

Specification for

Design and manufacture of electric boilers of welded construction

Conception et fabrication des chaudières
électriques de construction soudée —
Spécifications

Bemessung und Herstellung von geschweißten
Elektrokesseln

Committees responsible for this British Standard

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- Associated Offices Technical Committee
- BEAMA Ltd.
- Electricity Supply Industry in the United Kingdom
- Health and Safety Executive
- Heating and Ventilating Contractors' Association
- Institution of Electrical Engineers

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Foreword

This British Standard has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee and supersedes BS 1894 : 1952 which is withdrawn.

The main technical changes from the previous edition are as follows:

- a) this standard now applies to all types of electric boiler but only those of cylindrical design constructed from carbon or carbon manganese steels by fusion welding;
- b) the International System of Units (SI) has been used throughout;
- c) jointing gaskets made from compressed asbestos fibre (CAF) are introduced.

NOTE. The manufacture of all asbestos based products is covered by the requirements of The Control of Asbestos at Work Regulations 1987^[1], introduced on 1 March 1988. These set out comprehensive provisions covering work activities involving exposure to asbestos. Advice on how to comply with these regulations can be obtained from the manufacturers of the material, from the Asbestos Information Centre Ltd., Derby Road, Widnes, Cheshire WH8 9ND, from the local area office of the Health and Safety Executive or from the Environmental Health Department of the Local Authority.

Warning. Breathing asbestos dust is dangerous to health and precautions have to be taken during the manufacture and use of these products.

Particular note has to be taken of The Asbestos Products (Safety) Regulations 1985^[2], made under the Consumer Safety Act 1978^[3] and of The Asbestos (Prohibitions) (Amendment) Regulations 1988^[1]^[4] made under the Health and Safety at Work etc. Act 1974^[5], which prohibit the supply of products containing amosite or crocidolite and set out requirements for the labelling of all products containing asbestos.

All the above legislation implements European Directives.

Product certification. Users of this British Standard are advised to consider the desirability of third party certification of product conformity with this British Standard based on testing and continuing product surveillance which may be coupled with assessment of a supplier's quality systems against the appropriate Part of BS 5750.

Enquiries as to the availability of third party certification schemes are forwarded by BSI to the Association of Certification Bodies. If a third party certification scheme does not already exist, users should consider approaching an appropriate body from the list of Association members.

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

¹⁾Parallel regulations for Northern Ireland came into force on 6 March 1988.

Section 1. General

1.1 Scope

1.1.1 This British Standard specifies requirements for the design and manufacture, including materials, workmanship, inspection, testing, documentation and marking, of boilers utilizing electrical energy by the use of electrodes or immersion elements. The boilers dealt with are of cylindrical design, either horizontal or vertical, constructed from carbon or carbon manganese steels by fusion welding for which the limits of application are given in table 1.1.1.

Table 1.1.1. Limits of application	
Classification	Limit
Class I	Steam and hot water boilers which exceed the limitations specified for class II and class III boilers
Class II	Steam and hot water boilers the design pressure of which does not exceed 1.14 N/mm ² and the design pressure of which (in N/mm ²), multiplied by the internal diameter in millimetres, does not exceed 1450
Class III	Steam boilers the design pressure of which does not exceed 0.23 N/mm ² Unvented hot water boilers the design pressure of which does not exceed 0.45 N/mm ² Vented hot water boilers the design pressure of which does not exceed 0.77 N/mm ²

The standard applies to electric boilers which provide hot water, steam or superheated steam for use in industrial and commercial applications.

NOTE. Notwithstanding the materials quoted above this does not preclude the use of other materials, such as stainless steels or copper, copper linings, etc. (see 2.1) where the boiler otherwise falls within the limits of this specification, taking the allowable stresses from another appropriate specification.

1.1.2 In addition to the definitive requirements, this standard also requires the items detailed in 1.6 to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

1.2 References

1.2.1 Normative references

This British Standard incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on page 95. Subsequent amendments to, or revisions of, any of these publications apply to this standard only when incorporated in it by updating or revision.

1.2.2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

1.3 Definitions

For the purposes of this British Standard, the definitions given in BS 499 : Part 1 : 1991 apply, together with the following.

1.3.1 electric boiler

A boiler for producing steam or hot water by means of electrical energy.

1.3.2 electrode boiler

An electric boiler where the heat is produced by the passage of an alternating current through water.

1.3.3 immersion element boiler

An electric boiler where the heat is produced by an electric resistance element(s) immersed in the water.

1.3.4 electric steam superheater

A pressure vessel fitted with an electric resistance element(s) over which saturated steam flows for producing superheated steam.

NOTE. For the purposes of this specification, it is essential that the design pressure is that of the steam inlet pressure and that the design temperature is that of the superheated steam temperature.

1.3.5 high voltage

A voltage in excess of 1000 V a.c. between phases.

1.3.6 design pressure

- 1) The pressure used in the design calculations.
- 2) The maximum permissible setting of any safety valve fitted on the boiler.

1.3.7 design stress

The stress to be used for the calculation of pressure parts.

NOTE. The detailed design rules in section 3 will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

1.3.8 design temperature

The saturated steam temperature for the design pressure or 150 °C, whichever is the greater.

1.3.9 purchaser

The individual or organization that buys the completed boiler from the manufacturer.

1.3.10 designer

The individual or organization that determines the shape, dimensions and thickness of the boiler, and selects the materials and the details and methods of construction and testing.

1.3.11 manufacturer

The individual or organization that fabricates, or assumes responsibility for the fabrication of, the boiler or any component thereof.

1.3.12 material supplier

The individual or organization, other than a producer, that supplies material or prefabricated standardized parts to be used in the construction of the boiler or any component thereof.

1.3.13 producer of the supplied construction material or material producer

The individual or organization that produces materials for the fabrication of the boiler, for the components or for the prefabricated standardized parts thereof.

1.3.14 Regulating Authority

The authority in the country of installation that is legally charged with the enforcement of the requirements of the laws and regulations of that country relating to boilers.

1.3.15 Inspecting Authority

The independent body or association acting on behalf of:

- a) the purchaser or owner, and/or
- b) the manufacturer, and/or
- c) the Regulating Authority

that checks that the design, materials and construction conform to this standard (see also 7.1).

1.3.16 inspector

A person employed and trained by an Inspecting Authority to carry out the functions of that Inspecting Authority as indicated in 1.3.15 (see also 7.1).

1.4 Responsibilities

1.4.1 Purchaser

The purchaser shall be responsible for furnishing the manufacturer with the information required by 1.6.1 and annex A.

Where the Inspecting Authority is nominated by the purchaser, the purchaser shall be responsible for ensuring that any information which the manufacturer is required to supply, as specified in this standard, is made available to the Inspecting Authority.

Where necessary, it shall be the responsibility of the purchaser to ensure that the Inspecting Authority is acceptable to the Regulating Authority.

NOTE. This should be done at the time of the order.

1.4.2 Manufacturer

Prior to the construction of a boiler or a series of boilers, the manufacturer of the boiler shall supply the Inspecting Authority with a list of materials, calculations for major design details and fully dimensioned sectional drawings showing in full detail the construction of all the pressure parts of the boiler, including weld details (see annex B). The manufacturer is also required to furnish documentation and certificates in accordance with 8.1 and 8.2 and to arrange for the attendance of the Inspecting Authority at the appropriate time. The boiler manufacturer shall supply the purchaser with operating instructions appropriate to the equipment supplied. Where alternative methods of manufacture or testing are permitted by this standard, the manufacturer shall disclose to the purchaser or the Inspecting Authority or both the procedure selected by him before putting the work in hand.

In cases where the design and fabrication functions are carried out by separate organizations, the manufacturer's responsibilities as laid down in this standard shall be discharged in a manner agreed between the parties concerned (see 1.6.2.2 and 8.2).

Examinations carried out by the Inspecting Authority shall not absolve the manufacturer from his responsibility for compliance with the applicable requirements of this standard.

1.4.3 Inspecting Authority

For each Class I and Class II boiler the Inspecting Authority shall be responsible for checking that the design of the boiler conforms to this standard and that all inspections and tests required during the manufacture of the boiler are carried out.

NOTE. Because statutory requirements exist for the in-service examination of all steam boilers it is recommended that steam boilers to Class III are referred to the Inspecting Authority for design approval.

1.5 Terminology and symbols

At appropriate places in this standard, symbols used in the text concerned are defined. In some clauses of section 3 the same symbol is used in different formulae to represent different terms. However, in all such cases the special meaning of each symbol is indicated for each formula.

1.6 Information and requirements to be agreed and to be documented

1.6.1 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser and shall be fully documented (see 1.4.1). Both the definitive requirements specified throughout the standard and the following items a) to f) shall be satisfied before a claim of compliance with the standard can be made and verified.

- a) A specification of the working conditions of the boiler, together with details of any transient and/or adverse conditions under which the boiler is required to operate and of any special requirements for in-service inspection (see 3.1.1, 3.11.1 and annex A).
- b) The name of the Inspecting Authority to be commissioned by the purchaser, if required.
- c) Any additional requirements not given in this standard.
- d) Details of any special statutory or other regulations (e.g. boiler laws in countries other than that of manufacture).
- e) The name of the Regulating Authority (if any).
- f) If verification is required of the elevated temperature properties to be used in the determination of design stress (see 2.3.8).

1.6.2 Requirements to be agreed and documented

1.6.2.1 General

The items listed in 1.6.2.2 and 1.6.2.3 to be agreed, as appropriate, between the parties concerned, which are specified in the clauses referred to, shall be fully documented. Both the definitive requirements specified throughout this standard and the documented items shall be satisfied before a claim of compliance with this standard can be made and verified.

NOTE. Users of this standard should appreciate that a number of items for agreement, i.e. those listed under 1.6.2.3, cannot be agreed/documentated at the time of placing the contract or order for the boiler and do not necessarily apply in every case; they make provisions for individual agreements that could be necessary during the manufacturer's operations to deal with certain practical eventualities (see also 1.4.2). It is important to distinguish these items (1.6.2.3) from that in 1.6.2.2, which does need to be agreed and documented when the contract or order is placed.

1.6.2.2 Requirements to be agreed and documented at the contract or order stage

The manner in which the manufacturer's responsibilities are to be discharged in cases where the design, fabrication and erection functions are carried out by separate organizations shall be agreed and documented (see 1.4.2 and 8.2).

1.6.2.3 Requirements to be agreed and documented during the manufacturer's operations

The following items, as appropriate, shall be agreed and documented (see also 1.4.2).

- a) For pressure parts, the use of materials other than those covered by the standards referred to in tables 2.3(1) and 2.3(2) (see 2.2.2).
- b) The heat treatment condition of plates supplied for forming (see 2.4).
- c) The method of reinforcement of openings (see 3.8.1.3).
- d) The use of an alternative heat treatment to normalizing, after the forming of plates that have been dished or flanged at non-uniform temperatures or have been locally heated (see 4.6).
- e) The requirements for welding consumables, in the absence of a relevant British Standard (see 5.2).
- f) The heat treatment to be applied after the cold forming of welded plates where the inside radius of curvature after forming is less than 10 times the plate thickness (see 5.4.14.5c).
- g) In the event that weld defects in a continuous line are revealed by radiographic examination, whether the defective part of the weld is to be repaired or the entire weld is to be removed and rewelded (see 5.4.15.1).
- h) For parts not formed within the appropriate temperature range, the heat treatments, if other than normalizing, to be carried out before or after welding (see 5.5.4.1).
- i) Acceptance criteria for weld defects in welded joints, other than the main constructional welds of boilers, revealed by visual examination and non-destructive testing (see 5.7.1).

Section 2. Materials

2.1 General

This section deals with the selection of materials and the property values to be used in the determination of design stresses. Where materials other than carbon or carbon manganese steels are used for pressure parts they shall be used only with the express agreement of purchaser, manufacturer, user and Inspection Authority.

2.2 Selection of materials

2.2.1 The materials used in the manufacture of pressure parts shall conform to those materials referred to in tables 2.3(1) or 2.3(2) or with the other appropriate requirements specified in this section.

Welding consumables shall conform to 5.2 of this standard.

Studs, bolts and nuts shall conform to the material specifications listed in tables 3 and 4 of BS 4882 : 1990.

2.2.2 If alternative materials are used for pressure parts it shall be by express agreement between the manufacturer and Inspecting Authority (see 1.6.2.3a) irrespective of the classification of the boiler. In addition:

- a) they shall be of boiler quality;
- b) they shall conform to 2.3 and shall be covered by a written specification at least as comprehensive as the equivalent standard listed in tables 2.3(1) or 2.3(2) as appropriate; and
- c) they shall be of the same type and grade as the equivalent material listed in table 2.3(1) or 2.3(2), as appropriate.

2.2.3 Materials for lugs, brackets, casings and similar non-pressure parts welded to boilers shall be of established identity and shall be compatible with the material to which they are attached.

Table 2.3(1). Values of f for carbon and carbon manganese steels with specified minimum elevated temperature properties

Product form	Reference	Designation	Grade	Thickness or ruling section mm	Values of f at design temperatures shown					
					150 °C	200 °C	250 °C	300 °C	350 °C	400 °C
					N/mm ²	N/mm ²	N/mm ²	N/mm ²	N/mm ²	N/mm ²
Plate	BS 1501 : Part 1 : 1980	151 and 161	400B	≤ 16	133	130	117	97	92	89
				$> 16 \leq 40$	128	123	110	97	92	89
				$> 40 \leq 63$	121	117	108	97	92	89
				$> 63 \leq 100$	113	111	105	97	92	89
		430B	430B	≤ 16	148	143	128	107	102	99
				$> 16 \leq 40$	140	135	121	107	102	99
				$> 40 \leq 63$	133	128	119	107	102	99
				$> 63 \leq 100$	124	121	115	107	102	99
		164	400B	≤ 16	153	137	121	108	101	95
				$> 16 \leq 40$	149	135	121	108	101	95
Pipe	BS 3602 : Part 1 : 1987 and BS 3602 : Part 2 : 1991	HFS, CFS ERW CEW	360	≤ 65	125	117	111	97	87	78
				≤ 16	149	135	120	109	101	
		LAW	430	≤ 40						
				≤ 65	149	135	120	109	101	95
		HFS, CFS ERW CEW	430	≤ 16	165	153	143	131	121	
				≤ 40	194	178	163	148	135	125
		LAW	490	≤ 16						
				≤ 40						
		HFS, CFS	500Nb	≤ 40						
				≤ 100	171	156	142	128	121	115
Forgings	BS 1503 : 1989	164	490E	≤ 100	171	156	142	128	121	115
				≤ 100	125	121	112	100	95	92
				≤ 100	133	129	119	107	102	99
				≤ 100	145	140	129	117	112	108
		221	430E	≤ 100	157	151	140	128	122	118
				≤ 100	138	130	120	106	99	92
				≤ 100	148	139	128	114	107	100
				≤ 100	164	151	140	127	119	111
		223	460E	≤ 100	179	165	152	139	131	123
				≤ 100						
				≤ 100						
				≤ 100						

NOTE. Intermediate values of f are determined by linear interpolation.

Table 2.3(2). Values of f for materials without specified elevated temperature properties

Product form	Reference	Designation	Grade	Thickness or ruling section mm	Values of f at design temperatures shown					
					150 °C	200 °C	250 °C	300 °C	350 °C	400 °C
					N/mm ²	N/mm ²	N/mm ²	N/mm ²	N/mm ²	N/mm ²
Plate	BS 1501 : Part 1 : 1980	151 and 161	400 A	≤ 16	133	130	117	97	92	89
				$> 16 \leq 40$	128	123	110	97	92	89
				$> 40 \leq 63$	121	117	108	97	92	89
				$> 63 \leq 100$	113	111	105	97	92	89
			430 A	≤ 16	148	143	128	107	102	99
				$> 16 \leq 40$	140	135	121	107	102	99
				$> 40 \leq 63$	133	128	119	107	102	99
				$> 63 \leq 100$	124	121	115	107	102	97
		164	400 A	≤ 16	140	125	111	98	91	86
				$> 16 \leq 40$	138	125	111	98	91	86
Pipe	ASTM A 106 : 1989[6] API 5L : 1991[7] BS 3601 : 1987	HFS ERW SAW Carbon $\leq 0.25\%$	B	All						
					135	122	110	99	91	85
		ERW ERW, S ERW, S, SAW	320	≤ 16	108	97	86	77	71	68
				≤ 16	126	111	96	86	79	75
			360	$> 16 \leq 40$	122	109	96	86	79	75
				$> 40 \leq 65$	119	107	96	86	79	75
			430	≤ 16	149	132	115	103	95	89
				$> 16 \leq 40$	146	131	115	103	95	89
Sections and bars	BS 1502 : 1982	151, 161, 211 and 221	430	$> 40 \leq 63$	143	129	115	103	95	89
				$> 63 \leq 100$	124	121	115	107	102	97
Forgings	BS 1503 : 1989	164	490	≤ 100	171	156	142	128	121	115
			221	≤ 100	125	121	112	100	95	92
				≤ 100	133	129	119	107	102	99
				≤ 100	145	140	129	117	112	108
				≤ 100	157	151	140	128	122	118
		223	410	≤ 100	138	130	120	106	99	92
			430	≤ 100	148	139	128	114	107	100
			460	≤ 100	164	151	140	127	119	111
			490	≤ 100	179	165	152	139	131	123

NOTE. Intermediate values of f are determined by linear interpolation.

2.3 Material specifications

2.3.1 For materials other than those listed in tables 2.3(1) and 2.3(2), the general requirements given in 2.3.2 to 2.3.7 shall apply.

Notation

A_t	is the percentage elongation at fracture;
R_e	is the room temperature yield strength determined either as the upper yield strength (R_{eH}) or the 0.5 % proof strength (total extension) ($R_{t0.5}$) (in N/mm ²);
R_{eH}	is the upper yield strength (in N/mm ²);
R_{eL}	is the lower yield strength at elevated temperature (in N/mm ²);
R_m	is the room temperature tensile strength (in N/mm ²);
$R_{p0.2}$	is the 0.2 % proof strength at elevated temperature (in N/mm ²);
$R_{t0.5}$	is the 0.5 % proof strength (total extension) (in N/mm ²);
S_o	is the original cross section of the test piece subjected to a tensile test (in mm ²);
f	is the design stress (in N/mm ²).

2.3.2 The material specification (see 2.2.2) shall specify the steelmaking process, compositional limits for all constituents, deoxidation practice, and heat treatment and appropriate mechanical properties for acceptance and other purposes.

2.3.3 The upper limit of the carbon range in the ladle analysis shall not exceed 0.25 %. The maximum allowable phosphorous and sulfur content shall not exceed 0.05 % each in the ladle analysis.

2.3.4 The deoxidation practice shall be appropriate to the type of steel ordered, particularly where it can influence the level of elevated temperature properties. Fully-killed steel shall be used except in the following circumstances.

- Semi-killed steel may be used for plates and seamless and welded tubes with an upper limit on the specified tensile strength range of 640 N/mm².
- Rimming steel may be used for electric resistance-welded or induction-welded tubes with an upper limit on the specified tensile strength range of 490 N/mm² for design temperatures not exceeding 400 °C.

2.3.5 Mechanical properties at room temperature shall be specified for acceptance tests in accordance with BS EN 10002-1 : 1990 which deal with the following:

Tensile strength, R_m

Yield strength, R_e

Percentage elongation at fracture, A_t

The specified minimum percentage elongation at fracture referred to a gauge length of $5.65\sqrt{S_o}$ shall be appropriate to the type of steel, with a lower limit of 20 %.

2.3.6 The minimum value of the lower yield strength, R_{eL} , or the minimum value of the 0.2 % proof strength $R_{p0.2}$, at the appropriate elevated temperature, related to tests in accordance with BS 3688 : Part 1 : 1963, shall be specified for materials equivalent to those listed in table 2.3(1).

2.3.7 Materials shall be supplied in the heat treated condition required by the equivalent British Standard.

2.3.8 If verification of the property values is required by the purchaser this shall be stated in the enquiry and order (see 1.6.1f).

2.4 Forming of plates

The condition of plates supplied for forming shall be appropriate to the forming process used and shall be agreed between the manufacturer and the material supplier (see 1.6.2.3b).

Section 3. Design

3.1 Design criteria

3.1.1 General

The formulae dealing with the calculation of scantlings shall apply to boilers that are constructed throughout under the conditions required by this standard and that are operated with adequate supervision taking account of the parameters discussed in annex D.

CAUTION. If a risk of abnormal working conditions or environment is foreseen, the scantlings, etc. established by calculation from the given formulae should receive special consideration (see 1.6.1a).

In the case of fully flooded hot water boilers means shall be provided to ensure that air can be removed from the boiler.

3.1.2 Design pressure

The design pressure p is the pressure to be used in the formulae given in this section for the calculation of pressure parts (see 1.3.6).

If applicable, the hydrostatic head and, for fully flooded hot water boilers, the flash margin, shall be taken into consideration when determining the design pressure. The hydrostatic head need not be considered when it is less than 10 % of the boiler working pressure.

There shall be a margin between the actual pressure at which the boiler is to operate and the lowest pressure at which any safety valve is set to lift, to prevent unnecessary lifting of the safety valves.

Safety valves shall be capable of preventing the boiler pressure from increasing to more than 110 % of the design pressure as detailed in annex F.

3.1.3 Design stress

The designer shall determine the design stress f for the material from tables 2.3(1) and 2.3(2).

3.2 Cylindrical shells under internal pressure

3.2.1 Notation

The following notation shall be used.

- C is the corrosion allowance, to be taken as 1.0 mm unless a higher figure is agreed to take account of adverse conditions;
- D is the inside diameter of the shell (in mm);
- e is the minimum shell thickness (in mm);
- f is the design stress (in N/mm²) (see 3.1.3);
- p is the design pressure (in N/mm²);
- R_i is the inside radius of the shell (in mm);
- Z is a stress reduction factor with value as below;
 - 1.0 for Class I boilers or for seamless shells,
 - 0.85 for Class II boilers,
 - 0.65 for Class III boilers.

3.2.2 Minimum thickness for pressure loading only

The minimum thickness for pressure loading only shall be calculated from the following formula, but in no case shall it be less than 6 mm for shells having an outside diameter greater than 1000 mm; or less than 4 mm for shells having an outside diameter equal to or less than 1000 mm; or less than 2.5 mm for shells having an outside diameter equal to or less than 350 mm.

$$e = \frac{pR_i}{fZ - 0.5p} + C \quad (1)$$

Where set-in end plates are used (as in figure B.2(15) a) to e) inclusive) the thickness of the shell plate within a distance of 250 mm of the end plate shall be the greater of e obtained from the above formula and e_1 obtained from the following formula:

$$e_1 = e_{cs} + C \quad (2)$$

where

$$e_{cs} = \frac{pR_i}{fX - 0.5p} \quad (3)$$

where

X is a factor found from the following:

X	Ratio e_{cp}/e_{cs}
0.8	≥ 1.4
1.0	≤ 1.0

e_{cp} is the thickness of end plate at the junction with the shell (in mm).

For intermediate values of e_{cp}/e_{cs} the values of X shall be found by linear interpolation.

3.2.3 Applicability of the formulae in 3.2.2

The formulae given in 3.2.2 shall apply only if the following conditions are fulfilled.

- a) The ratio of the outside radius to the inside radius does not exceed 1.5.
- b) In the case of welded shells, the mid-thickness lines are an extension of each other at each longitudinal joint.

Deviations of alignment due to manufacturing imperfections shall not exceed the values indicated in 5.4.9 and 5.4.10.

- c) In the calculation of the thickness of cylindrical shells, stresses due to out-of-roundness up to the maximum limits indicated below need not be taken into consideration, and cylindrical shells shall conform to the tolerances given in 4.4.2.

1.5 % for a ratio of $e/D < 0.01$,

1 % for a ratio of $e/D \geq 0.01$.

3.2.4 Additional loads

No combination of stresses due to loads on the boiler shell shall exceed the limits given in table 2.3(1) or 2.3(2).

3.2.5 Boiler supports

3.2.5.1 Leg supports

If boilers are supported on legs, the shell thickness shall be calculated using a stress reduction factor not greater than 0.65. The calculated stresses in the shell, as a result of the leg supports, shall be not greater than the design value given in table 2.3(1) or 2.3(2).

In calculating the stresses all boilers shall be considered fully flooded at the design temperature which shall be not less than 150 °C.

3.2.5.2 Saddle supports

3.2.5.2.1 General

When boilers are supported on saddles, the subtended angle θ (see figure 3.2.5.2a) shall be not less than 60° for boilers with a shell outside diameter of less than 1500 mm and not less than 90° for boilers with a shell outside diameter equal to or greater than 1500 mm.

When θ is less than 90° in boilers with a shell outside diameter less than 1500 mm the shell thickness shall be calculated using a stress reduction factor not greater than 0.65 (see 3.2.1).

When boilers with a shell outside diameter equal to or greater than 1500 mm are supported on saddles the circumferential combined stress in the shell shall be in accordance with the requirements in 3.2.5.2.2 and 3.2.5.2.3.

In calculating the stresses all boilers shall be considered fully flooded at the design temperature which shall be not less than 150 °C.

3.2.5.2.2 Notation

The following notation shall be used. (See figure 3.2.5.2.)

- A is the distance from boiler end plate to centre of saddle (in mm);
- B is the width of saddle top plate (in mm) ($\geq 10e$);
- e is the nominal shell thickness minus corrosion allowance (in mm);
- k is the coefficient obtained from figure 3.2.5.2b;
- L is the length of boiler shell between end plates (in mm);
- p is the boiler design pressure (in N/mm²);
- Q is the force on saddle (in N);
- R is the mean radius of the cylindrical shell (in mm);
- θ is the angle subtended at the shell axis by the horns of the saddle (in degrees).

3.2.5.2.3 Determination of circumferential combined stress

The circumferential combined stress, σ , due to primary general membrane stress plus primary local membrane stress plus primary bending stress at the inner surface of the shell, obtained from the following shall not exceed 1.5 f .

If $\frac{L}{R} > 8$,

$$\text{then } \sigma = \frac{pR}{e} - \frac{Q}{4e(B + 10e)} + \frac{1.5kQ}{e^2} \quad (4)$$

If $\frac{L}{R} \leq 8$,

$$\text{then } \sigma = \frac{pR}{e} - \frac{Q}{4e(B + 10e)} + \frac{12kQR}{Le^2} \quad (5)$$

3.3 Dished and flanged ends

3.3.1 Notation

The following notation shall be used.

- D_o is the outside diameter of the end plate (in mm);
- e is the thickness of the end plate (in mm);
- H is the external height of dishing (in mm);
- r_i is the internal corner radius (in mm);
- R_i is the internal radius of dishing (in mm).

3.3.2 Torispherical, semi-ellipsoidal and hemispherical unstayed ends, dished from plate, having pressure on the concave side

3.3.2.1 Torispherical ends

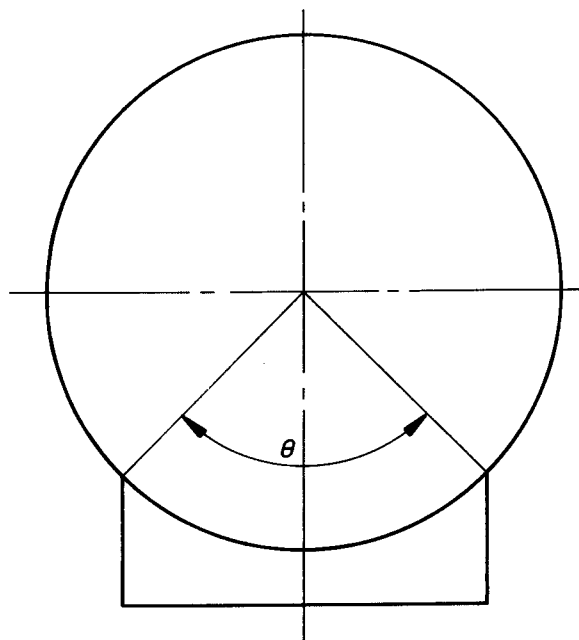
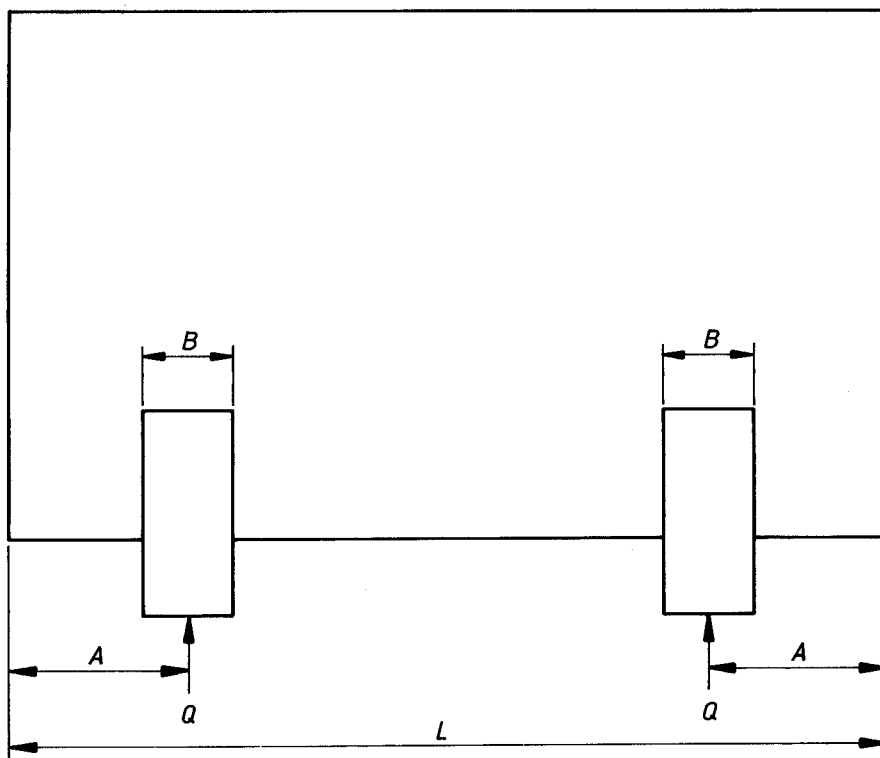
Torispherical ends shall conform to the following dimensional relationships (see figure 3.3(1)a):

$$\begin{aligned} 0.005 D_o &\leq e \leq 0.08 D_o \\ R_i &\leq D_o \\ r_i &\geq 0.1 D_o \\ r_i &\geq 2e \\ H &\geq 0.18 D_o \end{aligned}$$

3.3.2.2 Semi-ellipsoidal ends

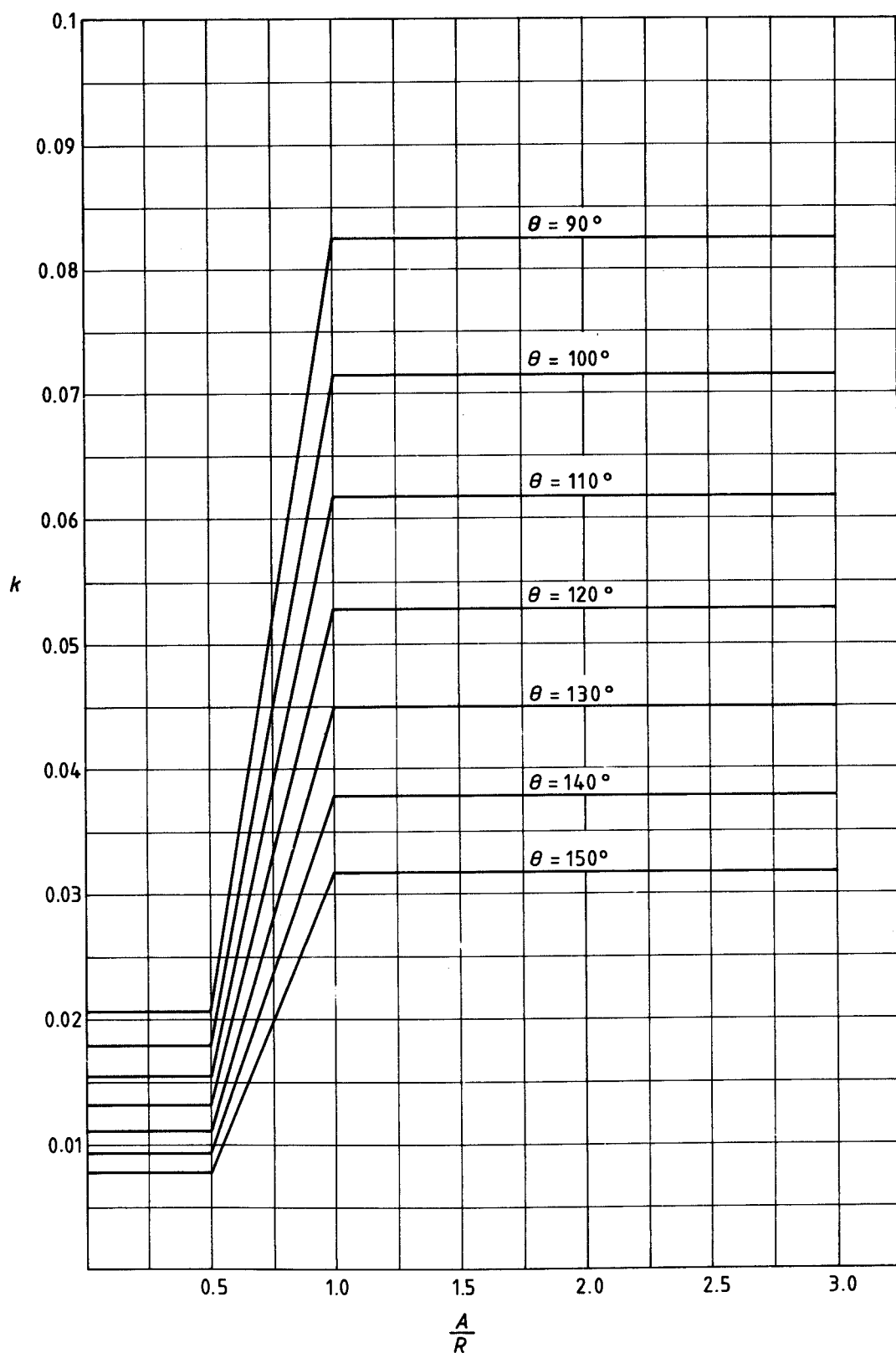
Semi-ellipsoidal ends shall conform to the following dimensional relationships (see figure 3.3(1)b):

$$\begin{aligned} 0.005 D_o &\leq e \leq 0.08 D_o \\ H &\geq 0.18 D_o \end{aligned}$$



a) Explanation of notation

Figure 3.2.5.2. Design of saddle supports



b) Evaluation of coefficient k

Figure 3.2.5.2. Design of saddle supports (concluded)

3.3.2.3 Hemispherical ends

Hemispherical ends shall conform to the following dimensional relationship:

$$0.005 D_o \leq e \leq 0.16 D_o$$

3.3.3 Thickness

3.3.3.1 The following notation shall be used.

Notation

- C* is the corrosion allowance to be taken as 1.0 mm unless a higher figure is agreed to take account of adverse conditions;
e is the thickness of the end plate, after dishing (in mm);
f is the design stress (in N/mm²) (see 3.1.3);
K is the shape factor (see 3.3.3.3);
p is the design pressure (in N/mm²).

3.3.3.2 Subject to the limitations given in 3.3.2 the thickness of any of the three forms of end shall be calculated from the following formula:

$$e = \frac{pD_oK}{2f} + C \quad (6)$$

The minimum thickness *e* shall in no circumstances be less than 6.0 mm for boilers with a shell with outside diameter greater than 1000 mm; or less than 4 mm for a shell with outside diameter equal to or less than 1000 mm; or less than 2.5 mm for a shell with outside diameter equal to or less than 350 mm.

3.3.3.3 The shape factor *K* used in 3.3.3.2 shall be obtained from the series of curves in figure 3.3(2) and depends on the ratio of height to diameter *H/D_o*.

The curve drawn with a full line in the series provides the factor *K* for plain (i.e. unpierced) ends. Where the value of *H/D_o* is lower than 0.25 the value of *K* depends on the ratio of thickness to diameter *e/D_o* as well as on the ratio *H/D_o* and a trial calculation could be necessary to arrive at the correct value of *K*.

3.3.4 Openings in dished ends

3.3.4.1 Notation

The following notation shall be used. (See figures 3.3(3) and 3.3(4).)

- A* is the effective cross-sectional area of reinforcement (in mm²) (twice the area shown shaded in figure 3.3(4));
d is the diameter of the largest opening in the end plate (in mm) (see figure 3.3(3)) (in the case of an elliptical opening, the major axis of the ellipse);
d₁ is the diameter of the smaller hole in figure 3.3(3) (in mm);
d_o is the internal diameter of the reinforcing ring (in mm) (see figure 3.3(4));
D_o is the outside diameter of the dished end (in mm);
e is the actual thickness of the end plate (in mm);
l₁ is the effective width of the reinforcement (in mm) (see figure 3.3(4));
l₂ is the effective length of the reinforcing ring (in mm) (see figure 3.3(4));
l_t is the actual thickness of the reinforcing ring (in mm);
r_m is the radius of flanging of the flanged openings (in mm);
R_i is the internal radius of the spherical part of a torispherical end (in mm), or for an ellipsoidal end, the internal radius of the meridian of the ellipse at the centre of the opening (in mm).

3.3.4.2 Unreinforced openings

3.3.4.2.1 Openings in dished ends may be circular or approximately elliptical. The curves drawn with broken lines in figure 3.3(2) provide values of *K* to be used in 3.3.3.2 for ends with unreinforced openings (e.g. manholes or tube holes). The selection of the correct curve depends on the value of $d\sqrt{(D_o e)}$.

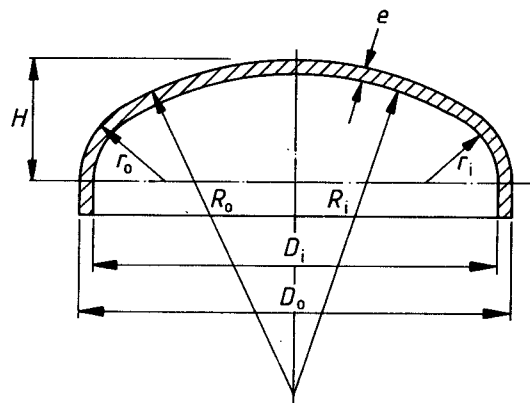
Trial calculation is necessary in order to select the correct curve. The following requirements shall be satisfied in all cases.

$$\frac{e}{D_o} \quad \text{shall not exceed } 0.1,$$

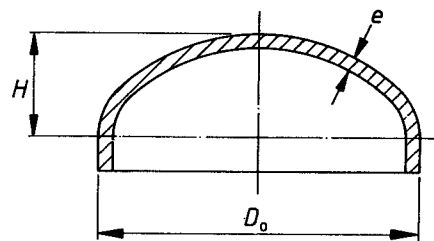
$$\frac{d}{D_o} \quad \text{shall not exceed } 0.5.$$

NOTE. It will be seen from figure 3.3(2) that for any selected ratio of *H/D_o* the curve for unpierced ends indicates a value for $d\sqrt{(D_o e)}$ as well as a value for *K*.

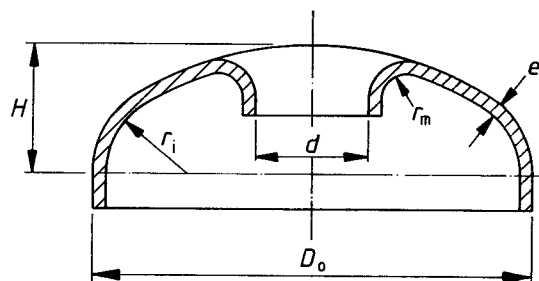
Holes giving a value of $d\sqrt{(D_o e)}$ not greater than the value so obtained may thus be cut in an end designed to be unpierced without any increase in thickness.



a) Torispherical end



b) Semi-ellipsoidal end



c) End with manhole (semi-ellipsoidal or torispherical)

Figure 3.3(1). Typical dished ends

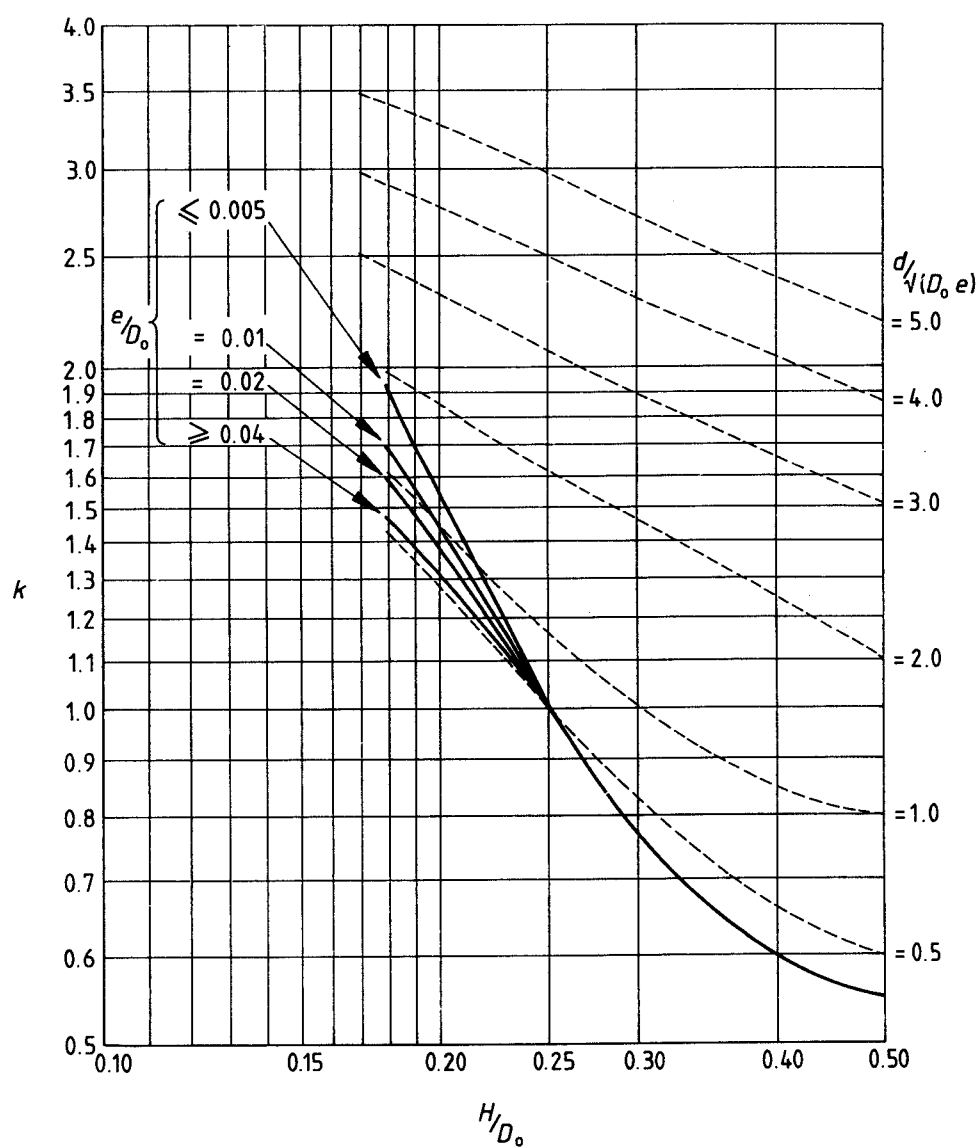
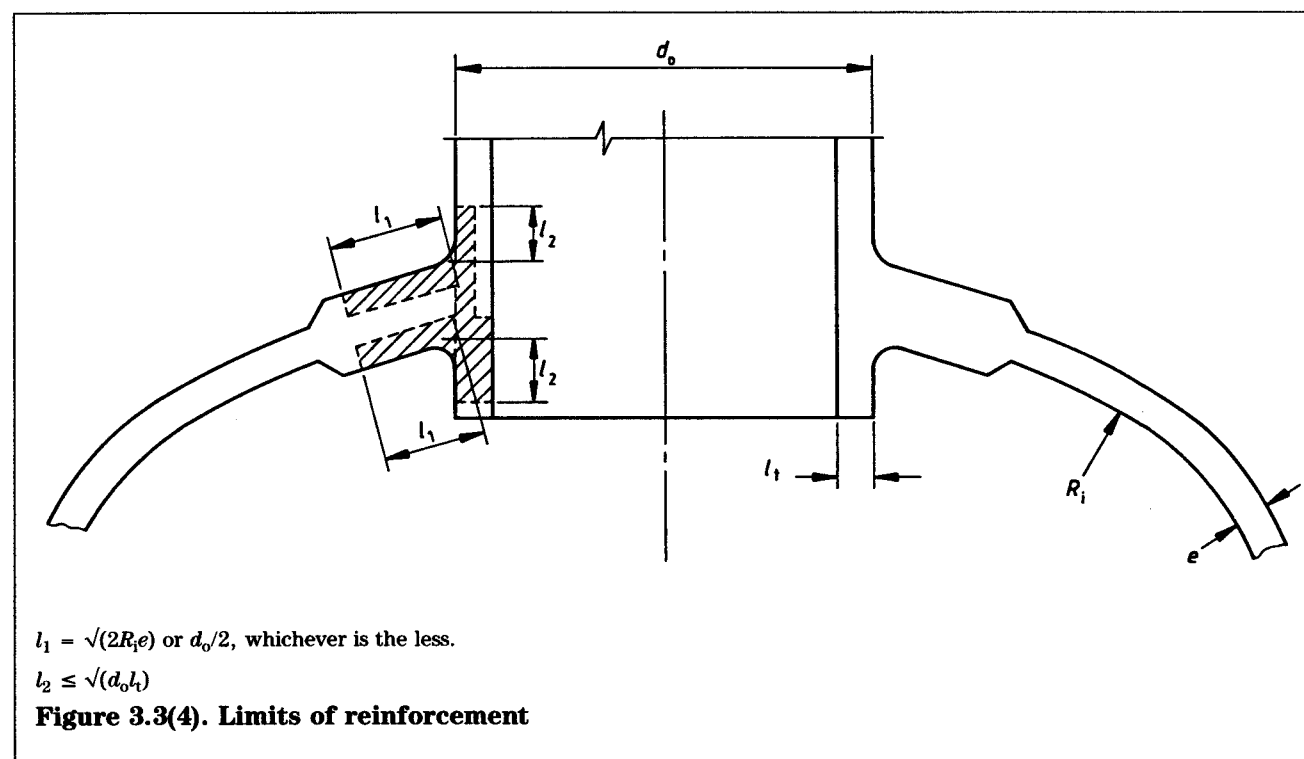
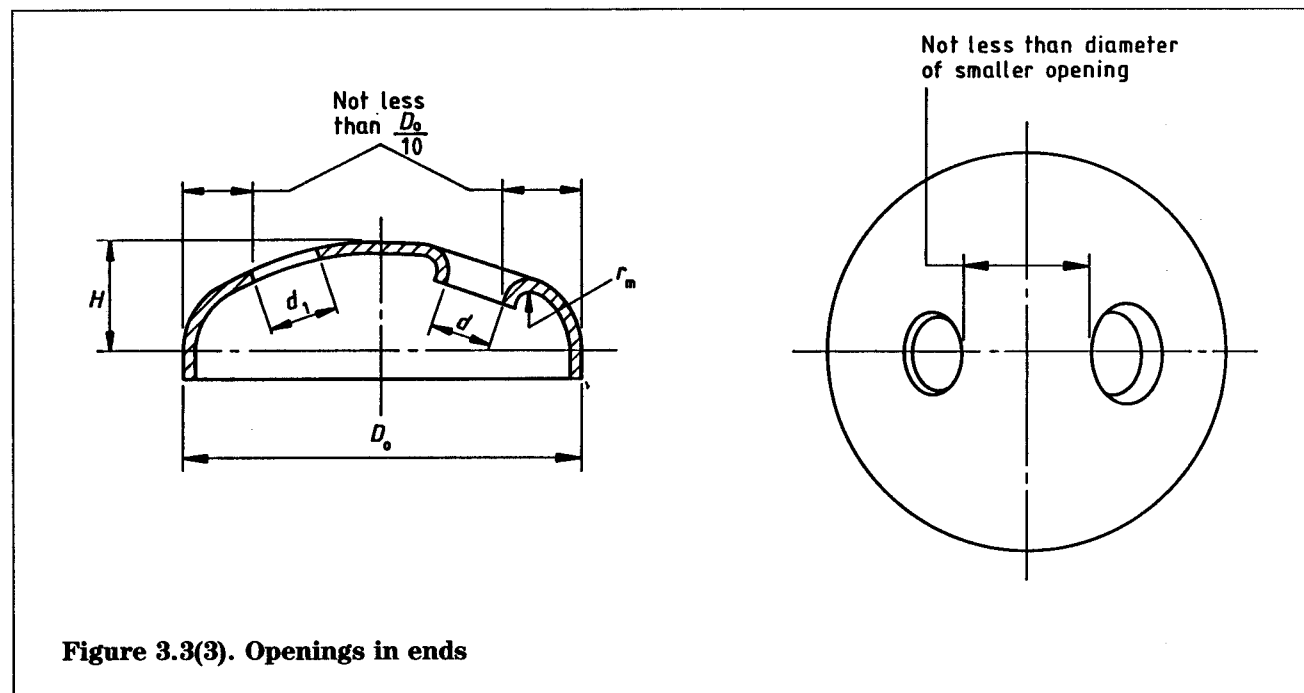


Figure 3.3(2). Shape factor



3.3.4.2.2 The requirements in 3.3.4.2.1 shall apply equally to flanged openings and to unflanged openings simply cut in the plate of an end. No reduction shall be made in end plate thickness on account of flanging.

If openings are flanged the radius r_m of the flanging shall be not less than 25 mm (see figures 3.3(1) and 3.3(3)).

3.3.4.2.3 Unreinforced and flanged openings in dished ends shall be so arranged that the distance from the edge of the hole to the outside edge of the plate and the distance between openings are not less than those shown in figure 3.3(3).

3.3.4.3 Reinforced openings

Where it is desired to use a large opening on a dished end of less thickness than would be required by the application described in 3.3.4.2.1, reinforcement of the end shall be provided. Reinforcement may consist of a ring or standpipe welded into the hole, or of reinforcing plates welded to the outside and/or the inside of the end plate in the region of the hole (see figure 3.3(4)) or a combination of both methods.

Account shall only be taken of added reinforcing material as effective reinforcement up to the following limits:

- the effective width l_1 of reinforcement shall not exceed $\sqrt{(2R_1e)}$ or $d_o/2$, whichever is the less;
- the effective length l_2 of a reinforcing ring shall not exceed $d_o l_t$.

The dimensions l_1 and l_2 are shown in figure 3.3(4).

The shape factor K for a dished end having a reinforced opening can be read from figure 3.3(2) by substituting

$$d_o - \frac{A}{e} \text{ for } \frac{d}{\sqrt{(D_o e)}}$$

The shaded area shown in figure 3.3(4) shall be calculated as follows:

- calculate the sectional area of reinforcement both inside and outside the end plate within the length l_1 ;
- add to it the full sectional area of that part of the stem of the nozzle which projects inside the end plate up to the distance l_2 ;
- add to it the full sectional area of that part of the stem of the nozzle which projects outside the internal surface of the end plate up to the distance l_2 and deduct from it the sectional area which the stem would have if its thickness were calculated in accordance with equation 21.

If the material of the ring or of the reinforcing plates has an allowable stress lower than that of the end plate, then the effective cross section A has to be reduced below that calculated in proportion to the difference in the allowable stresses for the materials. As in 3.3.4.2, trial calculation is necessary in order to select the correct curve.

No allowance shall be made for the additional strength of material having a higher stress value than that in the end plate.

3.4 Welded flat ends

3.4.1 Unpierced flat ends

The minimum thickness t_e (in mm) of an unstayed flat end without opening shall be

$$t_e = 0.41 d_i \sqrt{\left(\frac{p}{f}\right)} + C \quad (7)$$

where

- C is the corrosion allowance, to be taken as 1.0 mm unless a higher figure is agreed to take account of adverse conditions;
- d_i is the internal diameter of the cylindrical shell (in mm);
- p is the design pressure (in N/mm²);
- f is the design stress (in N/mm²).

3.4.2 Pierced flat ends

Where the flat end plates are pierced concentrically or eccentrically, the thickness required by 3.4.1 shall be increased by 15 %. Any eccentrically positioned hole shall not encroach into the attachment weld.

3.5 Bolted flat ends

3.5.1 Pierced and bolted flat circular ends and flanges

3.5.1.1 Notation

The following notation shall be used.

A_b	is the bolt stress area from data given in BS 4882 : 1990 (in mm ²);
A_m	is the required total cross-sectional area of bolts ($A_m = W_{m1}/S_b$) (in mm ²);
C	is the corrosion allowance to be taken as 1.0 mm unless a higher figure is agreed to take account of adverse conditions;
D	is the diameter of bolt circle (in mm);
d	is the diameter of bolts (not less than 16) (in mm);
d_b	is the diameter of bolt hole (in mm)

where

$$d_b = d + 2 \text{ for bolts M16 to M24 or } \\ d + 3 \text{ for bolts M27 to M45 or } \\ d + 4 \text{ for bolts M52 and above;}$$

d_h	is the mean effective diameter of holes after allowing for any serrations, counter-boring or recessing (in mm) and shall be less than $0.5D$;
D_o	is the diameter of outer hole limit circle (in mm);
e_1	is the calculated flat end thickness derived from operating considerations (in mm);
e_2	is the calculated flat end thickness of area within D_o (in mm);
f	is the design stress at design temperature (in N/mm ²);
G	is the mean diameter of contact face (in mm);
h_g	$= \frac{D - G}{2}$;

N	is the number of bolts (not less than A_m/A_b);
n	is the gasket seating width (in mm);
p	is the design pressure (in N/mm ²);
S	is the pitch of holes within D_o (in mm);
S_a	is the bolt stress at atmospheric temperature (in N/mm ²);
S_b	is the bolt stress at design temperature (in N/mm ²);
T	is the flat end thickness (in mm);
t	is the flange thickness (in mm);
W	is the flange design bolt load ($W = NS_a A_b$) (in N);
W_{m1}	is the minimum required bolt load for operating conditions ($W_{m1} = Gp(7n + 0.785G)$) (in N);
μ	is the ligament efficiency ($\mu = (S - d_h)/S$).

3.5.1.2 Thickness

The thickness of pierced and bolted flat circular ends and flanges shall be calculated from the following formulae. The formulae are applicable when:

- the jointing gasket is made from compressed asbestos fibre (CAF) to BS 1832 : 1991 grade A or B;
- the thickness of the jointing gasket is 3 mm;
- d_h is less than $0.5D$;
- the flange is welded as in figure B.2(14).

NOTE. Special precautions should be taken when asbestos or components containing asbestos are used (see foreword).

Where the above conditions cannot be met or where it is desired to make a more detailed analysis of the design, the pierced and bolted flat circular ends and/or flanges shall be calculated in accordance with BS 5500 : 1991.

1) With full face gasket:

$$e_1 = 0.41D \sqrt{\left(\frac{p}{f}\right)} \quad (8)$$

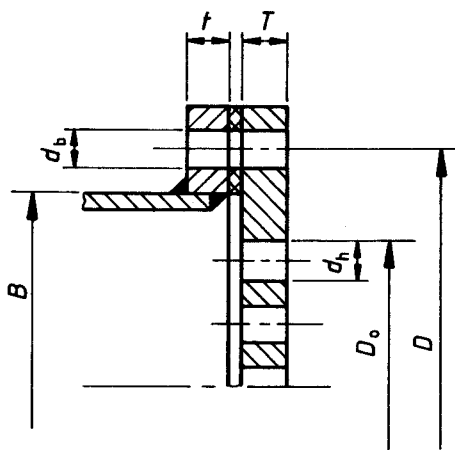
$$e_2 = 0.433D_o \sqrt{\left(\frac{p}{2\mu f}\right)} \quad (9)$$

T is the greater of $e_1 + C$ or $e_2 + C$ for multiple holes, or

$T = e_1 + C$ for single hole where $d_h \leq 0.1D$, or

$T = 1.15e_1 + C$, for single hole where $0.1D < d_h < 0.5D$

$$t = e_1 \sqrt{\left(1 + \frac{B}{D}\right)} \quad (10)$$



2) With gasket entirely within the bolt circle:

$$e_1 = \sqrt{\left(\frac{0.3G^2p}{f} + \frac{1.909Wh_g}{Gf}\right)} \quad (11)$$

$$e_2 = 0.433D_o \sqrt{\left(\frac{p}{2\mu f}\right)} \quad (12)$$

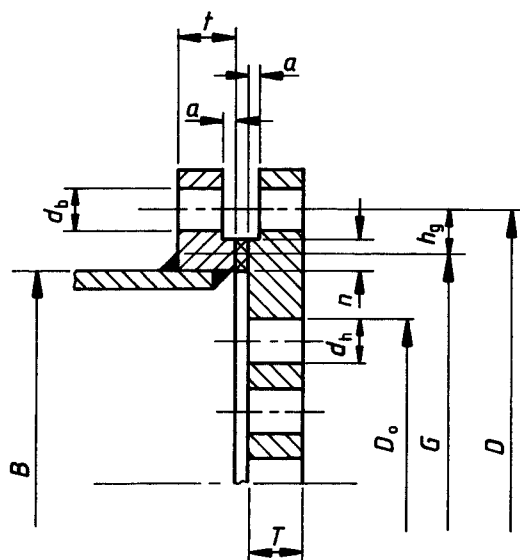
T is the greater of $e_1 + C$ or $e_2 + C$ for multiple holes, or

$T = e_1 + C$ for single hole where $d_h \leq 0.1D$, or

$T = 1.15e_1 + C$ for single hole where $0.1D < d_h < 0.5D$

$$t = e_1 \sqrt{\left(1 + \frac{B}{D}\right)} \quad (13)$$

a is max. 2 mm for nominal sizes up to DN32; or
max. 3 mm for nominal sizes DN40 to DN250; or
max. 4 mm for nominal sizes DN300 to DN500; or
max. 5 mm for nominal sizes DN600 and above.



3.5.1.3 Bolt pitch

The bolt pitch shall be not greater than six times the diameter of the bolt or stud.

3.6 Stayed flat ends

3.6.1 Flat plate margin

The width of the margin M (in mm), giving support in relief of the stay(s) may be attributed to the shell to which flat plate(s) are attached, and shall not exceed that determined by the following equation:

$$M = \frac{K(e - 1.0)}{\sqrt{p}} \quad (14)$$

where

- e is the thickness of plate (in mm);
- K = 9.8 for seal welded plates or 7.45 for plates without a seal weld;
- p is the design pressure (in N/mm²).

3.6.2 Thickness of plate

The thickness e (in mm) of the portion of the flat plate supported by the stay(s) shall be determined by the following equation:

$$e = Kdy \sqrt{\left(\frac{p}{f}\right)} + C \quad (15)$$

where

- C is the corrosion allowance to be taken as 1.0 mm unless a higher figure is agreed to take account of adverse conditions;
- d is the diameter of a circle drawn between the inside of the shell and the stay(s)/centre(s) (in mm);
- f is the design stress (in N/mm²);
- K is the average support constant from table 3.6.2;
- p is the design pressure (in N/mm²);
- y = 1.1 for a three point support (i.e. two stay bars) or 1.56 for a two point support (i.e. one stay bar);

Table 3.6.2 Thickness of plate-support constant

Form of support	Constant (K)
Stay bar	0.39
Flat end attachment to shell with seal weld and end plate thickness divided by shell thickness	
≤ 1.4	0.33
> 1.4 ≤ 1.6	0.36
> 1.6 ≤ 1.8	0.39
> 1.8	0.42
Flat end attachment to shell without seal weld	0.45

3.6.3 Pierced stayed flat ends

Where the stayed flat end plates are pierced concentrically or eccentrically, the thickness required by 3.6.2 shall be increased by 15 %. Holes shall not encroach into the attachment welds or staybar welds.

3.6.4 Staybars for flat ends

The permissible stress in the stay(s) calculated on the net cross-sectional area determined from the nominal diameter without allowance for the minus manufacturing tolerance shall not exceed 70 N/mm². The nominal diameter of any stay shall be not less than 20 mm.

3.7 Flanges

Flanges for flat ends shall be in accordance with BS 10 : 1962, BS 1560 : Section 3.1 : 1989 or BS 4504 : Section 3.1 : 1989 or as calculated in accordance with 3.5.1.

3.8 Openings in cylindrical shells

3.8.1 Design of an isolated opening

3.8.1.1 Notation

The following notation shall be used.

- A* see figure 3.8.1.3;
- B* see figure 3.8.1.3;
- C* see figure 3.8.1.3;
- d* is the bore of the opening (see figure 3.8.1.3) or, in the case of non-circular openings, *d* shall be taken to be the corresponding dimension of the major axis of the opening, except in that case in the ratio d/D_o in 3.8.1.2 and 3.8.1.3, *d* shall be taken as the corresponding dimension of the opening parallel to the longitudinal axis of the shell (in mm);
- D_o is the outside diameter of the shell (in mm);
- e* is the actual thickness of the shell (in mm);
- e_a is the actual thickness of the branch wall (in mm);
- e_r is the actual thickness of added reinforcement on the outside of the shell (in mm);
- f* is the design stress (in N/mm²) (see 3.1.3);
- H* see figure 3.8.1.3;
- p* is the design pressure (in N/mm²);
- X* see figure 3.8.1.3;
- Y* see figure 3.8.1.3.

3.8.1.2 Unreinforced openings

No reinforcement is required if the following relation obtains.

$$\frac{d}{D_o} \sqrt{\left(\frac{D_o}{2e}\right)} \leq 0.1$$

3.8.1.3 Reinforced openings

Openings larger than those permitted by 3.8.1.2 shall be reinforced, but in no case shall the ratio d/D_o be greater than 0.3 unless designed in accordance with the requirements for compensation of openings. Wherever practicable, reinforcement shall be achieved by taking account of the cross-sectional area of locally disposed material, including the attachment weld(s), in excess of the minimal requirements for plate and branch thickness as shown in figure 3.8.1.3, the branch thickness being increased where required. Compensation shall be considered adequate when the compensating area *Y* (see figure 3.8.1.3) is equal to or greater than the area *X* requiring compensation.

Area *X* shall be calculated as the product of the inside radius of the branch and the thickness *A* which would be required for the shell if it were

entirely unpierced by tubes or other holes and determined in accordance with the formula given in 3.2.2, taking *Z* equal to 1.0, disregarding the minimum thickness required by 3.2.2.

Area *Y* shall be measured in a plane through the axis of the branch parallel to the longitudinal axis of the shell and shall be calculated as follows.

a) For that part of the branch which projects outside the shell, calculate the full sectional area of the stem up to a distance *C* from the actual outer surface of the shell plate and deduct from it the sectional area which the stem would have if its thickness were calculated in accordance with the formula given in 3.2.2, taking *Z* = 1.0, disregarding the minimum thickness required by 3.2.2;

b) add to it the full sectional area of that part of the stem which projects inside the shell up to a distance *C* from the inside surface of the shell;

c) add to it the sectional area of the fillet welds on both sides of the shell;

d) add to it the area obtained by multiplying the difference between the actual shell thickness and the unpierced shell thickness *A* by the length *H*.

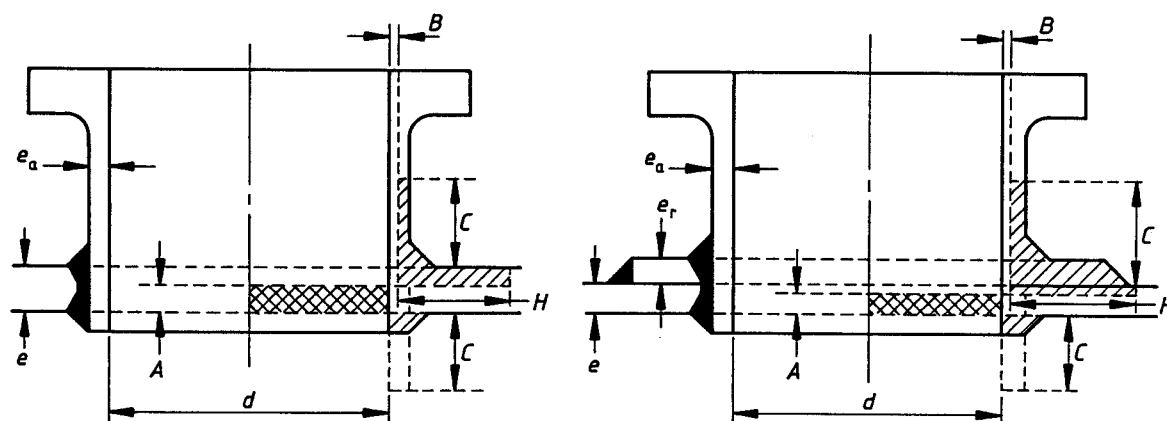
If achievement of an adequate area *Y* is not practicable using the above method, additional reinforcement shall be provided in accordance with any of the typical arrangements shown in figures B.2(9) or B.2(10) or by using an alternative method mutually agreed between the purchaser, the manufacturer and the Inspecting Authority (see 1.6.2.3c). In this case the sectional area of the additional reinforcement and its attachment welds shall be taken into account within the confines of dimensions *C* and *H*, *C* and *H* being as shown in figure 3.8.1.3.

If material having a lower allowable stress than that of the shell is used for compensation, its effective area shall be assumed to be reduced in the ratio of the allowable stress at the design temperature. No allowance shall be made for the additional strength of material having a higher stress value than that in the shell.

Welds attaching branches and reinforcing plates shall be of sufficient dimensions to transmit the full strength of the reinforcing area and all other loadings to which they could be subjected.

In the case of manholes, handholes or openings not fitted with branches attached by welding, the foregoing method shall apply, but the radius used to determine *X* shall be replaced by half the maximum width of the opening in the shell on the axis under consideration.

NOTE. Reinforcements designed in accordance with these requirements will always be adequate but can sometimes be greater than necessary because of the simplified nature of the design calculations. In special cases, an alternative design method based on more detailed analyses may be employed by agreement between the manufacturer, the purchaser and the Inspecting Authority.



All dimensions are in millimetres.

a) Welded branch

b) Welded branch with compensating plate

A is the thickness calculated in accordance with the formula given in 3.2.2 taking Z equal to 1.0 and disregarding the minimum thickness required by 3.2.2.

B is the thickness of the branch calculated in accordance with the formula given in 3.2.2 taking Z equal to 1.0 and disregarding the minimum thickness required by 3.2.2.

C is the smaller of the two values: $2.5e$ or $(2.5e_a + e_r)$.

H is the greater of the two values: $(e + 75 \text{ mm})$ or $d/2$.

X is the area requiring compensation, denoted by $\times\times\times\times$

Y is the compensating area, denoted by $////$

NOTE. e_r is to be equal to zero when there is no compensating plate on the side of the shell under consideration.

Figure 3.8.1.3. Compensation of welded branch up to one-third of the diameter of the boiler shell

3.8.2 Design of groups of openings and branch connections

3.8.2.1 Notation

The following notation shall be used.

A_n	are cross-sectional areas used in calculating compensation for adjacent branches (in mm ²) (see figure 3.8.2(2));
A_s	
A_{e_b}	
C	is a factor applied to e_r / e ;
D	is the mean diameter of cylindrical section of the shell, or in the case of dished and flanged ends $D = 2 R_i + e$ where R_i and e are as defined in 3.3.4.1 (in mm);
d	is the bore of opening not provided with branch, or mean diameter of branch; in the case of non-circular openings, the average of the two opening axes or the two mean axes (in mm);
d_A	is the average value of d for any two adjacent openings being considered (in mm);
e	is the shell or end thickness as calculated by the equation for pressure loading only in 3.3.3.2 for plain spherical or cylindrical shell or end section (in mm);
e_a	is the actual thickness of the shell or end (in mm);
e_r	is the total thickness of the shell or end as required by 3.2.2 or 3.4.1 (in mm);
e_m	is the modified thickness of shell inclusive of compensation (in mm);
e_b	is the branch thickness calculated using branch design stress by equations for pressure loading only where $Z = 1$ in 3.2.2 for a plain cylinder (in mm);
e_{b_a}	is the actual thickness of the branch wall (in mm);
g	is the arrangement factor from figure 3.8.2(1);
H	see figure 3.8.1.3;
K	is the compensation ratio;
P	is the pitch measured between centre lines of two openings along mid-thickness of shell or end (in mm).

3.8.2.2 Calculations

The following calculations shall be carried out.

a) Openings or branch connections are defined as a group where the shortest distance (measured along the mid-thickness line) between the bores of any two is less than $3\sqrt{(De)}$.

b) Calculate reinforcement required as for the isolated case assuming that the full width H is available.

c) Where the shortest distance (measured along the mid-thickness line) between the bores of adjacent openings is less than $2\sqrt{(De)}$, the reinforcement calculated in b) shall be increased if required so that, for each ligament (see figure 3.8.2(2)), $A_s + A_n - A_{e_b} \geq gPe$.

d) Where the shortest distance, s , (measured along the mid-thickness line) between the bores of adjacent openings lies between $2\sqrt{(De)}$ and $3\sqrt{(De)}$, the reinforcement required shall be determined by linear interpolation as follows, using the dimensions determined in b).

1) Calculate the compensation ratio K_1 using the reinforcement required in b):

$$K_1 = \frac{A_s + A_n - A_{e_b}}{ge\{d_A + 3\sqrt{(De)}\}} \quad (16)$$

2) Calculate the compensation ratio K_2 required at the actual pitch P from:

$$K_2 = 1 - (1 - K_1) \frac{\{s - 2\sqrt{(De)}\}}{\sqrt{(De)}} \quad (17)$$

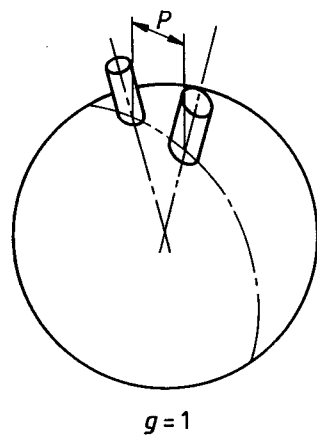
NOTE. If K_1 calculated from equation 16 is greater than unity use $K_1 = 1$ in this equation.

3) Increase the dimensions calculated in b) if required so that, for each ligament:

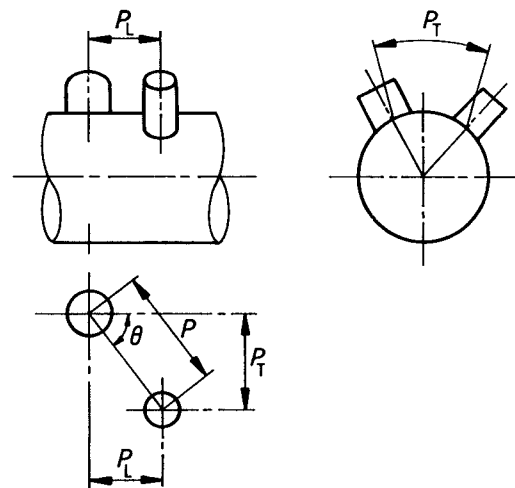
$$A_s + A_n - A_{e_b} \geq K_2 g P e$$

e) The final thickness of the branch, in millimetres, shall be less than $(2 - d/D)e_r$.

f) The transitions between sections of shell or between sections of branch or nozzle connections of different thickness shall be achieved by means of a smooth taper.



a) Spherical vessels



b) Cylindrical vessels

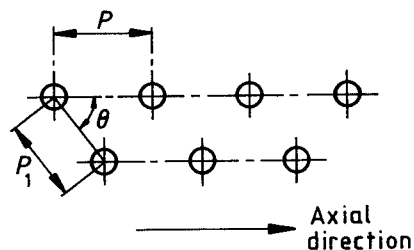
$$g = (1 + \cos^2 \theta) / 2$$

For holes arranged along the axial direction

$$(P = P_L), g = 1$$

For holes arranged along the transverse direction

$$P = P_T, g = 0.5$$



c) Cylindrical tube sheets

Take $g = 1$ or

$$g = \frac{P_1}{P} \times \frac{P - d}{P_1 - d} \times \frac{1 + \cos^2 \theta}{2}$$

whichever is larger

NOTE. For elliptical and oblique nozzles the value of d is the dimension of the opening in the direction of the relevant pitch.

Figure 3.8.2(1). Arrangement factor g

