslant 500$ mm

The lower limit of pipe diameter, D, depends on the internal roughness of the upstream pipeline and shall be in accordance with Table 2 and within the following limits:

$0.1 \leqslant \beta \leqslant 0.316$

$0.007 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.074$

$80 \leqslant Re_D \leqslant 2 \times 10^5\beta$

NOTE Within these limits, the value of β is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

Table 2 — Minimum internal diameter of upstream pipe for conical entrance orifice plates

Material	Condition	Minimum internal diameter
		mm
brass, copper, lead, glass, plastics, steel	smooth, without sediments	25
	new, cold drawn	25
	new, seamless	25
	new, welded	25
	slightly rusty	25
	rusty	50
	slightly encrusted	200
	bituminized, new or used	25
	galvanized	25
cast iron	bituminized	25
	not rusty	50
	rusty	200

7.3 Description

NOTE The axial plane cross section of the orifice plate is shown in Figure 1.
The letters shown in Figure 1 are for reference purposes in **7.3.2** to **7.3.8** only.

7.3.1 *General shape*

7.3.1.1 The part of the plate inside the pipe shall be circular and concentric with the pipe centreline. The faces of this plate shall always be flat and parallel.

7.3.1.2 Unless otherwise stated, the requirements of **7.3.1.4** and of **7.3.2** to **7.3.8** shall apply only to that part of the plate located within the pipe.

7.3.1.3 Care shall be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, does not cause the slope of the straight line defined in **7.3.2.1** to exceed 1 % under flowing conditions.

7.3.2 *Upstream face A*

7.3.2.1 The upstream face of the plate A shall be flat when the plate is installed in the pipe with zero differential pressure across it.

NOTE Provided it can be shown that the method of mounting does not distort the plate this flatness may be measured with the plate removed from the pipe. Under these circumstances the plate may be considered flat if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0.5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

7.3.2.2 The upstream face of the orifice plate shall have a roughness criterion $R_a \leqslant 10^{-4}\, d$ within a circle whose diameter is not less than $1.5d$ and which is concentric with the orifice.

NOTE It is useful to provide a distinctive mark which is visible even when the orifice plate is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

7.3.3 *Downstream face B.* The downstream face shall be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.

7.3.4 *Thicknesses* e_1, E_1 and E

7.3.4.1 The thickness, e_1, of the conical entrance shall be $0.084d \pm 0.003d$.

7.3.4.2 The thickness, E_1, of the orifice plate for a distance of not less than $1.0d$ from the centreline axis shall not exceed $0.105d$.

7.3.4.3 The thickness, E, of the orifice plate at a distance greater than $1.0d$ from the centreline axis may exceed $0.105d$ but shall not exceed $0.1D$ and the extra thickness if any shall be on the downstream face.

7.3.4.4 The values of E_1 measured at any point on the plate shall not differ from each other by more than 0.001D.

7.3.4.5 The values of E measured at any point on the plate shall not differ from each other by more than 0.005D.

7.3.5 *Conical entrance*. The upstream edge of the orifice shall be bevelled at an angle of 45° ± 1°.

7.3.6 *Parallel bore*

7.3.6.1 The bore of the orifice shall be parallel within ± 0.5° to the centreline axis.

7.3.6.2 The axial length, e, of the parallel bore shall be $0.021d \pm 0.003d$.

7.3.7 *Edges H, I and G*

7.3.7.1 The upstream edge H formed by the intersection of the conical entrance and the upstream face shall not be rounded.

7.3.7.2 The upstream edge I formed by the intersection of the parallel bore and the conical entrance shall not be rounded.

7.3.7.3 The upstream edges H and I and the downstream edge G shall not have wire-edges, burrs, or any peculiarities visible to the naked eye.

7.3.8 *Diameter of orifice*

7.3.8.1 The diameter of the orifice, d, shall be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter shall be made.

No diameter shall differ by more than 0.05 % from the value of the mean diameter.

7.3.8.2 The parallel bore of the orifice shall be cylindrical and perpendicular to the upstream face.

7.4 Pressure tappings

Corner tappings as specified in **8.2.2** of BS 1042-1.1:1992 shall be used with conical entrance orifice plates. Both the upstream and downstream tappings shall be the same.

7.5 Coefficients and corresponding uncertainties

7.5.1 The discharge coefficient, C, is equal to 0.734. The uncertainty on the value of C is 2 %.

7.5.2 The value of the expansibility factor, ϵ, for conical entrance orifice plates shall be taken as the mean of that for square-edged orifice plates and that for ISA 1932 nozzles specified in **8.3.2.2** and **9.1.6.3** of BS 1042-1.1:1992 respectively.

The values used shall be calculated at the same conditions. The uncertainty on the expansibility factor, in %, is given by $33(1 - \epsilon)$.

7.5.3 The uncertainties on other quantities shall be determined in accordance with clause **11** of BS 1042-1.1:1992.

8 Quarter circle orifice plates

8.1 General

NOTE A quarter circle orifice plate has the characteristic that its discharge coefficient remains constant down to a low Reynolds number thus making it suitable for measurement of flow rate of viscous fluids such as oil.

Quarter circle orifice plates shall be used and installed in accordance with clauses **6** and **7** of BS 1042-1.1:1992.

8.2 Limits of use

The limits of use for quarter circle orifice plates shall be as follows:

$d \geqslant 15$ mm

$D \leqslant 500$ mm

The lower limit of pipe diameter, D, depends on the internal roughness of the upstream pipeline and shall be in accordance with Table 3 and within the following limits:

$0.245 \leqslant \beta \leqslant 0.6$

$0.046 \leqslant C\beta^2 (1 - \beta^4)^{-0.5} \leqslant 0.326$

$Re_D \leqslant 10^5\beta$

The lower limit of the Reynolds number, Re_D, is given by the following equation:

$$Re_D \text{ (min.)} = 1\,000\beta + 9.4 \times 10^6 (\beta - 0.24)^8$$

For convenience, values of Re_D (min.) are given in Table 4.

NOTE Within these limits, the value of β is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

8.3 Description

NOTE The axial plane cross section of the orifice plate is shown in Figure 2.
The letters shown in Figure 2 are for reference purposes in **8.3.2** to **8.3.7** only.

8.3.1 *General shape*

8.3.1.1 The part of the plate inside the pipe shall be circular and concentric with the pipe centreline. The faces of this plate shall always be flat and parallel.

8.3.1.2 Unless otherwise stated, the requirements of **8.3.1.4** and of **8.3.2** to **8.3.7** shall apply only to that part of the plate located within the pipe.

8.3.1.3 Care shall be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, does not cause the slope of the straight line defined in **8.3.2.1** to exceed 1 % under flowing conditions.

Table 3 — Minimum internal diameter of upstream pipe for quarter circle orifice plates

Material	Condition	Minimum internal diameter
		mm
brass, copper, lead, glass, plastics, steel	smooth, without sediments	25
	new, cold drawn	25
	new, seamless	25
	new, welded	25
	slightly rusty	50
	rusty	100
	slightly encrusted	200
	bituminized, new	25
	bituminized, used	75
	galvanized	50
cast iron	bituminized	25
	not rusty	50
	rusty	200

8.3.2 ***Upstream face A***

8.3.2.1 The upstream face of the plate A shall be flat when the plate is installed in the pipe with zero differential pressure across it.

NOTE Provided it can be shown that the method of mounting does not distort the plate this flatness may be measured with the plate removed from the pipe. Under these circumstances the plate may be considered flat if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0.5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

8.3.2.2 The upstream face of the orifice plate shall have a roughness criterion $R_a \leqslant 10^{-4}\, d$ within a circle whose diameter is not less than 1.5d and which is concentric with the orifice.

NOTE It is useful to provide a distinctive mark which is visible even when the orifice plate is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

8.3.3 *Downstream face B.* The downstream face shall be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.

8.3.4 ***Thicknesses e and E***

8.3.4.1 The thickness, e, of the bore section shall be not less than 2.5 mm and shall not exceed 0.1D.

8.3.4.2 Where the radius, r, of the profile exceeds 0.1D, which is the case when β exceeds 0.571, the thickness of the plate shall be reduced from r to 0.1D by removing metal from the upstream face.

8.3.4.3 When the thickness, E, of the orifice plate exceeds the radius, r, then the thickness of the plate shall be reduced to equal this radius by removing metal from the downstream face to form a new downstream face in a recess of diameter 1.5d with its edge bevelled to 45°.

8.3.4.4 The values of e measured at any point on the plate shall not differ from each other by more than 0.001D.

8.3.5 ***Upstream orifice profile***

8.3.5.1 The profile of the upstream edge shall be circular and of radius r with its centre on the downstream face of the plate.

NOTE The profile may not be a full quarter circle due to the limit specified in **8.3.4.2**.

8.3.5.2 The radius, r, of the profile shall be determined from the following equation:

$$r/d = 3.17 \times 10^{-6} e^{16.8\beta} + 0.0554 e^{1.016\beta} + 0.029$$

within ± 0.05r.

For convenience, values of r/d are given in Table 4.

The radius of the profile shall be the same for all sections within ± 0.01r.

NOTE The permitted variation in profile radius allows an orifice plate designed for a given D to be used in pipes of 0.95D to 1.05D.

8.3.5.3 The tangent to the profile at the downstream edge shall be perpendicular to the upstream face of the plate within ± 1°

8.3.5.4 The profile surface shall not have wire-edges, burrs, or any peculiarities visible to the naked eye.

8.3.6 *Downstream edge.* The downstream edge of the orifice shall be square and shall not have wire-edges, burrs, nor any peculiarities visible to the naked eye.

8.3.7 *Diameter of orifice.* The diameter of the orifice, d, shall be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter shall be made.

No diameter shall differ by more than 0.1 % from the value of the mean diameter.

8.4 Pressure tappings

For pipes of diameter up to 40 mm, corner tappings as specified in **8.2.2** of BS 1042-1.1:1992 shall be used with quarter circle orifice plates. For pipes of diameter 40 mm or greater, either corner tappings as specified in **8.2.2** of BS 1042-1.1:1992 or flange tappings as specified in **8.2** of BS 1042-1.1:1992 shall be used with quarter circle orifice plates.

8.5 Coefficients and corresponding uncertainties

8.5.1 *Discharge coefficient*. The discharge coefficient, C, is given by the following equation:

$$C = 0.73823 + 0.3309\beta - 1.1615\beta^2 + 1.5084\beta^3$$

The uncertainty on the value of C is 2 % when $\beta > 0.316$ and 2.5 % when $\beta \leqslant 0.316$.

For convenience, Table 4 gives values of C as a function of β.

Table 4 — Discharge coefficients for quarter circle orifice plates

β	C	r/d	Re_D (min.)
0.245	0.772	0.100	250
0.250	0.772	0.101	250
0.260	0.772	0.101	260
0.270	0.773	0.102	270
0.280	0.773	0.103	280
0.290	0.773	0.104	290
0.300	0.774	0.105	300
0.310	0.774	0.106	310
0.320	0.775	0.106	320
0.330	0.775	0.107	330
0.340	0.776	0.108	340
0.350	0.776	0.109	350
0.360	0.777	0.110	360
0.370	0.778	0.111	370
0.380	0.779	0.112	380
0.390	0.780	0.114	390
0.400	0.781	0.115	400
0.410	0.783	0.116	420
0.420	0.784	0.118	430
0.430	0.786	0.119	450
0.440	0.787	0.121	460
0.450	0.789	0.123	490
0.460	0.791	0.125	510
0.470	0.794	0.127	540
0.480	0.796	0.129	580
0.490	0.799	0.132	630
0.500	0.802	0.135	700
0.510	0.805	0.139	780
0.520	0.808	0.143	880
0.530	0.812	0.147	1 000
0.540	0.816	0.153	1 200
0.550	0.820	0.159	1 400
0.560	0.824	0.167	1 600
0.570	0.829	0.174	1 900
0.580	0.834	0.183	2 300
0.590	0.839	0.194	2 700
0.600	0.844	0.207	3 300

8.5.2 *Expansibility (expansion) factor*. For the two tapping arrangements, the empirical formula for computing the expansibility (expansion) factor, ϵ, is as follows:

$$\epsilon = 1 - (0.41 + 0.35\beta^4)\frac{\Delta p}{\kappa p_1}$$

This formula is applicable only within the range of the limits of use given in **8.2**.

Test results for the determination of ϵ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours the isentropic exponent of which is known.

However, the formula is applicable only if

$$\frac{p_2}{p_1} \geqslant 0.75.$$

When β, $\Delta p/p_1$ and κ are assumed to be known without error, the percentage uncertainty of the value of ϵ is equal to 4 $(\Delta p/p_1)$ % when $\beta \leqslant 0.6$.

8.5.3 *Uncertainties*. The uncertainties of other quantities shall be determined in accordance with clause **11** of BS 1042-1.1:1992.

9 Eccentric orifice plates

9.1 General

The eccentric orifice plate is designed to be installed so that it does not obstruct the flow of entrained gas, liquid or sediments in a fluid, whilst remaining simple to manufacture and install. Eccentric orifice plates shall be used in accordance with clause **6**, and installed in accordance with clause **7** (except **7.5.2.3**) of BS 1042-1.1:1992.

9.2 Limits of use

The limits of use for eccentric orifice plate shall be as follows:

$d \geqslant 50$ mm

100 mm $\leqslant D \leqslant$ 1 000 mm

$0.46 \leqslant \beta \leqslant 0.84$

$0.136 \leqslant C\beta^2 (1 - \beta^4)^{0.5} \leqslant 0.423$

$2 \times 10^5\beta^2 \leqslant Re_D \leqslant 10^6\beta$

9.3 Description

NOTE The eccentric orifice plate is shown in Figure 3. The letters shown in Figure 3 are for reference purposes in **9.3.2** to **9.3.9** only.

9.3.1 ***General shape***

9.3.1.1 The part of the plate inside the pipe shall be circular and the orifice shall be internally tangential to the pipe bore. The faces of the plate shall be flat and parallel.

9.3.1.2 Unless otherwise stated, the requirements of **9.3.1.4** and of **9.3.2** to **9.3.9** shall apply only to that part of the plate located within the pipe.

9.3.1.3 Care shall be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, does not cause the slope of the straight line defined in **9.3.2.1** to exceed 1 % under flowing conditions.

9.3.2 *Upstream face A*

9.3.2.1 The upstream face of the plate A shall be flat when the plate is installed in the pipe with zero differential pressure across it.

NOTE Provided it can be shown that the method of mounting does not distort the plate this flatness may be measured with the plate removed from the pipe. Under these circumstances the plate may be considered flat if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0.5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

9.3.2.2 The upstream face of the orifice plate shall have a roughness criterion $R_a \leqslant 10^{-4}\ d$ within a circle whose diameter is not less than 1.5d and which is concentric with the orifice except for that part outside diameter D (see **9.3.1.2**).

NOTE It is useful to provide a distinctive mark which is visible even when the orifice plate is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

9.3.3 *Downstream face B.* The downstream face shall be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.

9.3.4 *Thicknesses e and E*

9.3.4.1 The thickness, e, of the orifice shall be between 0.005D and 0.02D.

9.3.4.2 The values of e measured at any point on the orifice shall not differ from each other by more than 0.001D.

9.3.4.3 The thickness, E, of the orifice plate shall be between e and 0.05D.

9.3.4.4 The values of E measured at any point on the plate shall not differ from each other by more than 0.001D.

9.3.5 *Angle of bevel*

9.3.5.1 If the thickness, E, of the plate exceeds the thickness, e, of the orifice, the plate shall be bevelled on the downstream side and the bevelled surface shall be well finished.

9.3.5.2 The angle of bevel, F, shall be 45° ± 15°.

9.3.5.3 The plate shall not be bevelled if its thickness, E, is less than or equal to 0.02D.

NOTE Although detrimental effect from debris trapped in the invert of the downstream bevel is considered unlikely, entrapment will be eliminated by restricting the thickness, E, of the plate to the thickness, e, of the orifice, so that no bevel is necessary.

9.3.6 *Edges G, H, and I*

9.3.6.1 The upstream edge G and the downstream edges H and I shall not have wire-edges, burrs, nor any peculiarities visible to the naked eye.

9.3.6.2 The upstream edge G shall be considered sharp if the edge radius is not greater than 0.0004d.

NOTE If $d \geqslant 125$ mm this requirement may be considered as satisfied by mere visual inspection, checking that the edge does not seem to reflect a beam of light when viewed by the naked eye. If $d > 125$ mm visual inspection is not sufficient but this requirement can be considered as satisfied if the upstream face of the orifice plate is finished by a very fine radial cut from the centre outwards.

However, if there is any doubt as to whether this requirement is satisfied, the edge radius shall be actually measured.

9.3.7 *Diameter of orifice*

9.3.7.1 The diameter of the orifice, d, shall be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter shall be made.

9.3.7.2 The parallel bore of the orifice shall be cylindrical and perpendicular to the upstream face.

No diameter shall differ by more than 0.05 % from the value of the mean diameter.

9.3.7.3 The diameter, d, shall be between 0.46D and 0.84D.

NOTE Within these limits, the value of β is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

9.3.8 *Symmetrical plates.* If the orifice plate is intended to be used for measuring reverse flows then

a) the plate shall not be bevelled;

b) the two faces shall be as specified for the upstream face in **9.3.2**;

c) the thickness, E, of the plate shall be equal to the thickness, e, of the orifice as described in **9.3.4.1**;

d) the two edges of the orifice shall be as specified for the upstream edge in **9.3.6.2**.

9.3.9 *Pressure tappings.* Eccentric orifice plates shall be used with a single pair of corner tappings as specified in **8.2.2** of BS 1042-1.1:1992 except that the pressure tapping hole diameter, a, shall be within the limits 3 mm $\leqslant a \leqslant$ 10 mm.

NOTE 1 In an eccentric orifice plate, the orifice is not concentric with the pipe bore and consequently the pressure difference depends on the angular position of the pressure tappings.

Ideally the pressure tappings should be diametrically opposite the point where the orifice is tangential to the wall of the pipe. All discharge coefficient values in this standard are based on such a disposition. However, rotating the tappings by only 90° from the ideal position would result in an error of not more than + 2 % in discharge coefficient.

NOTE 2 Since the orifice is usually either at the top or at the bottom of the pipe, placing the pressure tappings diametrically opposite may cause other problems; air entrainment if tappings are at the very top, or blockage by dirt when they are at the bottom of the pipe. In such cases it is permissible to rotate the tappings by 30° from the vertical centreline of the pipe without the risk of incurring any significant additional flow metering uncertainty.

9.4 Coefficients and corresponding uncertainties

9.4.1 The discharge coefficient, C, is given by the following equation:

$$C = 0.9355 - 1.6889\beta + 3.0428\beta^2 - 1.7989\beta^3$$

For convenience, Table 5 gives values of C as a function of β.

When β, D, Re_D and k/D are assumed to be known without error, the uncertainty of the value of C is 1 % when $\beta \leqslant 0.75$.

The uncertainty when $\beta > 0.75$ is 2 %.

9.4.2 The discharge coefficient shall be multiplied by the appropriate correction factor for pipe roughness, F_E, given in Table 6 in terms of β and relative pipe roughness k/D. The value of the uniform equivalent roughness, k, depends on several factors such as height, distribution, angularity and other geometric aspects of the roughness element at the pipe wall. A pressure loss test of a sample length of the particular pipe has to be carried out to determine the value satisfactorily. However, approximate values of k for different materials can be obtained from Table E.1 of BS 1042-1.1:1992.

9.4.3 The expansibility factor, ϵ, is given by the following equation and is only applicable if $p_2/p_1 \geqslant 0.75$:

$$\epsilon = 1 - (0.41 + 0.35\beta^4)\,\frac{\Delta p}{\kappa p_1}$$

When β, $\Delta p/p_1$ and κ are assumed to be known without error the percentage uncertainty in the value of ϵ is equal to $4\,\Delta p/p_1$.

Test results for the determination of ϵ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours the isentropic exponent of which is known.

Table 5 — Discharge coefficients for eccentric orifice plates

β	C
0.46	0.627
0.47	0.627
0.48	0.627
0.49	0.627
0.50	0.627
0.51	0.627
0.52	0.627
0.53	0.627
0.54	0.627
0.55	0.628
0.56	0.628
0.57	0.628
0.58	0.628
0.59	0.629
0.60	0.629
0.61	0.629
0.62	0.629
0.63	0.629
0.64	0.629
0.65	0.629
0.66	0.629
0.67	0.629
0.68	0.628
0.69	0.628
0.70	0.627
0.71	0.626
0.72	0.625
0.73	0.624
0.74	0.623
0.75	0.621
0.76	0.620
0.77	0.618
0.78	0.616
0.79	0.613
0.80	0.611
0.81	0.608
0.82	0.605
0.83	0.601
0.84	0.597

Table 6 — Roughness correction factor F_E for eccentric orifice plates

$F_E = 1.032 + 0.0178 (\log_{10}k/D) + 0.0939\beta^2 + 0.0126(\beta^2 \log_{10}k/D)$

Diameter ratio β	Roughness correction factor, F_E, for values of relative pipe roughness $10^4\ k/D$ of:					
	3	5	10	15	20	25
0.46	1.000	1.000	1.000	1.000	1.000	1.000
0.50	1.000	1.000	1.000	1.000	1.000	1.001
0.60	1.000	1.000	1.000	1.003	1.006	1.008
0.70	1.000	1.000	1.006	1.010	1.013	1.016
0.80	1.001	1.007	1.015	1.019	1.022	1.025
0.84	1.004	1.010	1.018	1.023	1.026	1.029

NOTE Minimum value for F_E is 1.000 when the pipe is considered to be smooth.

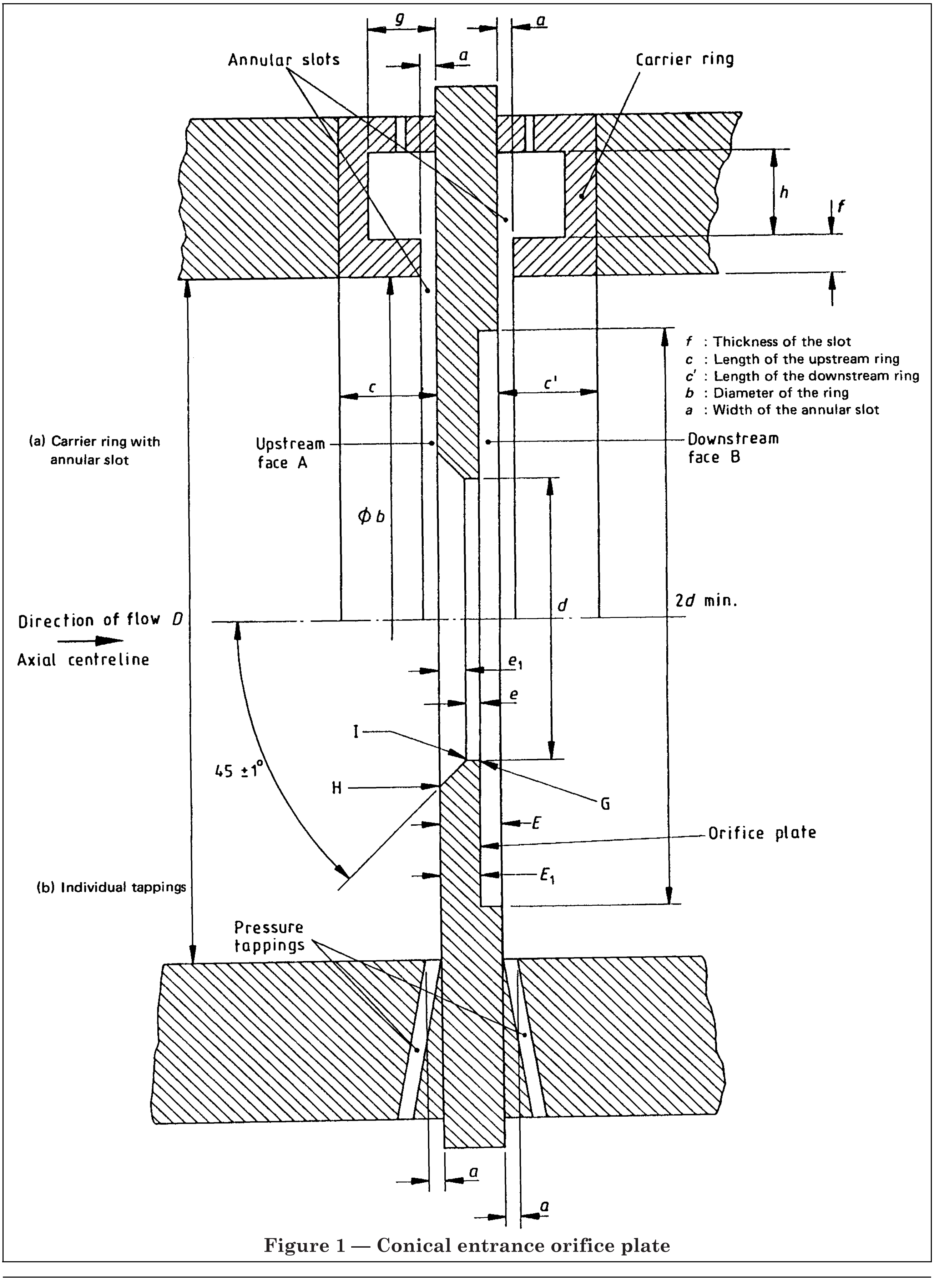

Figure 1 — Conical entrance orifice plate

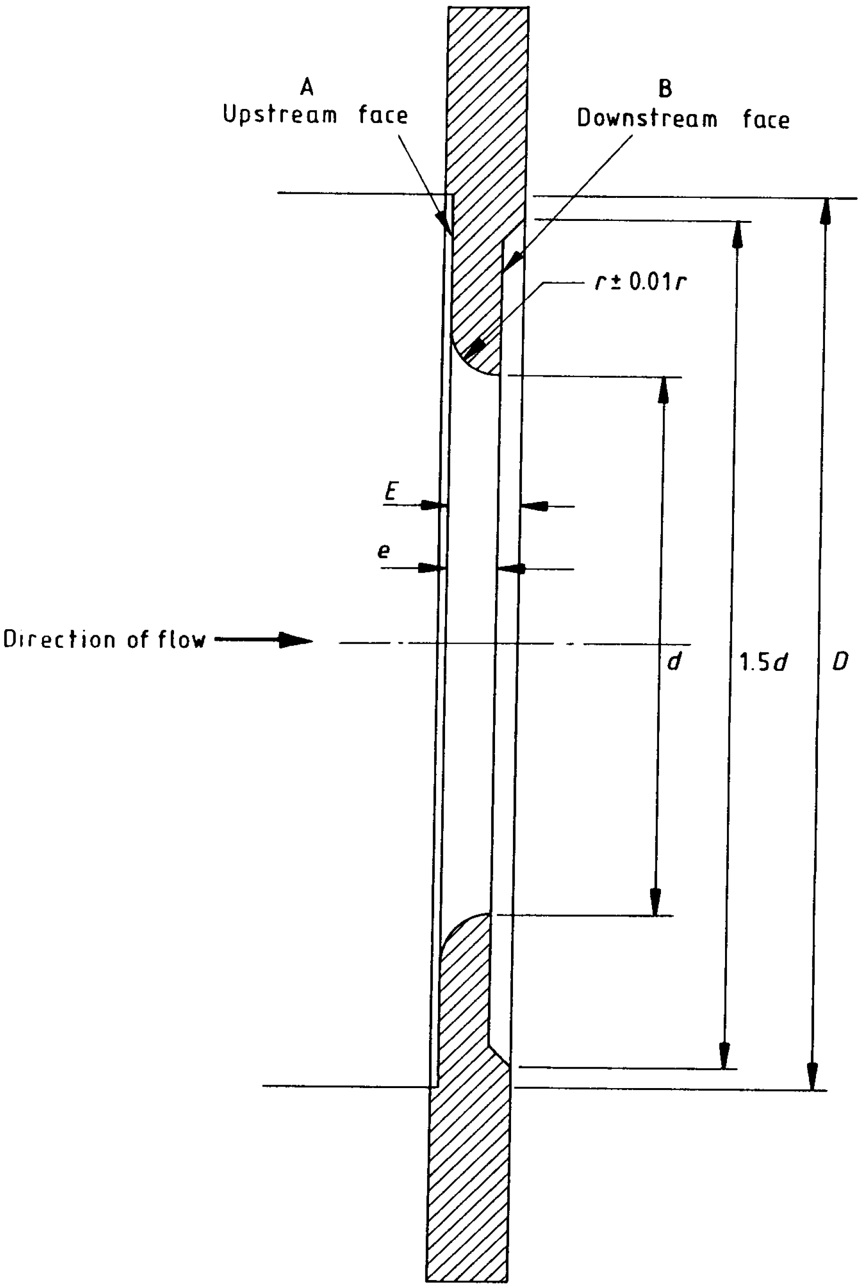

Figure 2 — Quarter circle orifice plate

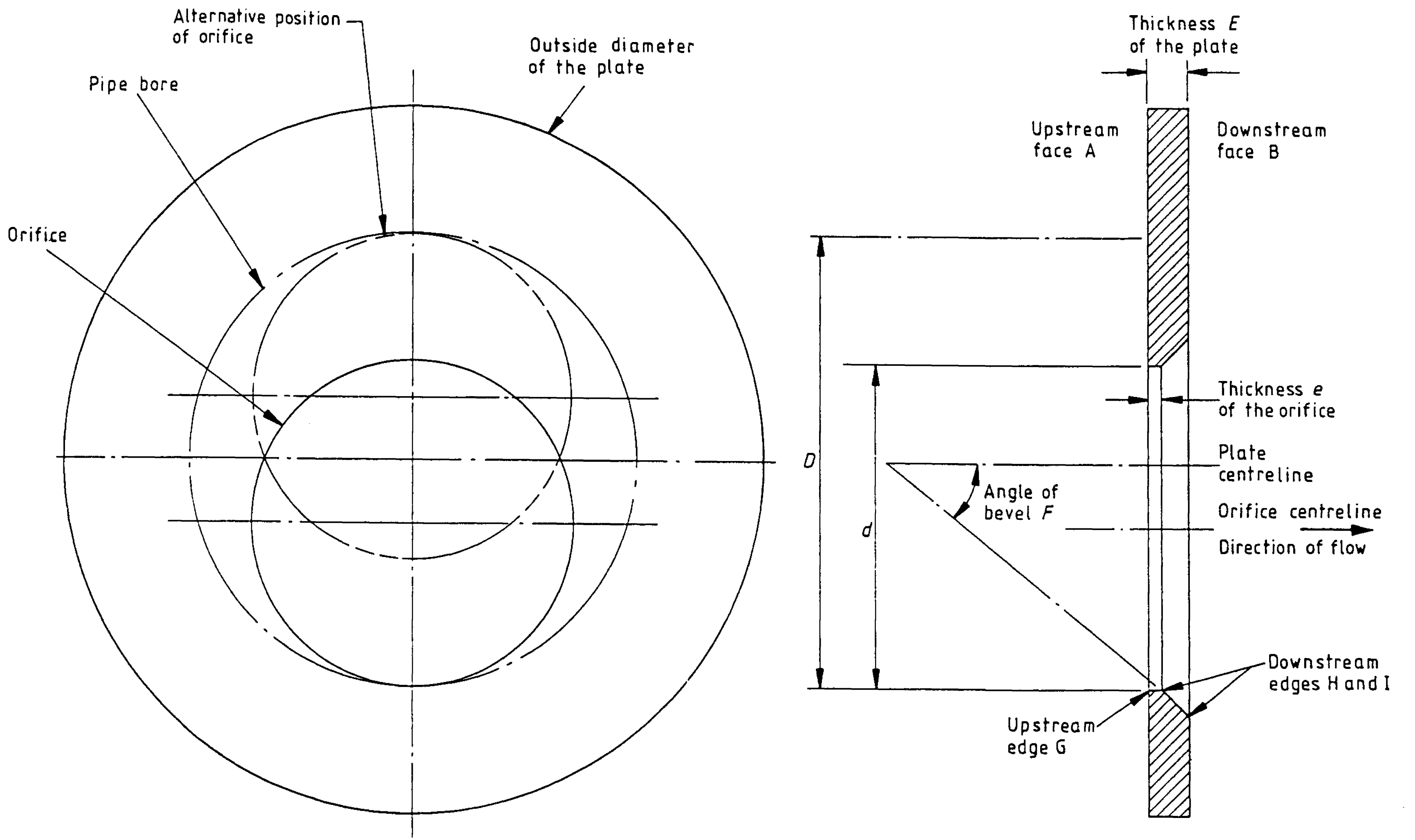

Figure 3 — Eccentric orifice plate

Publications referred to

BS 1042, *Measurement of fluid flow in closed conduits.*

BS 1042-1, *Pressure differential devices.*

BS 1042-1.1, *Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.*

BS 1042-1.4, *Guide to the use of devices specified in Sections 1.1 and 1.2.*

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