

Specification for

Design and manufacture of shell boilers of welded construction

ICS 27.060.30

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- Associated Offices Technical Committee
- Association of Shell Boilermakers
- British Combustion Equipment Manufacturers' Association
- British Steel Industry
- Department of Health
- Department of the Environment (Property Services Agency)
- Engineers Surveyors' Section of the Msf
- Health and Safety Executive
- Independent Engineering Insurers' Committee
- Lloyd's Register of Shipping

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Foreword

This British Standard, first published in 1956 under the title “*Cylindrical land steam boilers of welded construction*”, superseded by BS 2790-1 in 1969 and BS 2790-2 in 1973, and subsequently revised in 1982, 1986 and 1989, has been prepared under the direction of the Pressure Vessel Standards Policy Committee. This edition supersedes BS 2790:1989 which is withdrawn.

This 1992 edition incorporates all technical changes up to and including Amendment No. 3 (31 October 1991) associated with the 1989 edition. Changes of significance are to:—

- a) recommend the operation of a quality system to BS 5750;
- b) the tube plate metal temperature for waste heat boilers;
- c) safety factors for furnaces in waste heat boilers;
- d) the accumulator tests for safety valves.

This British Standard sets forth engineering requirements deemed necessary for the design and construction of shell boilers of welded construction. The purpose of this British Standard is unchanged from previous editions. Because of the wide range of shell boilers that may be designed and manufactured in accordance with this British Standard, general guidance has been given on some aspects with specific requirements being for agreement between the parties concerned according to the particular design and manufacturing details.

The user is cautioned that this British Standard is not a design and manufacturing handbook. It has been assumed, therefore, that the execution of its provisions is entrusted to appropriately qualified and experienced people.

Purchasers ordering to this British Standard are recommended to specify in their purchasing contract that the manufacturer operates a quality system in compliance with the appropriate Part of BS 5750 to assure consistency in quality management.

As with previous editions the loose-leaf format adopted will facilitate amendment and the standard will be kept up to date by the issue from time to time of replacement pages, or additional pages when necessary. Each replacement or added page will carry an issue number (with date) indicating its relationship to the original issue of this standard, the pages of which are marked “Issue 1”.

For example,

Issue 1 will indicate an original page or one that has been added to the original standard and has not been amended since insertion;

Issue 2 will indicate a first amendment of either an original page or an added page;

Issue 3 will indicate either an original page amended for the second time since publication or an added page amended for the second time since insertion.

Side-lining on replacement pages will indicate that changes of technical or of reference significance have been made at that point.

This standard may be referred to by the UK Health and Safety Executive (HSE)¹⁾ when giving guidance.

¹⁾ Health and Safety Executive, Rose Court, 2 Southwark Bridge, London SE1 9HS.

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 to viii, pages 1 to 174, 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.

Section 1. General

1.1 Scope

1.1.1 This British Standard specifies requirements for the design and the construction, including materials, workmanship, inspection, testing, documentation and marking, of directly fired and waste heat shell boilers. The boilers dealt with are of cylindrical design, either horizontal or vertical, constructed from carbon or carbon manganese steels by fusion welding to class I, class II or class III classifications, for which the limits of application are given in Table 1.1.1.

They are intended for land use to provide steam or hot water. This standard does not apply to water-tube boilers (see BS 1113) nor to boilers of the locomotive type.

Additionally requirements relevant to safe operation are specified for the installation of associated safety valves, fittings, mountings and automatic control equipment.

Table 1.1.1 — Limits of application

Classification	Limits of application
Class I	If either or both of the following apply: (a) design pressure $> 0.725 \text{ N/mm}^2$ (b) design pressure (in N/mm^2) multiplied by the mean diameter of the boiler shell in millimetres > 920
Class II	If neither of the following limits apply: (a) design pressure $> 0.725 \text{ N/mm}^2$ (b) design pressure (in N/mm^2) multiplied by the mean diameter of the boiler shell in millimetres > 920
Class III	If neither of the following limits apply: (a) design pressure $> 0.38 \text{ N/mm}^2$ (b) design pressure (in N/mm^2) multiplied by the mean diameter of the boiler shell in millimetres > 480

1.1.2 In addition to the definitive requirements, this standard also requires the items detailed in 1.7 to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

1.1.3 Design and construction of superheaters, economizers, air pre-heaters, mechanical stokers, gas or oil-burning equipment, forced or induced draught equipment or other ancillary equipment which may be required by the purchaser are not within the scope of this standard and are matters for mutual arrangement between the purchaser and the manufacturer. For specifications for such ancillary equipment, reference should be made to the appropriate British Standard (e.g. BS 1113 for superheaters, BS 759-1 and BS 6759-1 for boiler mountings).

1.1.4 This standard does not cover the design and construction of brickwork setting, insulation, furnace fittings or the design of boiler mountings.

1.1.5 Requirements for the repair or modification of in-service boilers are outside the scope of this standard.

1.2 References

The titles of the publications referred to in this standard are listed on page 174.

NOTE Attention is drawn to the additional bibliographical lists in C.4 and D.4.

1.3 Definitions

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

1.3.1

purchaser

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

1.3.2

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

1.3.3

manufacturer

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

1.3.4

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

1.3.5**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

1.3.6**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

1.3.7**inspecting authority**

the independent body or association acting on behalf of:

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

that checks that the design, materials and construction comply with the requirements of this standard (see also 6.1)

1.3.8**inspector**

a person employed and trained by an Inspecting Authority to carry out the functions of that Inspecting Authority as indicated in 1.3.7 (see also 6.1)

1.4 Responsibilities

1.4.1 Responsibilities of the purchaser. The purchaser shall be responsible for furnishing the manufacturer with the information required by 1.7.1 and Appendix 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.

The purchaser shall be responsible for ensuring that the boiler plant as supplied will be operated and maintained by properly trained staff of adequate competence, and to instructions which duly recognise the manufacturers recommendations.

1.4.2 Responsibilities of the 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 Appendix B). The manufacturer is also required to furnish documentation and certificates in accordance with 7.1 and 7.2.

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 1.7.2.2 and 7.2).

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

The boiler manufacturer shall supply the purchaser with recommendations for operation and maintenance appropriate to the boiler plant supplied and recognizing the measures necessary to ensure in-service safety, including, where applicable, those discussed in Appendix D.

1.4.3 Responsibilities of the Inspecting Authority.

The Inspecting Authority shall be responsible for checking that the design of the boiler complies with this standard and that all inspections and tests required during the manufacture of the boiler are carried out.

1.5 Interpretation

If any ambiguity is found or doubt arises as to the meaning or effect of any part of this standard or as to whether anything ought to be done or omitted in order to comply with this standard in full, the question shall be referred to the Shell Boilers Technical Committee (PVE/16) of the British Standards Institution whose interpretation of the requirements of this standard upon the matter at issue will be given free of charge and shall be accepted as final and conclusive. Parties adopting this standard for the purposes of any contract shall be deemed to have accepted this provision unless by their contract they either expressly exclude it or else include an arbitration provision extending the interpretation of this standard; however, this provision shall be limited to interpretation and shall not confer on the committee any power or jurisdiction to adjudicate upon the contractual rights or duties of any person under a contract except in so far as they may necessarily be affected by the interpretations arrived at by the committee.

Findings or rulings of the committee upon all enquiries, including matters of interpretation, that are of sufficient importance for both enquiries and replies to be made public as soon as possible will be published in an enquiry-reply form for inclusion in the BS 2790 ring binder as Enquiry Cases. Their availability will be notified in BSI News.

After taking into account any public comment thereon, Enquiry Cases will be incorporated, if appropriate, into the standard either by amendment or in the course of the next convenient annual updating.

1.6 Terminology and symbols

At appropriate places in this standard, symbols used in the text concerned are defined. In some clauses of section three 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.

1.7 Information and requirements to be agreed and to be documented

1.7.1 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 d) 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).
- b) The name of the Inspecting Authority to be commissioned by the purchaser.
- c) Any special statutory or other regulations with which the finished boiler is required to comply (e.g. boiler laws in countries other than that of manufacture).
- d) The name of the Regulating Authority (if any).

1.7.2 Requirements to be agreed and documented

1.7.2.1 General. The items listed in 1.7.2.2 and 1.7.2.3 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 of agreement, i.e. those listed under 1.7.2.3, 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 may 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 (1.7.2.3) from that in 1.7.2.2, which does need to be agreed and documented when the contract or order is placed.

1.7.2.2 Requirement 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 7.2).

1.7.2.3 *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) The use, for pressure parts, of materials other than those covered by the British Standards referred to in Table 2.5(1) and Table 2.5(2) (see 2.2.2).
- b) The heat treatment condition of plates supplied for forming (see 2.4).
- c) Methods of tube attachment other than those shown in Figure 3.9.2(1) and Figure 3.9.2(2) [see 3.1.3.2 e)].
- d) The method of reinforcement of openings (see 3.4.4).
- e) 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 4.6.1).
- f) The requirements for welding consumables, in the absence of a relevant British Standard (see 5.2).
- g) 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 5.4.14.4 c)].
- h) 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).
- i) If furnace atmosphere temperatures are to be used to indicate metal temperatures during post weld heat treatment, the limits within which the furnace atmosphere temperatures are to correspond with the metal temperatures [see 5.5.2.3 f)].
- j) 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).
- k) 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. Only carbon or carbon manganese steels shall be used.

2.2 Selection of materials

2.2.1 The materials used in the manufacture of pressure parts shall comply with either the appropriate British Standard referred to in Table 2.5(1) or Table 2.5(2) or with the other appropriate requirements specified in this section.

Plain tubes and stay tubes which are to be expanded shall be either seamless or electric resistance welded and shall meet the flattening and drift expanding test requirements of BS 3059.

Cross tubes shall be seamless.

Welding consumables shall comply with 5.2 of this standard.

Studs, bolts and nuts shall comply with the material specifications listed in BS 4882.

2.2.2 If other materials are used for pressure parts by express agreement between the purchaser, manufacturer and Inspecting Authority [see 1.7.2.3 a)], then:

- a) they shall be of boiler quality;
- b) they shall comply with the requirements of 2.3 and shall be covered by a written specification at least as comprehensive as the equivalent British Standard listed in Table 2.5(1) or Table 2.5(2) as appropriate; and
- c) they shall be of the same type and grade as the equivalent material listed in Table 2.5(1) or Table 2.5(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.

2.3 Material specifications

For materials other than those listed in Table 2.5(1) and Table 2.5(2), the general requirements given in 2.3.2 to 2.3.7 shall apply.

2.3.1 Notation

- A is the percentage elongation at fracture;
- E_t is the value of elevated temperature yield stress or 0.2 % proof stress to be used for deriving the design stress (see 3.1.4)
- R_e is the room temperature yield stress determined either as the upper yield stress (R_{eH}) or the 0.5 % proof stress (total elongation) ($R_{t0.5}$);

- R_{eH} is the upper yield stress;
- R_{eL} is the lower yield stress at elevated temperature;
- R_m is the room temperature tensile strength;
- $R_{p0.2}$ is the 0.2 % proof stress at elevated temperature;
- $R_{t0.5}$ is the 0.5 % proof stress (total elongation);
- S_o is the original cross section of the test piece subjected to a tensile test.

2.3.2 The material specification (see 2.2.2) shall specify the steelmaking process, compositional limits for all constituents, deoxidation practice, 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 sulphur 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.

- a) 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
- b) 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 which deals with the following:

Tensile strength,	R_m
Yield stress,	R_e
Percentage elongation at fracture,	A

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 stress, R_{eL} , or the minimum value of the 0.2 % proof stress, $R_{p0.2}$, at the appropriate elevated temperature, related to tests in accordance with BS EN 10002-5, shall be specified for materials equivalent to those listed in Table 2.5(1).

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

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 1.7.2.3 b)].

2.5 Elevated temperature properties

2.5.1 If materials are supplied in accordance with a British Standard listed in Table 2.5(1) or an equivalent specification giving elevated temperature lower yield stress or 0.2 % proof stress values which do not exceed the values specified in the British Standard, then either the lower yield stress value or the 0.2 % proof stress value specified in the British Standard or in the equivalent specification respectively shall be used as the value of E_t in the determination of design stress values (see 3.1.4.4) without verification.

2.5.2 If materials are supplied in accordance with a specification which gives elevated temperature lower yield stress or 0.2 % proof stress values greater than those specified in the British Standard for an equivalent material listed in Table 2.5(1), such values shall only be used as the value of E_t in the determination of design stress values (see 3.1.4.4) provided they have been verified by acceptance tests or were derived and verified in accordance with the procedure specified in BS 3920.

2.5.3 If materials are supplied in accordance with a standard which does not specify elevated temperature lower yield stress or 0.2 % proof stress values, i.e. either a British Standard material listed in Table 2.5(2) or its equivalent, then the value of E_t to be used in the determination of the design stress values shall be determined from Table 2.5(3). These values are not subject to verification.

Table 2.5(1) — Carbon and carbon manganese steels with specified minimum elevated temperature properties

Product form	BS number	Designation	Grade
Plate	BS EN 10028-2		P235 GH P265 GH P295 GH P355 GH
	1501-1 (withdrawn)	151	400 B 430 B
		161	400 B 430 B
		164	400 B
		223	460 B 490 B
Tube	3059-2	S1, S2 or ERW	360 440
	3602-1	HFS, CFS, ERW or CEW	360 430 500 Nb
	3602-2	LAW	430 490
Forgings	1503	164 221 or 223	490 E 410 E 430 E 460 E 490 E
NOTE BS 1501-1 was withdrawn on 15 February 1993 in favour of BS EN 10028-1, BS EN 10028-2 and BS EN 10028-3. The BS 1501 materials are regarded as obsolescent, but their use may be continued for as long as they are available.			

Table 2.5(2) — Carbon and carbon manganese steels without specified elevated temperature properties

Product form	BS number	Designation	Grade
Plate	1501-1 (withdrawn)	151	400 A 430 A
		161	400 A 430 A
		164	400 A
		223	460 A 490 A
Tube	3059-2	HFS, CFS or ERW	320
	3601	S or ERW ERW or CEW	320 360 430
Sections and bars	1502	151, 161, 211 or 221	430
Forgings	1503	164	490
		221 or 223	410 430 460 490
NOTE BS 1501-1 was withdrawn on 15 February 1993 in favour of BS EN 10028-1, BS EN 10028-2 and BS EN 10028-3. The BS 1501 materials are regarded as obsolescent, but their use may be continued for as long as they are available.			

Table 2.5(3) — Values of E_t for materials without specified elevated temperature properties

Product form	BS no.	Designation	Grade	Thickness or diameter	Values of E_t at design temperature shown			
					250 °C	300 °C	350 °C	400 °C
Plate	1501-1 (withdrawn)	151 and 161	400 A	mm	N/mm ²	N/mm ²	N/mm ²	N/mm ²
				≤ 16	163	136	128	125
				$> 16 \leq 40$	155			
				$> 40 \leq 63$	152			
				$> 63 \leq 100$	147			
		164	430 A	≤ 16	180	151	143	139
				$> 16 \leq 40$	170			
				$> 40 \leq 63$	167			
				$> 63 \leq 100$	161			
		223	400 A	≤ 63	171	152	143	134
		223	460 A	≤ 63	213	195	184	172
			490 A	≤ 63	225	206	193	183
Tube	3059-1	HFS	320	—	—	100	91	88
		CFS		—	125			
		ERW		—	—			
	3601	S	320	—	125	100	91	88
		ERW	360	—	145	122	111	109
			430	—	170	154	142	134
Sections and bars	1502	151, 161 211 and 221	430	≤ 16	180	151	143	139
				$> 16 \leq 40$	170			
				$> 40 \leq 63$	167			
				$> 63 \leq 100$	161			
Forgings	1503	164	490	≤ 100	200	180	171	162
		221	410	≤ 100	157	141	133	129
			430	≤ 100	167	150	144	139
			460	≤ 100	188	165	157	152
			490	≤ 100	197	180	172	166
			410	≤ 100	169	149	139	129
		223	430	≤ 100	180	160	150	141
			460	≤ 100	197	178	167	157
			490	≤ 100	214	195	184	172
			410	≤ 100	169	149	139	129
			430	≤ 100	180	160	150	141
			460	≤ 100	197	178	167	157
			490	≤ 100	214	195	184	172

NOTE 1 Intermediate values of E_t are determined by linear interpolation.

NOTE 2 BS 1501-1 was withdrawn on 15 February 1993 in favour of BS EN 10028-1, BS EN 10028-2 and BS EN 10028-3. The BS 1501 materials are regarded as obsolescent, but their use may be continued for as long as they are available.

Section 3. Design

3.1 Design criteria

3.1.1 General. The formulae dealing with the calculation of scantlings 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 Appendix D. It is intended that boilers designed in accordance with this standard should be operated under conditions free from internal scale. This requires feed water of a suitable quality.

CAUTION. If a risk of abnormal working conditions is foreseen, the scantlings, etc. established by calculation from the given formulae should receive special consideration [see 1.7.1 a)].

In the case of hot water boilers, the position of flow openings shall be such that air cannot be retained in the boiler shell or waterways.

Typical boilers and component terminology are given in Figure 3.1(1), Figure 3.1(2), Figure 3.1(3), Figure 3.1(4), and Figure 3.1(5).

For hot water boilers, the water differential temperature, within the boiler shell, shall be limited to 50 K. If the difference between the water flow temperature (outlet) and the water return temperature (inlet) is greater than 50 K, then internal and/or external mixing devices shall be used to limit the effective differential temperature within the boiler shell to 50 K.

To allow for increased thermally induced relative displacements due to large temperature differences in hot water boilers, breathing spaces (see 3.8.1) shall be increased by 50 %, and the maximum net heat input given in Figure 3.1(6) shall be reduced by 20 %, if the difference between the saturation temperature corresponding to the maximum total working pressure, and the water flow (outlet) temperature exceeds 80° K.

The return water entering the boiler shall not impinge directly on the furnace tube.

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.

If applicable, the hydrostatic head and, for 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.

The design pressure shall be not less than the highest pressure at which any safety valve is to be set to lift. It is desirable that there should 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.

3.1.3 Design temperature

3.1.3.1 Notation

- A is the effective radiant heating surface (in m²) [see Figure 3.1(1) to Figure 3.1(5)];
- e_1 is the nominal tube thickness (in mm);
- e_2 is the nominal plate thickness (in mm);
- H is the net heat input in watts (the maximum burner heat release rate based on the net calorific value of the fuel);
- t is the design temperature (in °C);
- t_G is the true gas entry temperature (in °C);
- t_s is the saturation temperature of water (in °C) at the design pressure, for both steam and hot water boilers.

3.1.3.2 Determination of metal temperature.

Combustion shall be completed in the furnace. In order to ensure safe burner/boiler combinations, the maximum net heat input for a given furnace diameter shall be in accordance with Figure 3.1(6). On/off burners shall not be used for heat inputs exceeding 1 MW. A sampling point shall be provided so that gas analysis and gas temperature in the reversal chamber may be determined.

The design temperature t used to evaluate the design stress shall be the mean metal temperature expected under operating conditions for the part considered at the coincident pressure which shall be taken as not less than 250 °C.

The design temperature for the various components of the boiler shall be determined as follows.

- a) For shells and other components not designed for heat transfer purposes, the design temperature may be taken as the maximum temperature of the contained water.
- b) For smoke tubes, the design temperature shall be determined in accordance with the following equations.

$$t = (t_s + 2e_1), \text{ or}$$

$$t = (t_s + 25), \text{ whichever be the greater.}$$

c) The design temperature for plain plates not swept by flame, for tube plates where the gas entry temperature is not greater than 800 °C and for reversal chamber wrapper plates, shall be determined in accordance with the following equations.

$$t = (t_g + 2e_2), \text{ or}$$

$$t = (t_g + 50), \text{ whichever be the greater.}$$

d) For tube plates in directly fired boilers where the true gas entry temperature t_g exceeds 800 °C, the design temperature and the maximum metal temperature shall be determined in accordance with Appendix C, using the data for natural gas and t_g as determined from the following equation.

$$t_g = 52.4 \left(\frac{H}{A} \right)^{0.25}$$

For tube plates in waste heat boilers, the design temperature and maximum metal temperature shall be determined in accordance with Appendix C using the specified gas entry temperature where this exceeds 800 °C.

e) The maximum metal temperature as determined in accordance with Appendix C shall not exceed 420 °C except where tubes produced from rimming steel are fitted, in which case the maximum metal temperature shall not exceed 380 °C.

These requirements apply to the methods of tube attachment shown in Figure 3.9.2(1) and Figure 3.9.2(2) where the methods of construction ensure good thermal contact between tube and tubeplate. Other constructions which do not ensure good thermal contact shall be used only with the agreement of the manufacturer and the Inspecting Authority [see 1.7.2.3 c)].

f) In the case of tube plates of waste heat boilers where the specified gas entry temperature exceeds 800 °C and where the maximum metal temperature determined in accordance with Appendix C would exceed the limits in e), it is permissible to line the tube plate with permanently and securely installed refractory and to provide protective ferrules in the tube entries to reduce the metal temperature.

In such cases the requirements of c) shall be applied subject to the thickness of refractory being such as to ensure that the design temperature so determined is not exceeded.

In order to determine the required thickness of refractory, it shall be assumed that the hot face temperature of the refractory is equal to the gas temperature t_g and the tube plate waterside temperature is equal to t_s . The tube plate temperature t , at the interface, shall be determined by the use of simple heat convection formula, taking into account the thickness of the refractory and tube plate, and their individual conductivities.

g) The design metal temperature for furnaces and fireboxes shall be determined in accordance with the following equation.

$$t = t_g + 4e_2 + 15$$

3.1.4 Design stress

3.1.4.1 Notation

- E_t is the value of elevated temperature yield stress or 0.2 % proof stress at design temperature t (see 2.5);
- f is the design stress (in N/mm²);
- R_m is the room temperature tensile strength (in N/mm²);
- t is the design temperature (in °C).

3.1.4.2 The term “design stress”, designated by the symbol f , is the stress to be used in the formulae in this standard for the calculation of pressure parts. The detailed design rules in this section will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

3.1.4.3 The designer shall determine the design stress f from the material properties as defined in section 2 and the factors given in 3.1.4.4.

For the steels concerned, it may be assumed that post weld heat treatment will not affect the strength values to be used for calculation purposes.

NOTE Any reduction in the properties of such steels is regarded as being consistent with the overall benefit obtained by stress relief of the structure. However, post weld heat treatment in this context means heat treatment within the limits given in 5.5.2. In designs where slight deformation is important, plate that will meet the minimum specified property values in the normalized plus simulated (3 h) post weld heat treated condition should be specified. See 19.4.3 of BS 1501-1:1980.

3.1.4.4 The design stress f shall be the lower of

$$\frac{E_t}{1.5} \text{ and } \frac{R_m}{2.4}$$

NOTE For design temperatures other than the temperatures at which values of E_t are stated in the material specifications, intermediate values are determined by linear interpolation.

3.2 Cylindrical shells under internal pressure

3.2.1 Notation

- C is the corrosion allowance, to be taken as 0.75 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;
- f is the design stress (in N/mm²) (see 3.1.4);
- 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
 = 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 1 000 mm or less than 4 mm for shells having an outside diameter equal to or less than 1 000 mm.

$$e = \frac{PR_i}{fZ - 0.5P} + C$$

Where set-in end plates are used [as in Figure B(3)(a) and Figure B(3)(b)] 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_i obtained from the following formula.

$$e_i = e_{cs} + C$$

where

$$e_{cs} = \frac{PR_i}{fX - 0.5P}$$

X is a factor found from the following table.

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.

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 apply only if the following conditions are fulfilled:

- The ratio of the outside radius to the inside radius does not exceed 1.5.
- 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 5.4.10 and 5.4.11.

- 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 Appendix A of BS 5500:1991

3.2.5 Boiler supports

3.2.5.1 Leg supports. If boilers with a shell outside diameter of less than 1 500 mm are supported on legs, the shell thickness shall be calculated using a stress reduction factor not greater than 0.85 (see 3.2.1) unless, in the case of class I boilers, the stresses in the shell calculated in accordance with Appendix G of BS 5500:1991 are within the acceptable limits given in BS 5500.

If boilers with a shell outside diameter of 1 500 mm or greater are supported on legs, the stresses in the shell, calculated in accordance with Appendix G of BS 5500:1991 shall not exceed the acceptable limits given in BS 5500.

In calculating the stresses all boilers shall be considered fully flooded at the design temperature which shall be not less than 250 °C.

NOTE An example of a calculation, in accordance with Appendix G of BS 5500:1991, to determine the shell stresses for a boiler with leg supports is given in Appendix F.

3.2.5.2 Saddle supports

3.2.5.2.1 General. When boilers are supported on saddles, the subtended angle θ [see Figure 3.2.5.2(a)] shall be not less than 60° for boilers with a shell outside diameter of less than 1 500 mm and not less than 90° for boilers with a shell outside diameter equal to or greater than 1 500 mm.

When θ is less than 90° in boilers with a shell outside diameter less than 1 500 mm the shell thickness shall be calculated using a stress reduction factor not greater than 0.85 (see 3.2.1).

When boilers with a shell outside diameter equal to or greater than 1 500 mm are supported on saddles the circumferential combined stress in the shell shall be in accordance with the following requirements.

In calculating the stresses all boilers shall be considered fully flooded at the design temperature which shall be not less than 250 °C.

3.2.5.2.2 Notation (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_c is the nominal shell thickness minus corrosion allowance (in mm);
 k is the coefficient obtained from Figure 3.2.5.2(b);
 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 .

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

$$\text{then } \sigma = \frac{PR}{e_c} - \frac{Q}{4e_c(B + 10e_c)} + \frac{1.5kQ}{e_c^2}.$$

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

$$\text{then } \sigma = \frac{PR}{e_c} - \frac{Q}{4e_c(B + 10e_c)} + \frac{12kQR}{Le_c^2}.$$

3.3 Dished and flanged ends

3.3.1 Notation

- 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 comply with the following dimensional relationships [see Figure 3.3(1)(a)]:

$$0.005 D_o \leq e \leq 0.08 D_o$$

$$R_i \leq D_o$$

$$r_i \geq 0.1 D_o$$

$$r_i \geq 2e$$

$$H \geq 0.18 D_o$$

3.3.2.2 Semi-ellipsoidal ends. Semi-ellipsoidal ends shall comply with the following dimensional relationships [see Figure 3.3(1)(b)]:

$$0.005 D_o \leq e \leq 0.08 D_o$$

$$H \geq 0.18 D_o$$

3.3.2.3 Hemispherical ends. Hemispherical ends shall comply with the following dimensional relationship:

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

3.3.3 Thickness

3.3.3.1 Notation

- C is the corrosion allowance to be taken as 0.75 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 3.1.4);
 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.

$$e = \frac{PD_o K}{2f} + C$$

The minimum thickness e shall in no circumstances be less than 6.0 mm.

3.3.3.3 The shape factor K used in 3.3.3.2 is 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 may be necessary to arrive at the correct value of K .

3.3.4 Openings in dished ends

3.3.4.1 Notation [see Figure 3.3(3) and Figure 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);
- d_1 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);
- l_1 is the effective width of the reinforcement (in mm) [see Figure 3.3(4)];
- l_2 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. 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.

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

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

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.

3.3.4.3 The rules in 3.3.4.2 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 Figure 3.3(1) and Figure 3.3(3)].

3.3.4.4 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).

3.3.4.5 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, 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 $\sqrt{2R_i e}$ 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

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

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 3.9.4.1 disregarding the minimum thickness from Table 3.9.4.1.

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 must 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.

3.3.5 Dished and flanged ends for Cornish and Lancashire boilers

3.3.5.1 Notation

- C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;
- e is the thickness of the end plate (in mm);
- f is the design stress (in N/mm²) (see **3.1.4**);
- $f_1 = 0.8f$;
- h_f is the overall depth of the compensating flange (in mm);
- P is the design pressure (in N/mm²);
- R_i is the internal radius of curvature of the end plate (in mm);
- w is the minor axis of the manhole (in mm).

3.3.5.2 The minimum thickness of dished ends formed in one piece with external or internal flanges for furnaces without stays shall be determined from the following formula.

$$e = \frac{PR_i}{2f_1} + C$$

The internal radius of curvature of the end plate shall not exceed 1.5 times the external diameter of the shell to which it is attached.

The inside knuckle radius of the arc joining the cylindrical flange to the spherical surface of the end shall be not less than three times the thickness of the plate, but in no case shall it be less than 64 mm.

3.3.5.3 Where the end plate has a manhole, compensation shall be obtained by flanging the edge of the opening, or by providing a stiffening ring; see Figure 3.6.2. In either case the total depth of flanging, or ring, measured at the minor axis shall be not less than that determined by the following formula.

$$h_f = \sqrt{(ew)}$$

3.3.6 Dished and flanged crowns for vertical boilers

3.3.6.1 Notation

- C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;
- e is the thickness of the crown plate (in mm);
- f is the design stress (in N/mm²) (see **3.1.4**);
- $f_2 = 0.65f$;
- $f_3 = 0.5f$;
- $f_4 = 0.3f$;
- h_f is the total depth of the manhole flange (in mm);
- P is the design pressure (in N/mm²);
- R_i is the internal radius of curvature of the crown plate (in mm).

3.3.6.2 The minimum thickness of dished and flanged crowns for vertical boilers which are subject to pressure on the concave side and are supported by central uptakes shall be determined from the following formula.

$$e = \frac{PR_i}{2f_2} + C$$

The inside radius to which a crown plate is dished shall be not greater than the external diameter of the cylinder to which it is attached.

The inside radius of the flange to the shell or firebox shall be not less than four times the thickness of the crown plate, and in no case less than 64 mm.

The inside radius of curvature of flanges to the uptake shall be not less than twice the thickness of the crown plate, and in no case less than 25 mm.

3.3.6.3 Where a dished crown has a manhole the opening shall be strengthened by flanging. The total depth h_f of the flange, measured from the outer surface of the plate on the minor axis, shall be not less than that determined from **3.3.5.3**.

3.3.6.4 The minimum thickness of dished and flanged crowns for vertical boiler fireboxes which are subject to pressure on the convex side and are supported by a central uptake shall be determined from the following formula.

$$e = \frac{PR_i}{2f_3} + C$$

The general shape and size of the corner radii shall be the same as specified in **3.3.6.2**.

3.3.6.5 The thickness of dished and flanged crowns for vertical boiler fireboxes which are subject to pressure on the convex side and are without support from stays of any kind shall be determined from the following formula, but in no case shall the thickness be less than that of the firebox.

$$e = \frac{PR_i}{2f_4} + C$$

The general shape and size of the corner radii shall be the same as specified in **3.3.6.2**.

3.4 Openings in cylindrical shells

3.4.1 Notation

- A* see Figure 3.4.4;
- B* see Figure 3.4.4;
- C* see Figure 3.4.4;
- d* is the bore of the opening (see Figure 3.4.4) 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 **3.4.2** and **3.4.4**, *d* shall be taken as the corresponding dimension of the opening parallel to the longitudinal axis of the shell;
- D* see Figure 3.4.4;
- 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 **3.1.4**);
- P* is the design pressure (in N/mm²);
- X* see Figure 3.4.4;
- Y* see Figure 3.4.4.

3.4.2 Unreinforced openings. No reinforcement is required if the following relation obtains.

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

3.4.3 Openings in a definite pattern. Openings in a definite pattern, such as tube holes, shall be designed in accordance with the rules for ligaments given in BS 1113, provided that the diameter of the largest hole in the group does not exceed that permitted by **3.4.2**.

3.4.4 Reinforced openings. Openings larger than those permitted by **3.4.2** shall be reinforced, but in no case shall the ratio d/D_o be greater than 0.3 unless designed in accordance with the rules for compensation of openings given in BS 1113. 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 3.4.4, the branch thickness being increased where required. Compensation shall be considered adequate when the compensating area *Y* (see Figure 3.4.4) 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 *D*.

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 Figure B(26) or Figure B(27) or by using an alternative method mutually agreed between the purchaser, the manufacturer and the Inspecting Authority [see **1.7.2.3 d**]. 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 *D*, *C* and *D* being as shown in Figure 3.4.4.

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 may 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 parallel to the longitudinal axis of the shell.

NOTE Reinforcements designed to these rules will always be adequate but may 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.

3.4.5 Openings in furnaces. Reinforcement for openings in cylindrical furnaces shall be designed in accordance with 3.4.4 except that:

- a) pad type reinforcement is not permitted; and
- b) the calculation shall be made assuming an internal pressure in the furnace equals to the design pressure of the boiler.

3.5 Fillet welds attaching pads and compensating plates to cylindrical shells

3.5.1 Leg length. The leg length of outer peripheral fillet welds by which pads (see Appendix B) and compensating plates [see Figure 3.5(a), Figure 3.5(b) and Figure 3.5(c)] are attached to shell places shall be determined by using the following equation, but shall in no case be less than those of the inner welds nor less than the minimum plate thickness referred to in 3.2.2.

$$L_o = \frac{4X - D_i L_i}{D_o}$$

3.5.2 Notation

- α_i is the inner major axis of the compensating plate (in mm);
- α_o is the outer major axis of the compensating plate (in mm);
- b_i is the inner minor axis of the compensating plate (in mm);

- b_o is the outer minor axis of the compensating plate (in mm);
- D_i is the diameter of the opening in the shell (in mm);
- D_o is the diameter of the outer periphery of the circular pad or compensating plate (in mm);
- L_i is the length of leg of the fillet weld around the inner periphery of the pad or compensating plate (in mm);
- L_o is the length of leg of the fillet weld around the outer periphery of the pad or compensating plate (in mm);
- X is half the cross-sectional area of the opening of diameter D_i in the shell based on the shell thickness determined in accordance with the formula given in 3.2.2 taking $Z = 1.0$ (in mm²), disregarding the minimum thickness required by 3.2.2;

For elliptical compensating plates,

$$D_o = \frac{a_o + b_o}{2}$$

$$D_i = \frac{a_i + b_i}{2}$$

3.6 Openings and branches

3.6.1 Isolated openings in flat end plates supported by stays

3.6.1 Notation

3.6.1.1 Manholes, headholes and handholes [see Figure 3.6.1(1) and Figure 3.6.1(2)]

- d_{io} is half the mean of the major and minor semi-axes of the opening (in mm);
- D is the greater of the two values: ($e_{rep} + 75$) or d_{io} (in mm);
- e_{cp} is the thickness of the flat end plate calculated in accordance with 3.8.2.5 (in mm);
- e_{rep} is the nominal thickness of the flat end plate (in mm);
- e_{sr} is the thickness of the ring (in mm);
- h_f is the depth of the ring (in mm).
- W is the width (in mm) of the opening measured on the minor axis.

3.6.1.1.2 Branch openings [see Figure 3.6.1(3)]

- C is the smaller of the two values: $2.5 e_{\text{rep}}$ or $(2.5 e_b + e_{\text{rp}})$ (in mm);
- d_{ib} is the bore of the branch opening (in mm);
- D is the greater of the two values: $(e_{\text{rep}} + 75)$ or $(d_{\text{ib}} + 4)$ (in mm);
- e_b is the nominal thickness of the branch wall (in mm);
- e_{cb} is the thickness of the branch wall calculated in accordance with the equation for e in 3.2.2 taking $Z = 1.0$ (in mm);
- e_{cp} is the thickness of the flat end plate calculated in accordance with 3.8.2.5 (in mm);
- e_{rep} is the nominal thickness of the flat end plate (in mm);
- e_{rp} is the thickness of the reinforcing plate (in mm).

3.6.1.2 Unreinforced openings. The maximum diameter d_{max} (or major axis) of an unreinforced opening in a flat end plate shall be determined from the following equation:

$$d_{\text{max}} = 8e_{\text{rep}} \left(\frac{1.5 e_{\text{rep}}^2}{e_{\text{cp}}^2} - 1.0 \right)$$

3.6.1.3 Branch openings. Reinforcement for branch openings shall be achieved by taking account of locally disposed material, including the attachment welds, in excess of the minimal requirements for end plate and branch thickness as shown in Figure 3.6.1(3), the branch thickness being increased where required. Compensation shall be considered adequate when the compensating area Y is equal to or greater than the area X requiring compensation.

Area X shall be obtained by multiplying 25 % of the inside radius of the branch by the thickness of the flat end plate, calculated from equation 3.8.2.5 for the part of the end plate under consideration.

Area Y shall be measured in a plane through the axis of the branch and shall be calculated as follows.

- For that part of the branch which projects outside the boiler, calculate the full sectional area of the branch up to a distance C from the actual outer surface of the flat end plate and deduct it from the sectional area which the branch would have within the same distance if its thickness were calculated in accordance with the equation for e in 3.2.2, taking $Z = 1.0$.
- Add to it the full sectional area of that part of the branch which projects inside the boiler (if any) up to a distance C from the inside surface of the flat end plate.
- Add to it the sectional area of the fillet welds.

d) Add to it the area obtained by multiplying the difference between the actual flat end plate thickness and its thickness calculated from equation 3.8.2.5 for the part of the end plate under consideration by the length D .

e) Add to it the area of the compensating plate (if any) within the limits of reinforcement shown in Figure 3.6.1(3).

Where material having a lower nominal design stress than that of the flat end plate is taken as compensation, its effective area shall be reduced in the ratio of the nominal design stresses at the design temperature. No credit shall be taken for the additional strength of material having a higher nominal design stress than that of the flat end plate.

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

3.6.1.4 Manholes, headholes and handholes. When elliptical manholes, headholes or handholes are located in flat end plates, the openings shall be compensated [see Figure 3.6.1(1) and Figure 3.6.1(2)]. Weld dimensions for set-on stiffening rings shall be as shown in Figure 3.6.1(1). The method given in 3.6.1.3 for calculating the required area of reinforcement shall be used where applicable except that the width of the ring e_{sr} shall be not less than 19 mm for manholes, 15 mm for headholes and 10 mm for handholes, and in the case of set-in stiffening rings shown in Figure 3.6.1(1) not less than $0.875 e_{\text{rep}}$. The depth of the ring h_f shall be not less than $\sqrt{(e_{\text{sr}} W)}$.

Area X shall be obtained by multiplying half the mean of the major and minor semi-axes of the opening by the thickness of the flat end plate, calculated from equation 3.8.2.5 for the part of the end plate under consideration.

The full width of the flange or stiffening ring e_{sr} may be used when calculating area Y .

3.6.2 Branches

3.6.2.1 The thickness of branches shall be calculated in accordance with 3.9.4.1 making such additions as may be necessary to allow for bending, static loads and vibration.

In no case shall the thickness be less than that calculated from

$$e = 0.015 d_o + 3.2$$

where

- e is the minimum thickness (in mm);
- d_o is the outside diameter of the standpipe or branch (in mm).

If a branch is connected by screwing, the thickness e shall be measured at the root of the thread.

3.6.2.2 Pads and bolted flanges for branches shall be in accordance with BS 10, BS 1560-3.1 or BS 4504-3.1, as appropriate.

3.7 Access and inspection

3.7.1 General

3.7.1.1 All boilers shall be provided with openings adequate in size and number to allow safe access for fabrication, cleaning, internal inspection and ventilation (see also Appendix E). The dimensions of the openings shall be in accordance with **3.7.2**.

3.7.1.2 Boilers with a shell diameter of 1 500 mm or greater shall be designed to permit safe entry of a person with or without removal of internal parts of the boiler and shall be provided with a manhole for this purpose, except in the case of hot water boilers where the distance between the shell and furnace would not permit safe entry even with the removal of tubes. In such cases access shall be provided by means of a combination of sight holes, handholes and headholes in accordance with **3.7.1.1**.

Boilers with a shell diameter less than 1 500 mm that are capable of being safely entered by a person shall be provided with a manhole. Boilers with a shell diameter between 800 mm and 1 500 mm shall be provided with a headhole as a minimum requirement.

3.7.1.3 Detachable ends or doors may replace all the other examination holes, if by their dimensions and position a general view of the interior is provided at least equivalent to that obtained by the examination holes which would otherwise be required.

3.7.1.4 The design of smoke boxes and other attachments shall be such as to allow adequate access for in-service inspection of the boiler seams.

3.7.2 Types and minimum dimensions of access and inspection openings

3.7.2.1 Sight holes. Sight holes shall have an inside diameter of at least 50 mm if the neck height does not exceed 50 mm (otherwise see **3.7.2.4**).

3.7.2.2 Handholes. A handhole shall have a size of at least 80 mm × 100 mm or an inside diameter of 100 mm if the neck height or ring height does not exceed 65 mm, or in the case of a conical shape 100 mm (otherwise see **3.7.2.4**). If only one handhole is provided, it shall not be less than 100 mm × 120 mm.

3.7.2.3 Headholes. Headhole dimensions shall be at least 220 mm × 320 mm or 320 mm in inside diameter if the neck height or ring height does not exceed 100 mm (otherwise see **3.7.2.4**).

3.7.2.4 If neck or ring heights exceed the limiting values given in **3.7.2.1** to **3.7.2.3**, the size of the hole shall be increased to give an adequate inspection facility.

3.7.2.5 Manholes. Elliptical manholes shall be not smaller than 400 mm × 300 mm. Circular manholes shall be not less than 400 mm diameter.

NOTE Section 30 of the Factories Act 1961 applies if there is a likelihood of dangerous fumes being present within a boiler to such an extent as to involve risk of persons being overcome.

The relevant part of Section 30 of the Factories Act 1961 states:

“The confined space shall, unless there is other adequate means of egress, be provided with a manhole, which may be rectangular, oval or circular in shape, and shall be not less than 18 inches long and 16 inches wide or (if circular) not less than 18 inches diameter.”

These sizes are equivalent to 457.2 mm × 406.4 mm and 457.2 mm diameter respectively.

Section 30 also applies to the lack of oxygen within a confined space. Reference may be made to sub-sections (9) and (10) of Section 30 for the full legal requirements.

If boilers are not provided with openings which comply with Section 30 of the Factories Act 1961, the manufacturer shall inform the purchaser that precautions need to be taken to ensure that dangerous fumes are not liable to be present to such an extent as to involve risk of persons being overcome.

3.7.2.6 Thickness of internally fitted doors. The minimum calculated thickness of a door of flat plate construction (i.e. unstiffened) made from one plate shall be not less than that determined by the following appropriate equation:

$$e = \sqrt{\left\{ \frac{0.35pd^2 + W}{f} \right\}} \quad \text{for a circular door}$$

$$e = \sqrt{\left\{ \frac{0.35p(2 - a/b)a^2 + W}{f} \right\}} \quad \text{for an elliptical door}$$

where

- e is the minimum calculated thickness of the flat door at or near the centre;
- p is the calculation pressure (in N/mm²);
- d is the diameter of the opening to which the door is fitted if round (in mm);
- a is the minor axis of the opening to which the door is fitted if an ellipse (in mm);
- b is the major axis of the opening to which the door is fitted if an ellipse (in mm);
- W is the full load capacity of one stud (effective stud area × design stress value at design temperature) (in N);
- f is the maximum allowable stress in the plate at the design temperature (in N/mm²).

NOTE A design stress value of 50 N/mm² may be used for carbon steel bolts of grade 4.6 or equivalent for design temperatures not exceeding 300 °C. For other bolting materials and greater temperatures refer to BS 5500 for allowable stresses when deriving W .

3.7.3 Minimum gasket bearing width and clearance for manhole doors. See **4.8**.

3.8 Stays, stiffeners and supported surfaces

3.8.1 Breathing space

3.8.1.1 Arrangement of stays. Stays shall be arranged to give sufficient breathing space around the furnace connections and tube nests [see Figure 3.8.1(1)], and shall divide the unstayed areas equally.

3.8.1.2 Multi-tubular boilers. For both the front and rear attachment of furnaces, the breathing spaces between furnace and tube nests or between furnace and shell shall be a minimum of 50 mm or 5 % of the shell inside diameter, whichever is the larger, with a maximum requirement of 100 mm.

Clearances between the furnace and wet-back wrapper plates shall not require consideration as breathing spaces.

In the case of reverse flame boilers the breathing space at the front end between furnace and tube nests shall be not less than 50 mm. Additionally the sum of this breathing space and the breathing space formed by the outer annular area of the furnace rear plate shall be not less than 50 mm or 5 % of the shell inside diameter, whichever is the larger, with a maximum of 100 mm.

Breathing spaces between gusset or link stays and tube ends shall be not less than 100 mm. Clearances between the tubes and wet-back wrapper plates shall not require consideration as breathing spaces. Breathing spaces between tubes and shells shall be not less than 40 mm.

Breathing spaces between gusset or link stays and furnaces shall be not less than 200 mm except that for shell outside diameters exceeding 1 800 mm and furnace lengths exceeding 6 000 mm they shall be not less than 250 mm and for shell outside diameter less than 1 400 mm and furnace lengths less than 3 000 mm they shall be not less than 150 mm.

All other breathing spaces shall be a minimum of 50 mm or 3 % of the shell inside diameter, whichever is the larger, with a maximum requirement of 100 mm [see 3.8.2.3, 3.8.2.4 and Figure 3.8.1(1)].

3.8.1.3 Cornish and Lancashire boilers. In Cornish boilers, the circle defining the breathing space shall be as shown in Figure 3.8.1(2), i.e. the distance AB between the centre of the stay circle and the centre of the flue shall be not less than $3e + 63$, where e is the thickness of the end plate in millimetres.

For Lancashire boilers, the proportions shown in Table 3.8.1.3 are recommended for the portion of the end plates above the furnaces and flues. It is recommended that the breathing space below the flues be approximately one-half of the dimensions given in Table 3.8.1.3.

Table 3.8.1.3 — Breathing space

Thickness of end plate (in mm)	13	14	16	18	20	Over 20
Dimensions L (in mm) [see Figure 3.8.1(3)]	255	280	305	330	330	340

3.8.2 Stayed flat surfaces

3.8.2.1 Notation

- a is the major dimension of oval or rectangular areas (in mm) [for examples, see Figure 3.8.1(1), Figure 3.8.2(1) and Figure 3.8.2(2)];
- b is the minor dimensions of oval or rectangular areas or diameter of main circle, as appropriate (in mm) [for examples see Figure 3.8.1(1), Figure 3.8.2(1) and Figure 3.8.2(2)];
- C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;
- e is the thickness of the flat plate (in mm);
- f is the design stress (in N/mm²) (see 3.1.4);
- j is a constant, depending on the method of support as given in 3.8.2.6;
- P is the design pressure (in N/mm²);
- y is a factor determined from Figure 3.8.2(3) using the ratio b/a .

3.8.2.2 Stayed flat surfaces shall comply with the requirements of 3.8.2.3 to 3.8.2.5.

3.8.2.3 Radius of flange. If flat end plates are flanged for connection to the shell, the inside radius of flanging shall be not less than twice the thickness of the plate, with a minimum of 38 mm. If reversal chamber or firebox plates are flanged for connection to the wrapper plate, the inside radius of flanging shall be equal to the thickness of the plate, with a minimum of 25 mm.

3.8.2.4 Point of support. If the flange curvature is a point of support, this shall be taken at the commencement of curvature, or at a line 3.5 times the thickness of the plate measured from the outside of the plate, whichever is nearer to the flange. If a flat plate is welded directly to a shell or wrapper, the point of support shall be taken at the inside of the shell or wrapper plate.

3.8.2.5 Thickness. The thickness of portions of flat plates supported by stays shall be determined from the following formula.

$$e = bjy \sqrt{\left(\frac{P}{f}\right)} + C$$

When considering areas enclosed by circles which pass through four or more evenly distributed points of support, y shall be taken as

When considering areas enclosed by circles which pass through three points of support, not more than two of them shall be on one side of any diameter and y shall be taken as not less than 1.1. When, in addition to the main circle, a sub-circle of diameter equal to 0.75 times that of the main circle can be drawn such that its centre lies outside the main circle, y shall be determined using dimensions a and b as indicated in Figure 3.8.2(1) and Figure 3.8.2(2).

When considering annular areas, e.g. areas supported only by shell and uptake (see 3.8.3), y shall be taken as 1.56.

When considering an unstayed area of rectangular shape, the dimensions a and b shall be as indicated in Figure 3.8.1(1).

If various forms of support apply to the portion of flat plate under consideration, the constant j shall be the mean of the values for the respective methods adopted.

3.8.2.6 Value of constant j . The value of constant j in the equation in 3.8.2.5 shall be as stated in Table 3.8.2.6.

3.8.3 Flat end plates for vertical boilers

3.8.3.1 Support. Flat end plates shall be supported by the uptake or bar stays, or stay tubes or combinations of these.

3.8.3.2 Radius of flange. The inside radius of curvature of the flange to the shell or firebox shall be not less than twice the thickness of the plate, and in no case less than 38 mm. If the plate is flanged for attachment to the uptake, the inside radius of curvature of the flange shall be not less than the thickness of the plate, and in no case less than 25 mm.

3.8.3.3 Thickness. The thickness of flat end plate shall be determined by the formula given in 3.8.2.5 (see Figure 3.8.3).

3.8.4 Girders for wet back reversal chamber top plates [see Figure 3.8.2(8)(a) to Figure 3.8.2(8)(f)]

3.8.4.1 The proportions for girders shall be calculated from the following formula.

$$e = \frac{L^2 P S_i}{c d^2 f}$$

where

$c = 1.13$

d is the effective depth of the girder (in mm), i.e. the total depth less the depth of waterway, if such is provided;

e is the total thickness of the girder (in mm);

f is the design stress (in N/mm²) (see 3.1.4);

L is the length of the girder (in mm) between supports, i.e. measured between the inside of the tubeplate and the firehole (or back) plate, or between the inside of the side-plates, according to the method of support;

P is the design pressure (in N/mm²);

S_i is the pitch of the girders (in mm).

3.8.4.2 If girders are welded to the top plate, the dimensions of the welds shall be such that the stress, calculated on an area equal to the sum of the effective lengths of the welds attaching each girder multiplied by the effective throat thickness, shall not exceed 52 N/mm² multiplied by the appropriate weld factor in Table 3.8.8.6 ("effective length" and "effective throat thickness" are defined in 3.8.8.6). The load on the welds shall be taken as that due to the design pressure acting on the area LS_i , where L and S_i are defined in 3.8.4.1.

3.8.4.3 For slung girders, the proportions of slings, links, pins and connections to the shell shall be sufficient to carry the whole load that would otherwise be carried on the toes of the girders; for any of the above parts in tension, a stress of 62 N/mm² on the net section, or for parts in shear, a stress of 55 N/mm² on the net section, shall not be exceeded (see 3.8.8.5).

3.8.4.4 The depth of waterway, if provided, shall be not less than 38 mm [see Figure 3.8.2(8)(a) to Figure 3.8.2(8)(d)].

3.8.5 Stays for fireboxes and wet back reversal chambers [See Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b).]

Table 3.8.2.6 — Value of constant j

Form of support	j
Gusset stay or link stay	0.30
Gusset stays in which the angle θ shown in Figure 3.8.2(4) is more than 30°	0.45
Unstayed tube bank with plain tubes welded at both ends	0.30
Isolated plain bar stays [Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b)] or stay tubes [Figure 3.9.2(1)] NOTE Stays are considered isolated if they do not form part of a regular geometric pattern and therefore may be subject to undefined bending moments in addition to axial loads. An example of an isolated plain bar stay is given in Figure 3.8.2(2).	0.45
Non-isolated plain bar stays [Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b)] or stay tubes [Figure 3.9.2(1)]	0.39
Bar stays with washers as shown in Figure 3.8.2(6)(a) and Figure 3.8.2(6)(b)	0.35
Bar stays with washers as shown in Figure 3.8.2(6)(c) and Figure 3.8.2(6)(d)	0.33
Reversal chamber bar stays [see Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b)]	0.39
<i>Flat end plate or tube plate attachments to shell</i>	
Flanged end plate	0.32
Set-in end plate with internal fillet weld as shown in Figure B(3)(a) and Figure B(3)(b)	
Set-on end plates as shown in Figure B(3)(c) and Figure B(3)(d)	
end plate thickness divided by the shell plate thickness	
≤ 1.4	0.33
$> 1.4 \leq 1.6$	0.36
$> 1.6 \leq 1.8$	0.39
> 1.8	0.42
Set-in end plate as shown in Figure B(3)(a) and Figure B(3)(b) with no internal fillet weld	0.45
<i>Reversal chamber or firebox flat tube plate or end plate attachment to wrapper plates</i>	
Flanged end plate as shown in Figure B(4)(a)	0.32
Set-in tube plate or end plate as shown in Figure B(4)(b), Figure B(4)(c), Figure B(4)(d) and Figure B(4)(e), with internal fillet weld	0.33
Set-in tube plate or end plate as shown in Figure B(4)(b), Figure B(4)(c), Figure B(4)(d) and Figure B(4)(e), with no internal fillet weld	0.45
<i>Flat end plate attachment to reversal chamber access tube</i>	
As shown in Figure 3.8.2(7) with internal fillet weld	0.30
As shown in Figure 3.8.2(7) with no internal fillet weld	0.45
<i>Flat end plate attachment to furnaces</i>	
As shown in Figure B(5)(a) and Figure B(5)(b) with internal fillet weld	
Plain furnace	0.30
Corrugated furnace with corrugations less than 50 mm deep	0.32
Corrugated furnace with corrugations 50 mm deep or greater	
length > 4 m	0.37
length ≤ 4 m	0.34
Bowling hoop furnaces	0.32
As shown in Figure B(5)(a) and Figure B(5)(b) with no internal fillet weld	0.45
Top plates of fireboxes or reversal chambers supported by continuously welded-on girders or welded-on girders provided with waterways [see Figure 3.8.2(8)(a) to Figure 3.8.2(8)(f)]	0.51
Lower portion of front end plate of twin flue boilers containing the manhole, when the distance from the edge of the manhole reinforcing ring to the edge of the furnace or shell is not more than four times the end plate thickness If the distance from the edge of the manhole reinforcing ring to the edge of the furnace or shell is more than four times the end plate thickness, the manhole is ignored when determining the constant. In applying the formula given in 3.8.2.5, b shall be taken as the diameter (in mm) of the largest circle which can be drawn enclosing the manhole and passing through the points of support formed by the gusset stays and the connections to the shell and furnaces. If the circle passes through only three of the possible five points of support mentioned, the remaining two shall be included within the circle.	0.27

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

Stays in the rear plate of wet back reversal chambers shall comply with the following rule (see Figure 3.8.5.1).

$$\frac{DL_1}{L_2^2} \leq 2.0$$

where

D is the diameter of the stay (in mm);

L_1 is the shortest distance from the edge of the access opening to the centreline of the stay furthest away from the access opening (in mm) or where there is no access opening half the maximum distance between centrelines of stays;

L_2 is the distance between the rear plate of the chamber and the boiler back endplate (in mm).

3.8.5.2 Radial stays for fireboxes. The diameter of the stay shall be not less than 22 mm nor less than twice the thickness of the firebox plate, whichever is the greater.

The pitch of the stays at the firebox shall not exceed 14 times the thickness of the firebox plate.

3.8.6 Longitudinal bar stays

3.8.6.1 The diameter of each bar stay shall be such that the stress calculated on the least cross-sectional area determined from the nominal diameter without allowance for minus manufacturing tolerance, shall not exceed the specified minimum tensile strength of the material divided by 5.3. In no case shall the nominal diameter of the stay at any point be less than 25 mm.

Supports shall be provided for longitudinal bar stays 5 000 mm in length and longer.

3.8.6.2 If bar stays are fitted in vertical boilers, not less than four bar stays shall be fitted to boilers of 1 200 mm and over but under 1 500 mm in diameter; five bar stays to boilers of 1 500 mm and over but under 1 800 mm in diameter; six bar stays to boilers of 1 800 mm and over in diameter.

3.8.7 Loads on stay tubes and bar stays. Stay tubes and bar stays shall be designed to carry the whole load due to the pressure on the area to be supported, the area being calculated as follows.

a) For a stay tube within the tube nest the net area to be supported shall be the product of the horizontal and vertical pitches (in mm) of the stay tubes, less the area of the tube holes embraced. If the pitch of the stay tubes is irregular, the area shall be taken as the square of the mean pitch of the stay tubes (i.e. the square of one-quarter of the sum of the four sides of any quadrilateral bounded by four adjacent stay tubes) less the area of the tube holes embraced.

b) For a stay tube in the boundary row, or for a bar stay, the net area to be supported shall be the area (in mm²) enclosed by lines bisecting at right angles the lines joining the stay and the adjacent point of support, less the area of any tubes or stays embraced [see Figure 3.8.1(1)].

3.8.8 Gusset and link stays (corner stays)

3.8.8.1 General. To prevent local deformation of the shell plates in large diameter boilers with end plates supported by corner stays, it may be necessary to spread the load by using a large number of stays. Therefore consideration should be given to operating and inspection requirements and when space permits longitudinal bar stays should be fitted in preference to corner stays.

3.8.8.2 Load on each stay. Each gusset or link stay supporting the flat end plate of a boiler shall be designed to carry the whole load due to pressure on the area it supports. The area supported by any one stay shall be obtained by considering the total area to be supported and dividing this area by boundary lines drawn between the stays. These boundary lines shall be at all points equidistant from the adjacent points of support in the area under consideration.

3.8.8.3 Gusset stays. Gusset stays shall be so proportioned that the angle V [see Figure 3.8.8.3(1) and Figure 3.8.8.3(2)] is not less than 60°.

The thickness of the gusset stay shall be determined in accordance with the following.

The gusset shall be radiused at the attachment to the shell and end plate as shown in Figure 3.8.8.3(1).

$$bh = \frac{2F}{f \sin V}$$

$$e_2 \leq b \leq 1.7e_2$$

$$b \geq 0.7e_1$$

where

- b is the thickness of the gusset stay (in mm);
- e_1 is the end plate thickness (in mm);
- e_2 is the shell plate thickness (in mm);
- f is the design stress (see 3.1.4) (in N/mm²);
- F is the force exerted by the pressure on the plate in the zone assumed to be supported by the gusset (in N);
- h is the minimum width of the gusset stay (in mm).

The size and shape of the parts of the end plate supported by each gusset stay shall be such that the entire surface area of the end plate in the gusset stay zone is supported. Gusset stays shall be fitted radially to the end plate and the angle between gusset stays shall be between 15° and 30°.

In positioning gusset stays consideration shall be given to the anticipated degree of deformation of the end plate, adopting the most suitable design in zones subject to the highest deformation.

NOTE The suitability of the design depends mainly upon two criteria: the avoidance of sudden changes of contour and the sufficiency of the breathing space, both being in order to limit stress concentrations (see 3.8.1).

Welded gusset stays shall not be used if the stay would be welded to a plate area subject to a gas temperature exceeding 600 °C.

3.8.8.4 Link stays. Link stays shall be so arranged that the angle V (Figure 3.8.8.4) is not less than 60° and the dimensions shall be such that the stress in the stay at its weakest part does not exceed one-seventh of the minimum tensile strength of the plate used.

3.8.8.5 Anchor plate, links and link pins. The strength of anchor plates, and link pins calculated at the weakest section shall be as follows.

- a) Link pins shall be so designed that the shear stress does not exceed 55 N/mm², the strength of pins in double shear being taken as 1.875 times the strength of pins in single shear.
- b) Anchor plates shall be so designed that the calculated stress does not exceed one-seventh of the minimum tensile strength of the material used, but in no case shall the thickness be less than seven-eighths of the thickness of the shell plate, with a minimum of 12.5 mm, nor shall the length of the portion attached to the end plate be less than the distance between the lines of end-to-shell flat plate breathing space and the breathing space line around the flues or tube nests.

- c) Links, anchor plates and pins constructed from material having a minimum tensile strength of 430 N/mm² shall be so designed that the crushing stress on the projected area does not exceed 103 N/mm².

3.8.8.6 Weld attachments. If gusset plates are welded to the shell and/or end plates, the attachment shall be by means of full penetration welds in accordance with Figure 3.8.8.3(1) or Figure 3.8.8.3(2).

If anchor plates are welded to the shell and/or end plates, the attachment shall be by means of continuous fillet welds on each side or by full penetration welds. The welds shall be of such dimensions that the stress calculated on an area equal to the effective length of the weld multiplied by the effective throat thickness shall not exceed that permitted for the parent metal multiplied by the appropriate weld factor in Table 3.8.8.6.

Care shall be taken in profiling the welds to avoid the formation of notches or abrupt changes of contour. Welds shall blend smoothly into the parent plate.

The effective length of a weld shall be taken as that length of weld which is of the specified dimensions throughout. For open-ended fillet welds, the effective length shall be the overall length less twice the throat thickness.

For the purposes of stress calculation, the effective throat thickness of a butt weld shall be taken as the thickness of the gusset or anchor plate, and the effective throat thickness of a fillet weld shall be taken as 0.7 of the leg length. For compound welds the effective throat thickness shall be the sum of the constituent parts.

Table 3.8.8.6 — Weld attachments

Form of weld	Weld factor
Single J or bevel butt welds (with or without superimposed fillets)	
Unsealed	0.45
Sealed	0.70
Double J or bevel butt welds (with or without superimposed fillets)	0.80
Double fillet welds	0.65

3.8.9 A corrosion allowance shall not be required on stay bars and other structural members in the steam or water space.

3.9 Tubes and tube plates

3.9.1 Thickness of tubes subject to external pressure. The thickness of tubes under external pressure shall be calculated using the following formula.

$$e = \frac{PD}{2f_1} + C$$

where

C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;

D is the outside diameter of the tube (in mm);

e is the minimum thickness of the tube (in mm).

The tube ordered may have a negative tolerance, and the calculated thickness shall be increased to take account of this tolerance;

$f_1 = 0.8f$, where f is the design stress (in N/mm²) (see 3.1.4);

P is the design pressure (in N/mm²).

In no case, however, shall the thickness of tubes under external pressure be less than the values given in Table 3.9.1.

Table 3.9.1 — Minimum thickness of tubes under external pressure

Nominal outside diameter	Minimum nominal thickness
mm	mm
Not exceeding 38	2.28
Exceeding 38 not exceeding 51	2.81
Exceeding 51 not exceeding 70	3.12
Exceeding 70 not exceeding 76.1	3.38
Exceeding 76.1 not exceeding 88.9	3.96
Exceeding 88.9 not exceeding 101.6	4.26

3.9.2 Stay tubes and plain tubes. Stay tubes are tubes having a weld depth equal to the nominal tube thickness plus 3 mm as shown typically in Figure 3.9.2(1)(a) to Figure 3.9.2(1)(d). These stay tubes are not required within tube nests except when the tube nests comprise tubes which are expanded only as shown typically in Figure 3.9.2(c). If tube nests comprise plain tubes that are expanded and beaded, expanded and belied [as shown typically in Figure 3.9.2(2)(d)] or expanded and welded [as shown typically in Figure 3.9.2(2)(a) and Figure 3.9.2(2)(b)], welded stay tubes [as shown typically in Figure 3.9.2(1)(a) to Figure 3.9.2(1)(d)] shall be used in boundary rows in sufficient numbers to carry the flat plate loadings outside the tube area.

For plain tubes and stay tubes exposed to flame or gas temperatures exceeding 600 °C, the ends of welded tubes shall be dressed flush with the welds and the ends of the expanded tubes shall be as shown in Figure 3.9.2(2)(c) and Figure 3.9.2(2)(d). If not so exposed, the ends of welded tubes shall extend a maximum of 10 mm beyond the weld or, in the case of expanded tubes, the tubes shall project beyond the tube plate up to a maximum of 15 mm.

Each stay tube shall be designed to carry its due proportion of the load on the plates which it supports. The thickness of stay tubes welded into tube plates shall be such that the axial stress on the thinnest part of the tube does not exceed 70 N/mm².

3.9.3 Pitch of tubes. The spacing of tube holes shall be such that the minimum width in millimetres of any ligament between the tube holes shall be not less than $0.125 D_h + 12.5$ mm, where D_h is the diameter of the tube hole in millimetres.

3.9.4 Tubes subject to internal pressure

3.9.4.1 The thickness of straight tubes subject to internal pressure shall be determined by the following formula.

$$e = \frac{PD}{2f + P} + C$$

where

C is the corrosion allowance, to be taken as 0.75 mm, unless a higher figure is agreed to take account of adverse conditions;

D is the outside diameter of tube (in mm);

e is the minimum thickness of the tube (in mm).

The tube ordered may have a negative tolerance, and the calculated thickness shall be increased to take account of this tolerance;

f is the design stress (in N/mm²) (see 3.1.4);

P is the design pressure (in N/mm²).

In no case, however, shall the thickness of tubes under internal pressure be less than the values given in Table 3.9.4.1.

Table 3.9.4.1 — Minimum thickness of straight tubes under internal pressure

Nominal outside diameter	Minimum nominal thickness
mm	mm
Not exceeding 38	1.75
Exceeding 38 not exceeding 51	2.16
Exceeding 51 not exceeding 70	2.40
Exceeding 70 not exceeding 76	2.60
Exceeding 76 not exceeding 95	3.05
Exceeding 95 not exceeding 102	3.28
Exceeding 102 not exceeding 127	3.50

3.9.4.2 Where tubes are bent, the following requirements shall apply.

a) *Thinning*

1) At any location around the bend extrados the reduction in thickness below the calculated minimum thickness required for the straight tube, expressed as a percentage, (see **3.9.4.1**) shall not exceed:

$$\frac{100}{(4R/D) + 2}$$

where

R is the mean radius of the bend to the centre line of the tube;

D is the ordered outside diameter of the tube.

2) In addition, for cold formed bends that will receive no post bend heat treatment, the amount of thinning at any location around the bend extrados shall not exceed 20 % of the nominal thickness of the tube on the straight.

b) *Ovality*. The bending process shall be controlled so that any distortion from a circular cross section tends only to ovality and the ovality measured at the bend apex shall not exceed 10 %.

The percentage ovality is given by:

$$\frac{D_{\max} - D_{\min}}{D} \times 100$$

where

$D_{\max}$ is the maximum outside diameter of the tube measured at the bend apex;

$D_{\min}$ is the minimum outside diameter of the tube measured at the same cross section as $D_{\max}$;

D is the nominal outside diameter of the tube.

3.9.5 Thickness of tube plates within tube nests

The minimum thickness of any tube plate where plain tubes are attached, as shown in Figure 3.9.2(2)(a) to Figure 3.9.2(2)(d), shall be 12.5 mm if the diameter of the tube hole does not exceed 50 mm, or 14 mm if the diameter of the tube hole is greater than 50 mm.

If the tubes are attached to the tube plates by deep welds which have an unwelded land of not more than 3 mm, the tube plates shall be not less than 9 mm thick.

The thickness of tube plates shall be calculated using the formula given in **3.8.2.5**, taking b as the pitch of the plain tubes and y as 1.56.

3.9.6 Horizontal shelves of tube plates forming part of the shell

3.9.6.1 To withstand the vertical load owing to pressure on the boiler ends, one of the following two methods shall be used.

a) If gussets or other stays are not fitted to the shelves, the strength of the parts of the circumferential seams at the top and bottom of these plates from the outside of one tube plate to the outside of the other tube plate shall be sufficient to withstand the whole load on the boiler end. The stress on these parts of the circumferential seams shall not exceed $R_m/4.5$ (see **3.1.4**).

b) If the horizontal shelves of the tube plates are supported by gussets or other stays, the number of such gussets or stays shall be calculated as follows, using the parameter C :

$$C = \frac{AD_i P}{e}$$

where

A is the maximum horizontal dimension of the shelf from the inside of the shell plate to the outside of the tube plate (in mm);

D_i is the inside diameter of the boiler (in mm);

e is the thickness of the tube plate (in mm);

P is the design pressure (in N/mm²).

Then for the combustion chamber tube plates, the minimum number of gussets shall be as follows.

1 gusset where C exceeds 25 000;

2 gussets where C exceeds 35 000;

3 gussets where C exceeds 42 000.

And for the smoke box tube plate, the minimum number of gussets shall be as follows.

1 gusset where C exceeds 25 000;

2 gussets where C exceeds 47 000.

3.9.6.2 The shell plates to which the sides of the tube plates are connected shall be not less than 1.5 mm thicker than is required by the formula applicable to shell plates with continuous circularity (see 3.2.2).

3.9.7 Horizontal tube nests in vertical boilers. If vertical boilers have a nest or nests of horizontal tubes, so that there is direct tension on the tube plates due to the vertical load on the boiler ends or to tube plates acting as horizontal ties across the shell, each alternate tube in the outer vertical rows of tubes shall be a stay tube and the thickness of the tube plates shall be determined by the following formula.

$$e = \frac{2PD}{JR_m} + C$$

where

C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;

D is twice the radial distance of the centre of the outer row of tube holes from the axis of the shell (in mm);

e is the thickness of the tube plate (in mm);

J is the efficiency of ligaments between tube holes expressed as a fraction

$$\frac{(S - d)}{S}$$

where

S is the pitch of the tubes in the outer vertical row (in mm);

d is the diameter of the tube holes (in mm).

P is the design pressure (in N/mm²);

R_m is the specified minimum tensile strength at room temperature (in N/mm²).

Tube plates between the stay tubes shall comply with the requirements for tube plates (see 3.9.5).

3.10 Furnaces, furnace components, wet back reversal chambers and fireboxes of cylindrical form subject to external pressure

3.10.1 Furnaces

3.10.1.1 Maximum furnace diameter. The mean diameter of furnaces shall not exceed 1 800 mm.

3.10.1.2 Notation

b	is the pitch of the furnace corrugations (in mm);
C	is the corrosion allowance = 0.75 mm;
d	is the mean diameter of furnace (in mm) (see note 1);
$d_{\max}$	is the maximum mean diameter of the furnace (in mm);
$d_{\min}$	is the minimum mean diameter of the furnace (in mm);
e	is the furnace plate thickness (in mm);
E	is Young's modulus of elasticity (in N/mm ²)
E_t	is the specified minimum elevated temperature yield stress or the 0.2 % proof stress at the design temperature (see 3.1.3.2);
F	is the cross-sectional area of a longitudinal section of the corrugated furnace wall, of length b and thickness $(e - C)$ (in mm ²) [see Figure 3.10.1.2(a) to Figure 3.10.1.2(g)];
I	is the second moment of area of one complete corrugation about its neutral axis, excluding the corrosion allowance (in mm ⁴) [see Figure 3.10.1.2(a) to Figure 3.10.1.2(g)];
I_s	is the second moment of area of a plain stiffener section [see Figure 3.10.1.9.2(a) and Figure 3.10.1.9.2(b)] about its neutral axis, including a length of the furnace of $0.55\sqrt{de}$ on each side of the stiffener (in mm ⁴) (see note 2);
L	is the distance between the centres of two effective points of support (in mm) (see note 3);
P	is the design pressure (in N/mm ²);
S_1	is the factor of safety = 2.5 for furnaces in classes I and II directly fired and waste heat boilers, = 3.5 for furnaces in class III directly fired and waste heat boilers, = 2.0 for tubes not exposed to flame;
S_2	is the factor of safety = 3.0 for classes I and II directly fired and waste heat boilers, = 3.9 for class III directly fired and waste heat boilers;
u	is the percentage out-of-roundness to be taken as 1.5 for plain furnaces and 1.0 for corrugated furnaces;
W	is the depth of corrugation (in mm).

NOTE 1 For corrugated furnaces, mean diameter is equal to inside diameter plus full depth of one corrugation; referring to Figure 3.10.1.2 this is equal to the inside diameter + e + W .

NOTE 2 When calculating I_s , it is only necessary to take into account a corrosion allowance on the furnace gas side.

NOTE 3 Stiffeners complying with Figure 3.10.1.9.2 and boiler and reversal chamber end plates are considered to be effective points of support.

3.10.1.3 Evaluation of Young's modulus at the design temperature. Values of E shall be obtained from the following table (by linear interpolation if required).

Design temperature °C	Values of E N/mm ² × 10 ³
250	195
300	191
350	186
400	181
450	178

3.10.1.4 Plain furnaces. The design pressure of plain furnaces shall be the lower of those obtained using equations (1) and (2) as follows, but the thickness shall be not less than 7 mm and shall not exceed 22 mm.

$$P = \frac{2E_t(e - C)}{S_1 d} \left\{ \frac{1 + \frac{d}{15L}}{1 + \frac{0.03du}{(e - C) \left(1 + \frac{d}{0.3L}\right)}} \right\} \quad (1)$$

$$P = \frac{1.73E(e - C)^{2.5}}{S_2 L d^{1.5}} \quad (2)$$

Equations (1) and (2) may be expressed in terms of thickness using equations (3) and (4), respectively, as follows, and the greater of the thicknesses obtained shall be used.

$$e = \frac{B}{2} \left[1 + \sqrt{1 + \frac{0.12du}{B \left(1 + \frac{d}{0.3L}\right)}} \right] + C \quad (3)$$

where

$$B = \frac{PdS_1}{2E_t \left(1 + \frac{d}{15L}\right)}$$

$$e = d^{0.6} \left(\frac{LS_2P}{1.73E} \right)^{0.4} + C \quad (4)$$

3.10.1.5 Furnace components. The thickness of furnace components, e.g. ash drop-out tubes and fuel inlet connections, shall be calculated in accordance with 3.10.1.4, with a minimum thickness of 10 mm and a maximum thickness of 22 mm.

Compensation for openings in furnaces shall be provided in accordance with 3.4 except that the use of pad reinforcement is not permitted and neither furnace nor branch shall have a thickness exceeding 22 mm.

3.10.1.6 Corrugated furnaces. The design pressure of corrugated furnaces shall be determined using the following equation but the thickness shall be not less than 10 mm and shall not exceed 22 mm.

$$P = \frac{2FE_t \left(1 + \frac{0.1d}{L}\right)}{S_1 bd \left[1 + \frac{FWdu}{800I \left\{ 1 + \frac{5d}{L} \left(\frac{e - C}{W} \right)^3 \right\}} \right]}$$

3.10.1.7 Tolerances and corrosion allowances. The calculated wall thickness contains a fixed allowance of 0.75 mm for corrosion and wear. For corrugated furnaces the calculated wear thickness shall be the minimum thickness of the finished furnace. For plain furnaces and reversal chambers, allowance shall be made to take account of any minus tolerances on the plate thickness.

3.10.1.8 Out-of-roundness. The percentage out-of-roundness is as follows.

$$u = \frac{200(d_{\max} - d_{\min})}{d_{\max} + d_{\min}}$$

This shall be included in the calculation as $u = 1.0$ for corrugated furnaces and $u = 1.5$ for plain furnaces.

3.10.1.9 Stiffeners

3.10.1.9.1 Stiffeners shall have a second moment of area not less than given by the following equation.

$$I_s = \frac{Pd^3 L}{1.33 \times 10^6}$$

3.10.1.9.2 If stiffeners are made in sections from bar or plate, the abutting ends shall be prepared so as to ensure that full penetration welds are made.

The thickness of the stiffening ring shall be kept to the minimum required [for limiting dimensions see Figure 3.10.1.9.2(a) and Figure 3.10.1.9.2(b)]. Full penetration welds shall be used to attach stiffeners to furnaces.

3.10.1.9.3 Bowling hoops are considered as effective points of support. The minimum pitch of bowling hoop centres shall, for calculation purposes, be taken as not less than 500 mm. If bowling hoops are used, the furnace thickness shall be calculated from **3.10.1.4**. The dimensions of bowling hoops shall be in accordance with Figure 3.10.1.9.3(a), Figure 3.10.1.9.3(b) and Figure 3.10.1.9.3(c) and their second moment of area, determined from the tables given in these figures, shall be not less than required by **3.10.1.9.1**.

3.10.1.9.4 If corrugated furnaces are equipped with several stiffeners, e.g. one on each corrugation or on each second corrugation, the cross-sectional area and the second moment of area of the stiffeners shall also be taken into consideration when using the equation given in **3.10.1.6**. A height of not more than six times the furnace thickness shall be used for the calculation.

3.10.1.10 Flexibility

3.10.1.10.1 Plain furnaces shall not exceed 3 m in length except in the case of reverse flame boilers, which are considered to be inherently flexible. In all other cases flexibility shall be provided in the furnace by means of corrugations or bowling hoops. If corrugations are used to provide flexibility, at least one-third of the furnace length shall be corrugated.

3.10.1.10.2 If the length of the plain portion of a corrugated furnace does not exceed 250 mm, it is not necessary to calculate the thickness. If the length of the plain portion of a corrugated furnace exceeds 250 mm, the total length of both sections shall be used for calculating the thickness of the corrugated furnace and 1.5 times the length of the plain sections shall be used for calculating the thickness of the plain section.

3.10.2 Reversal chambers

3.10.2.1 The thickness of wrapper plates of cylindrical reversal chambers of horizontal multi-tubular boilers shall be calculated in accordance with the equations given in **3.10.1.4**. Where non-circular geometry is employed using plates of differing radii, the thickness shall be calculated using the maximum radius. Where the use of reversed curvature sections is involved, a check shall be made that the sections will sustain the design pressure without the design stress being exceeded and, if necessary, the thickness appropriately increased. A suggested method is given in Appendix G. The thickness shall be not greater than 35 mm and shall be not less than 10 mm.

3.10.2.2 The thickness of access tubes shall be calculated in accordance with **3.10.1.4** with a minimum thickness of 10 mm.

3.10.3 Fireboxes and associated components

3.10.3.1 Fireboxes of vertical boilers. The thickness of fireboxes shall be obtained by use of the equations given in **3.10.1.4**, where all the symbols have the same significance except that

- d* is the mean diameter of firebox (in mm).
If the firebox is tapered, the diameter taken shall be the mean of that at the top and at the bottom where it meets the substantial support from the flange or ring;
- L* is the effective length (in mm) of the firebox as indicated in Figure 3.1(5)(b).

In no case shall the thickness be less than 10 mm, nor shall it exceed 22 mm, and the mean diameter of fireboxes shall not exceed 1 800 mm.

3.10.3.2 Uptakes. The thickness of uptakes shall be obtained by use of the equations given in **3.10.1.4** using a corrosion allowance of 4 mm instead of 0.75 mm.

3.10.3.3 Cross tubes. Cross tubes shall not exceed 300 mm internal diameter. The thickness shall be determined from the equation given in **3.2.2** but in no case shall it be less than 10 mm.

3.10.3.4 Hemispherical fireboxes. The minimum thickness of unsupported hemispherical fireboxes subject to pressure on the convex surface shall be determined in accordance with **3.10.3.5** but the thickness shall be not less than 10 mm and shall not exceed 22 mm.

3.10.3.5 Spherical shells under external pressure

3.10.3.5.1 General. The design of spherical shells shall be checked to ensure that neither elastic instability nor membrane yield occur. The allowable design pressure shall be the smaller of the values of P obtained in 3.10.3.5.2 and 3.10.3.5.3.

3.10.3.5.2 Calculation of elastic instability. The design pressure P shall be determined from the following equation.

$$P = \frac{0.8E}{9 + 0.006 (R_o/e)} \left(\frac{e}{R_o} \right)^2,$$

where

- e is the thickness (in mm);
- E is Young's modulus at the design temperature (in N/mm²);
- P is the design pressure (in N/mm²);
- R_o is the outside radius (in mm);

3.10.3.5.3 Calculations of membrane yield. The design pressure P shall be determined from the following equation.

$$P = \frac{0.833eE_t}{R_o}$$

where

- E_t is the lower yield stress or 0.2 % proof stress at the design temperature (in N/mm²).

The remaining symbols are as in 3.10.3.5.2.

3.10.3.6 Dished ends having pressure on the convex side (excluding the top end plates of vertical boiler fireboxes); see 3.3.6.

3.10.3.6.1 Dished heads shall comply with the shape limitations given in 3.3. Hemispherical heads shall be designed as spherical shells, in accordance with 3.10.3.5.

3.10.3.6.2 Torispherical heads shall be designed as spherical shells as outlined in 3.10.3.5 and in addition the thickness shall not be less than 1.2 times the thickness required for a head of the same shape subject to internal pressure.

3.10.3.6.3 Semi-ellipsoidal heads shall be designed as spherical shells as required by 3.10.3.5, taking the maximum radius of the crown as the equivalent spherical radius, and in addition the thickness shall not be less than 1.2 times the thickness required for a head of the same shape subject to internal pressure.

3.10.3.7 Ogee rings and base flanges

[see Figure 3.10.3(a) and Figure 3.10.3(b)]. The thickness of the Ogee ring or base flange which connects the bottom of the firebox to the shell of a vertical boiler and sustains the whole vertical load on the firebox shall be determined as follows.

$$e_g = \sqrt{\left(\frac{PD_i (D_i - d_o)}{990} \right)} + C$$

where

- C is the corrosion allowance, to be taken as 0.75 mm unless a higher figure is agreed to take account of adverse conditions;
- d_o is the outside diameter of the lower part of the firebox where it joins the Ogee ring or base flange (in mm);
- D_i is the inside diameter of the boiler shell (in mm);
- e_g is the thickness of the Ogee ring or base flange [in (mm)];
- P is the design pressure (in N/mm²).

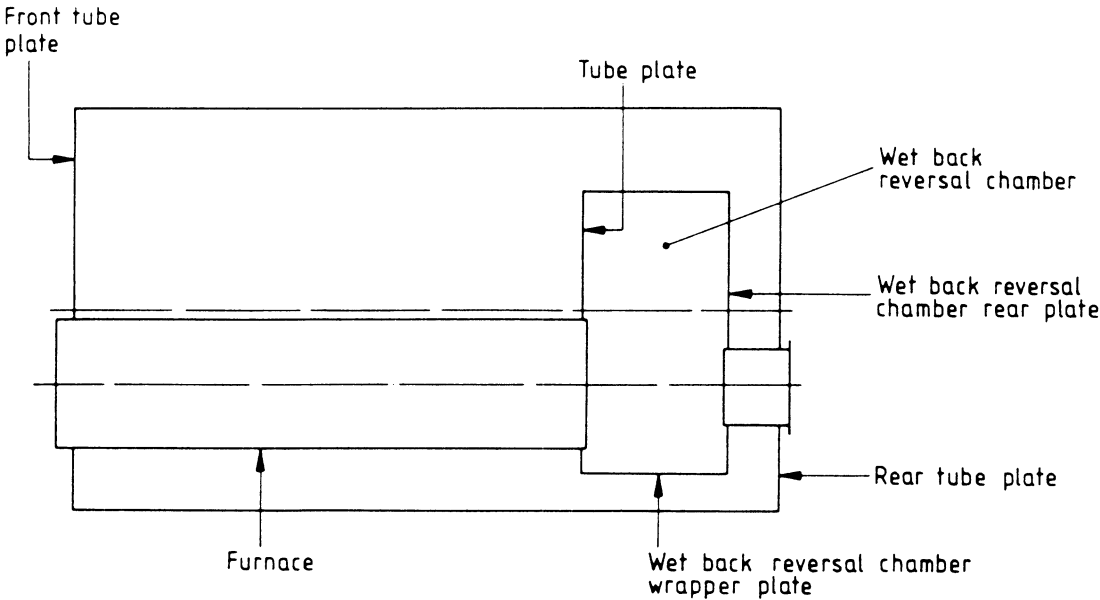
3.10.3.8 U-rings. Where a U-ring section is used as shown in Figure 3.10.3(c) the thickness obtained from the equation given in 3.10.3.7 shall be increased by 20 %.

3.10.3.9 Firebox plates under compression. The thickness of firebox tube plates under compression due to the pressure on the crown plate, based on a compressive stress of 97 N/mm², shall not be less than that given by

$$e = \frac{PIV}{193(V - d_i)}$$

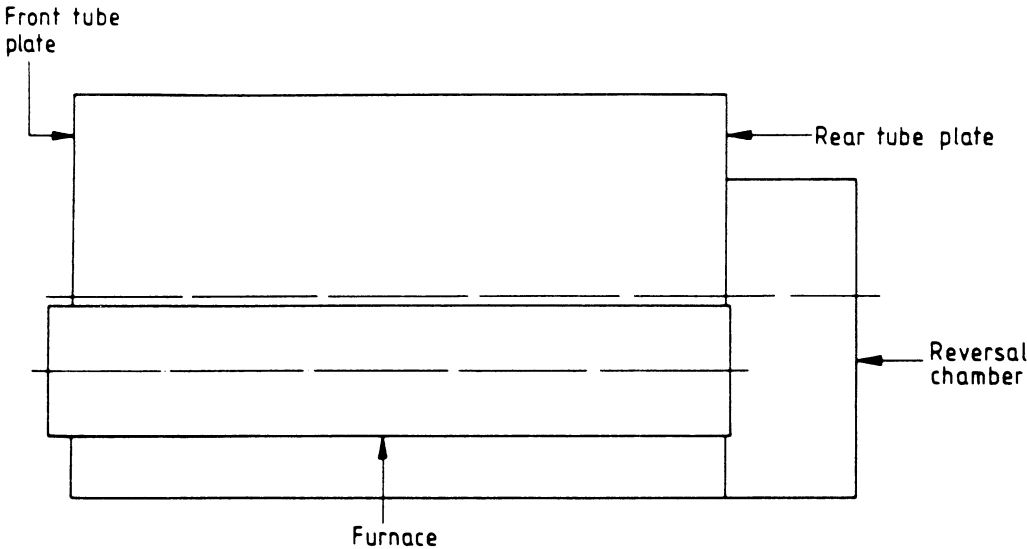
where

- d_i is the internal diameter of the plain tubes (in mm);
- e is the thickness of the plate (in mm);
- l is the internal length of firebox (in mm) measured at the top between the tube plate and the back plate;
- P is the design pressure (in N/mm²);
- V is the pitch of tubes (in mm) measured horizontally where the tubes are chain pitched, or diagonally where the tubes are zig-zag pitched and the diagonal pitch is less than the horizontal pitch.



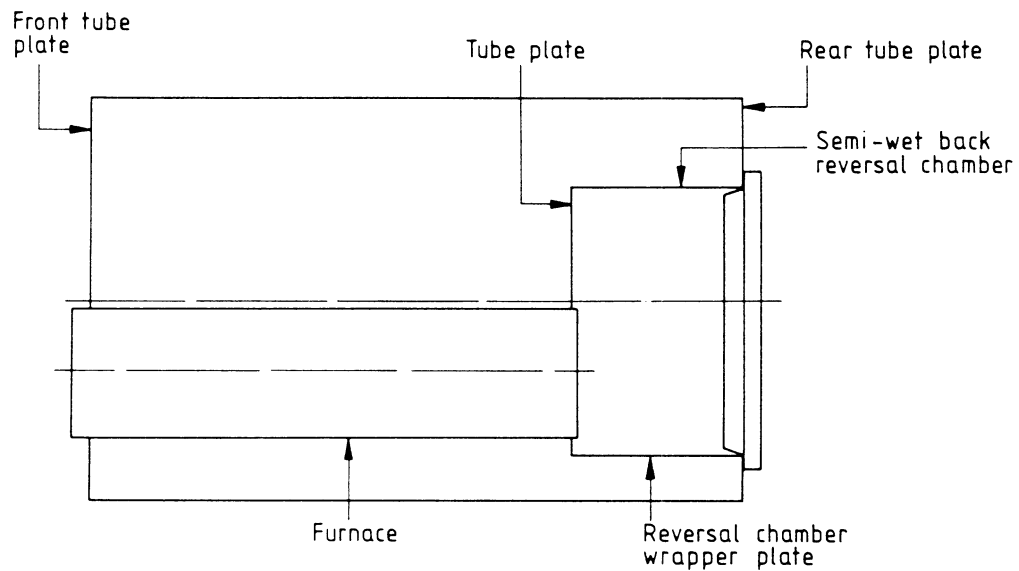
NOTE The radiant heating surface consists of the furnace, the wrapper plate and the wet back rear plate.

Figure 3.1(1) — Wet back boiler



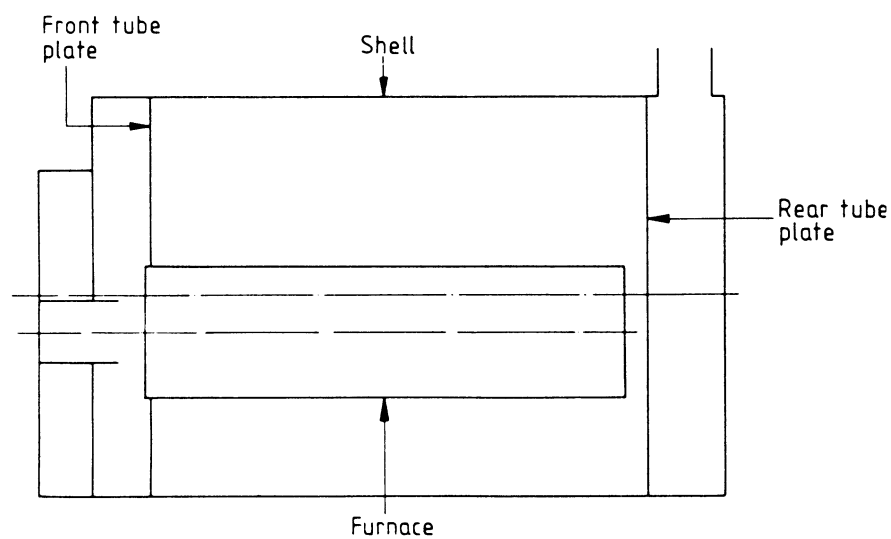
NOTE The radiant heating surface consists of the furnace.

Figure 3.1(2) — Dry back boiler



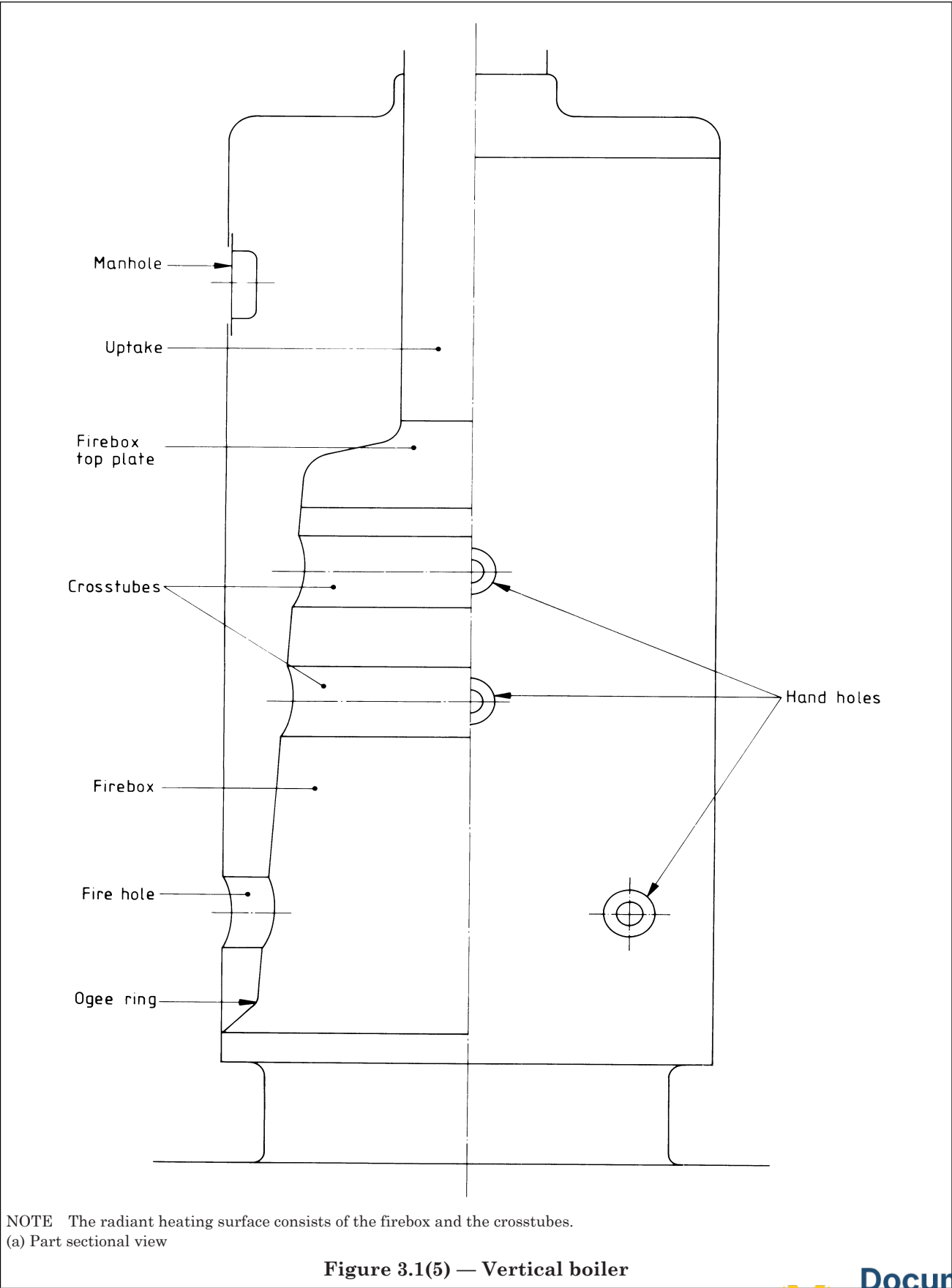
NOTE The radiant heating surface consists of the furnace and the wrapper plate.

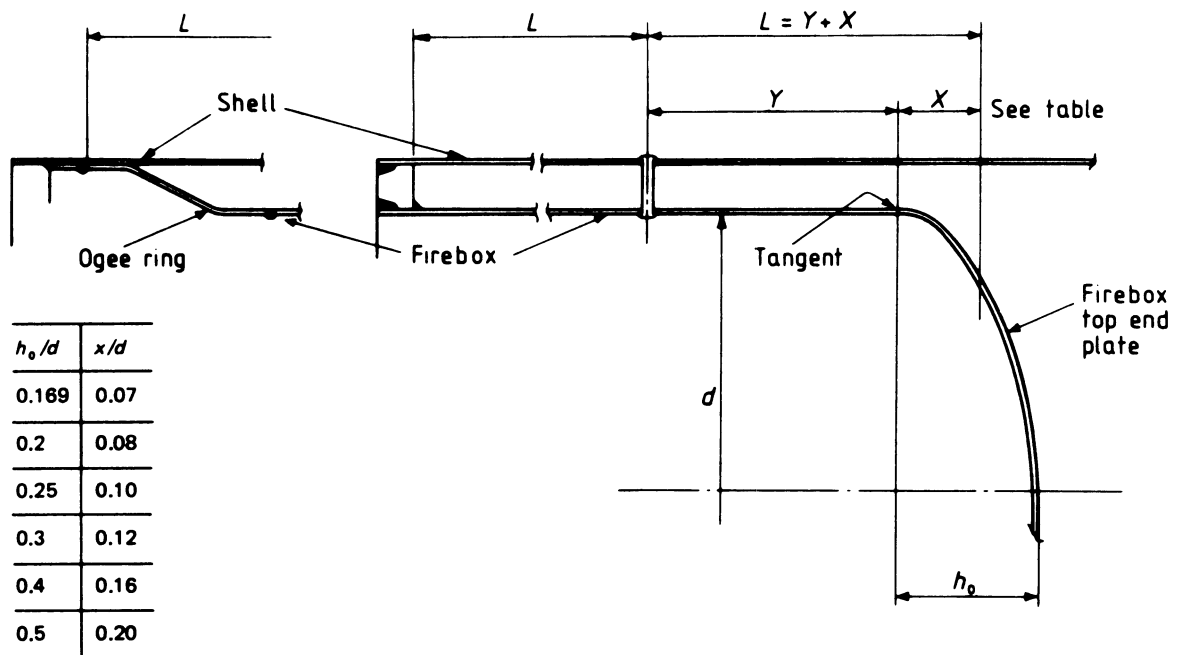
Figure 3.1(3) — Semi-wet back boiler



NOTE The radiant heating surface consists of the furnace.

Figure 3.1(4) — Reverse fired boiler





(b) Firebox showing the effective length L for use in the equations given in 3.10.1.4

Figure 3.1(5) — Vertical boiler (concluded)

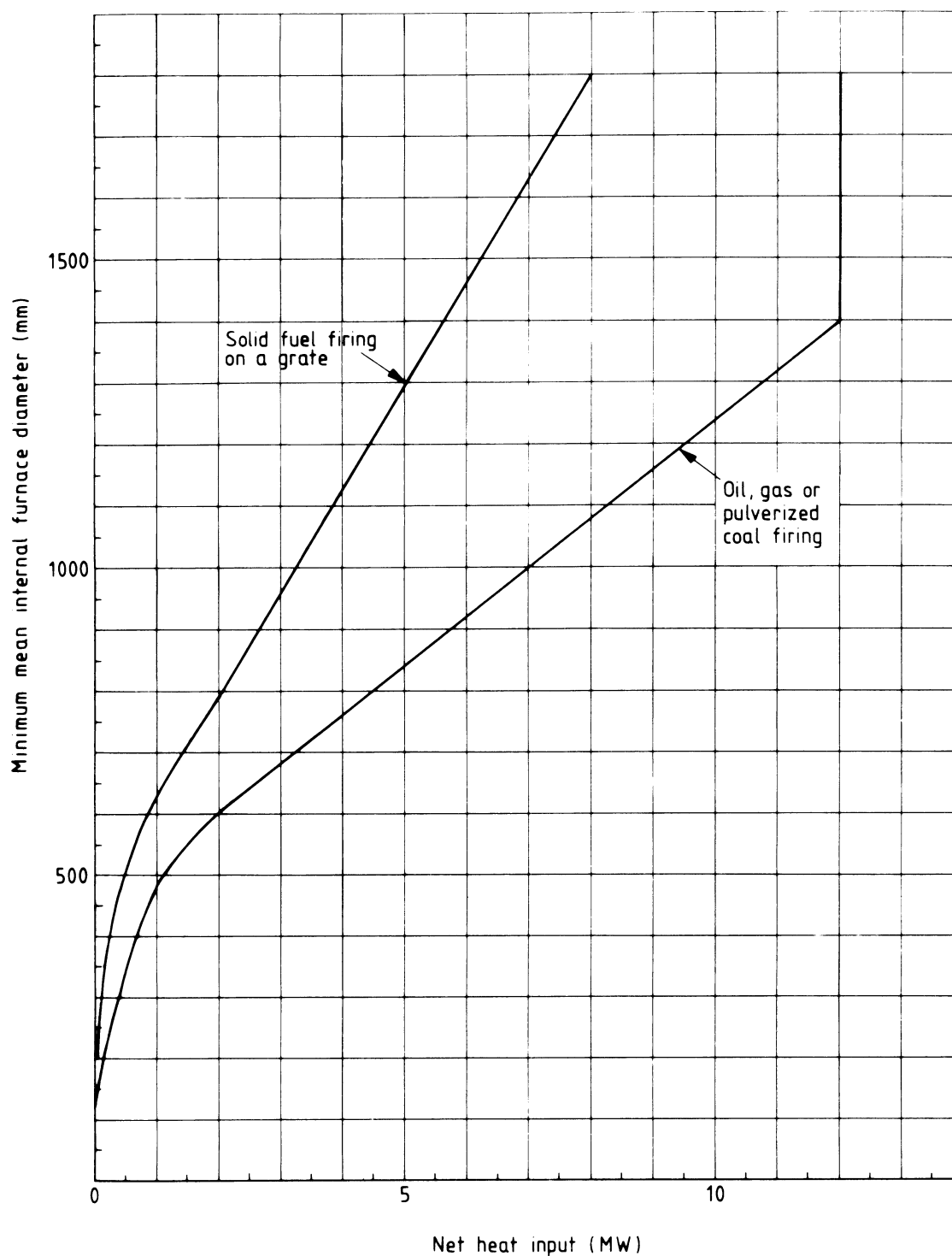
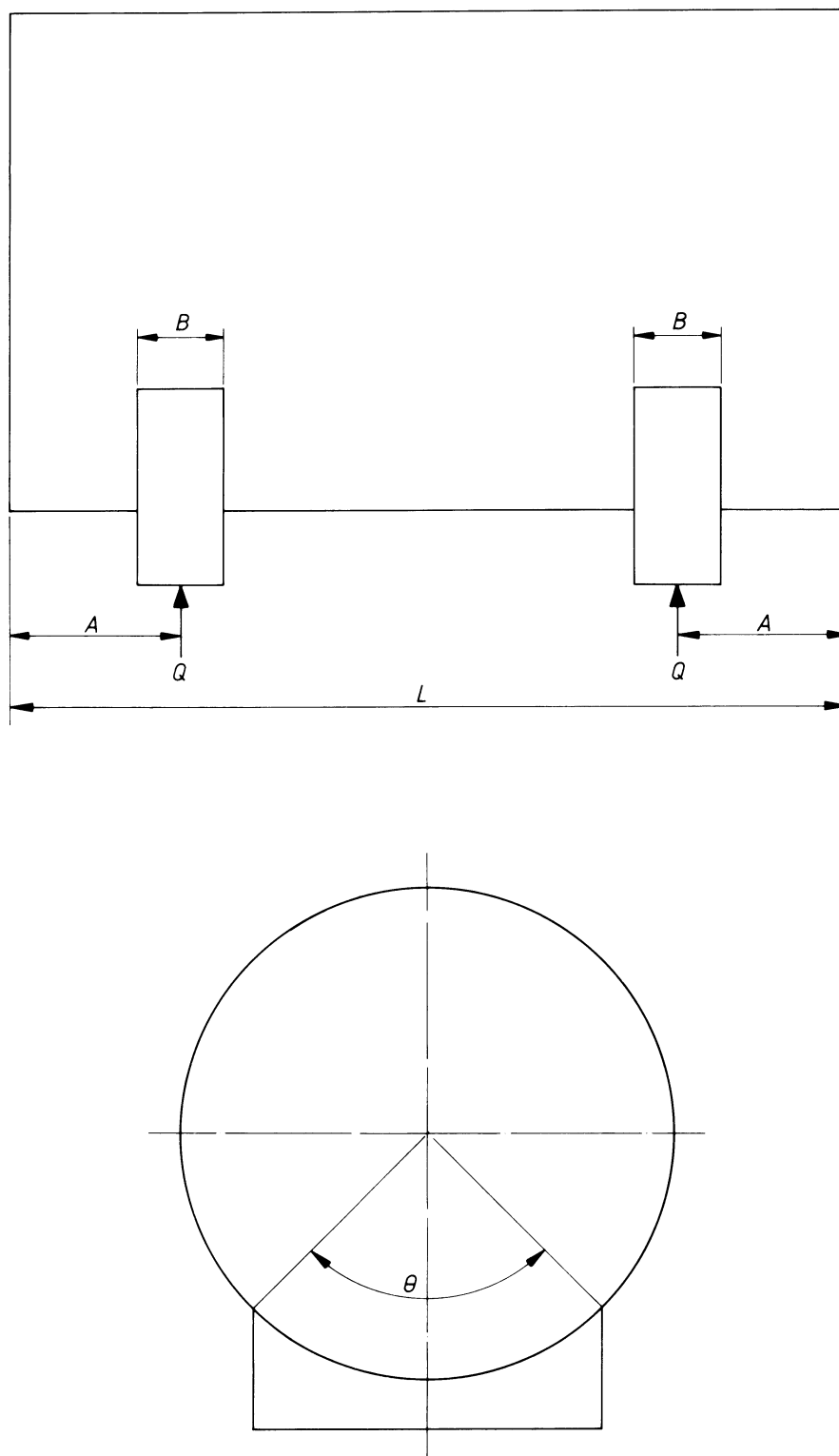
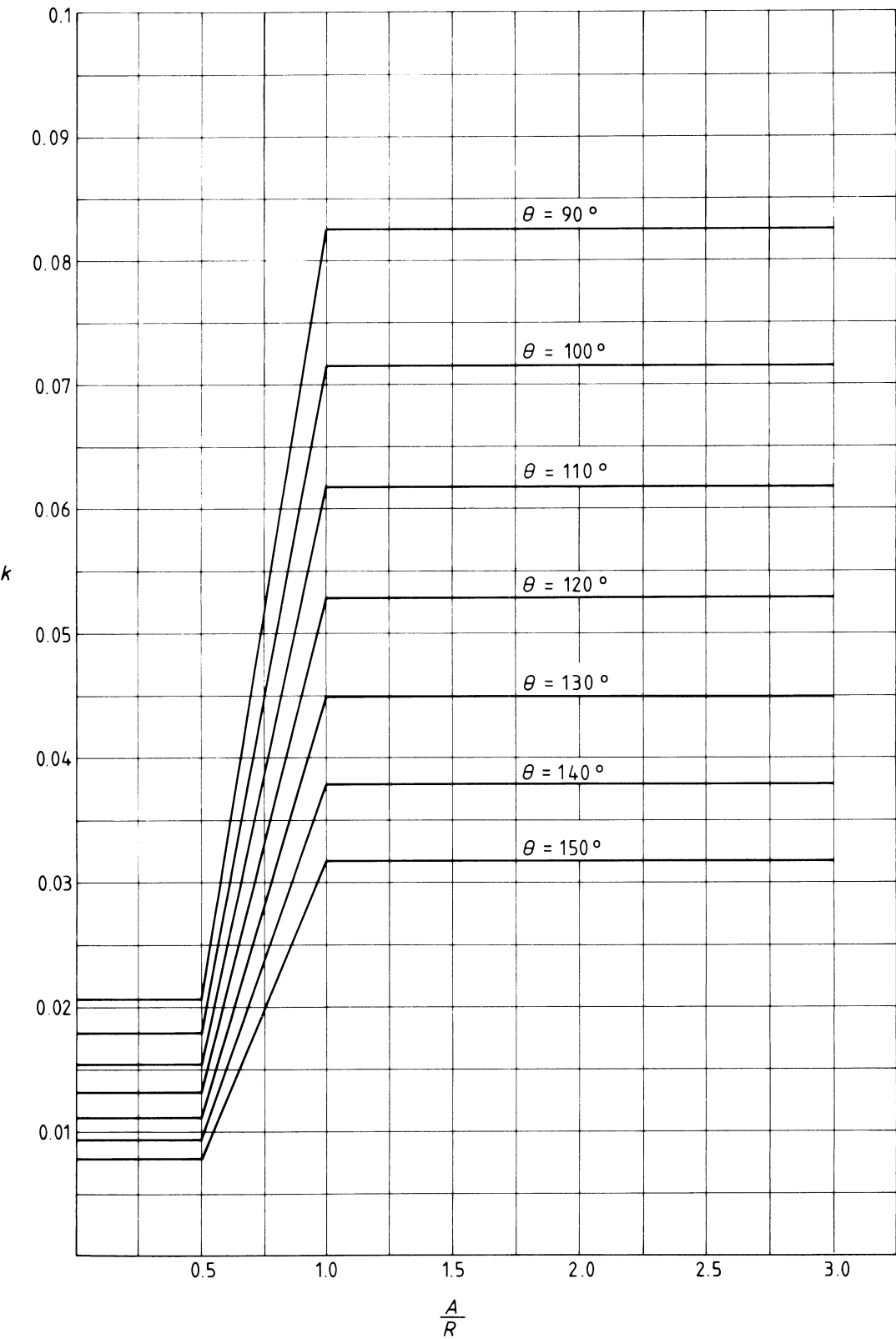


Figure 3.1(6) — Relationship between furnace diameter and permissible heat input



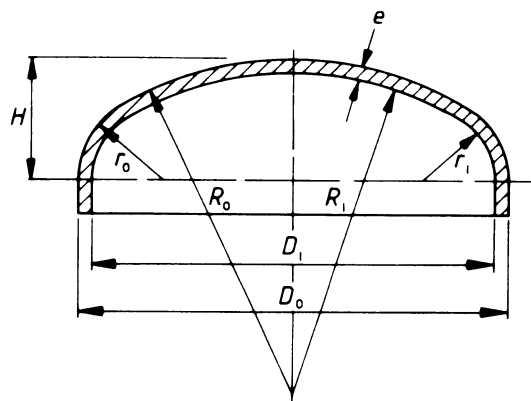
(a) Explanation of notation

Figure 3.2.5.2 — Design of saddle supports

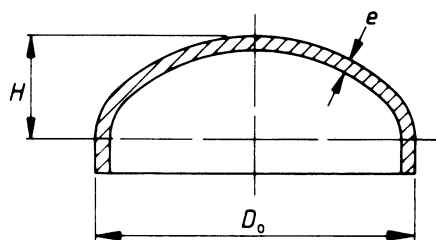


(b) Evaluation of coefficient k

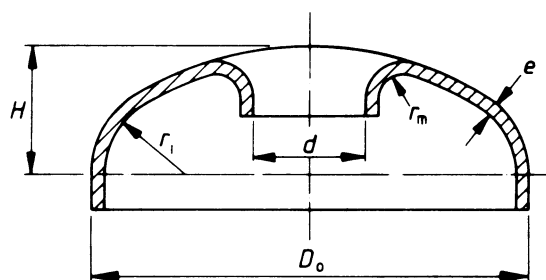
Figure 3.2.5.2 — Design of saddle supports (concluded)



(a) Torispherical end



(b) Semi-ellipsoidal end



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

Figure 3.3(1) — Typical dished ends

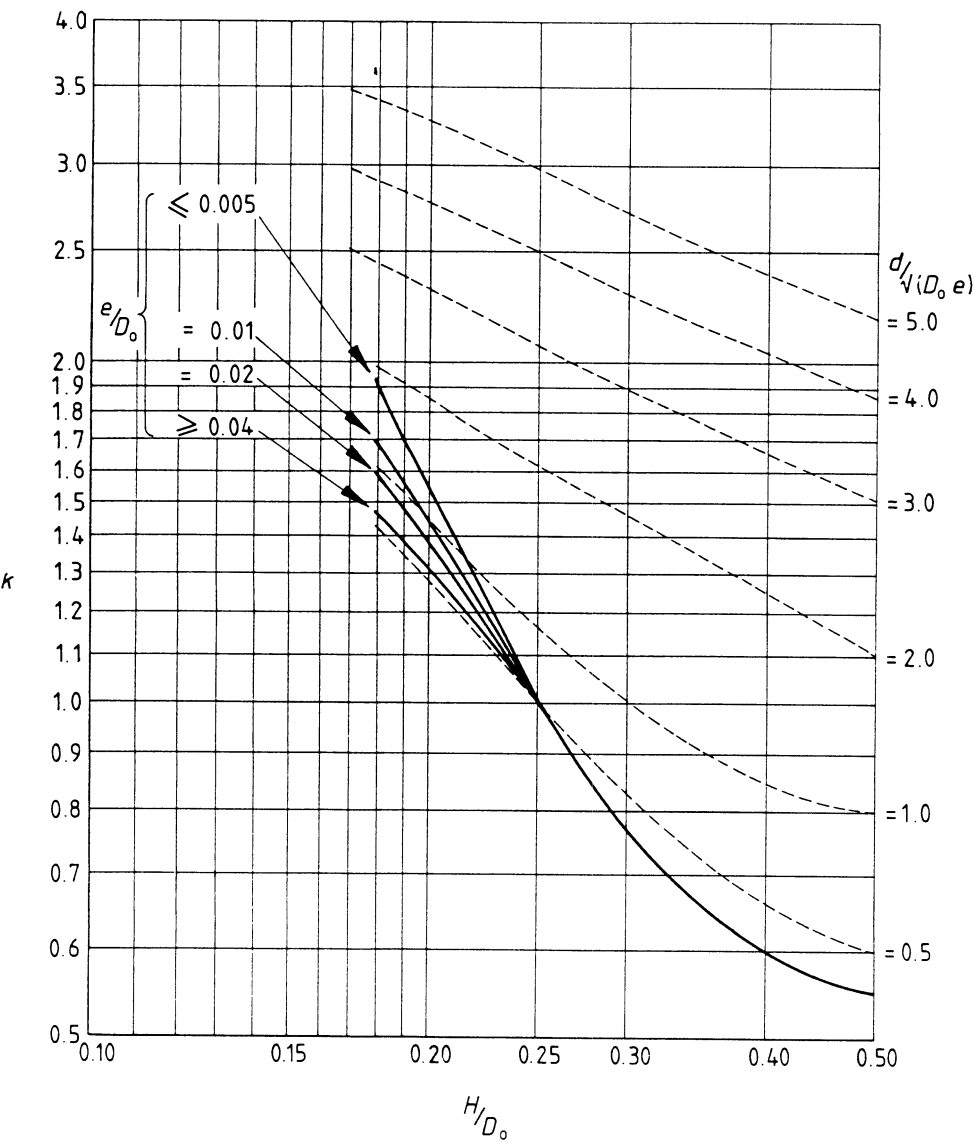
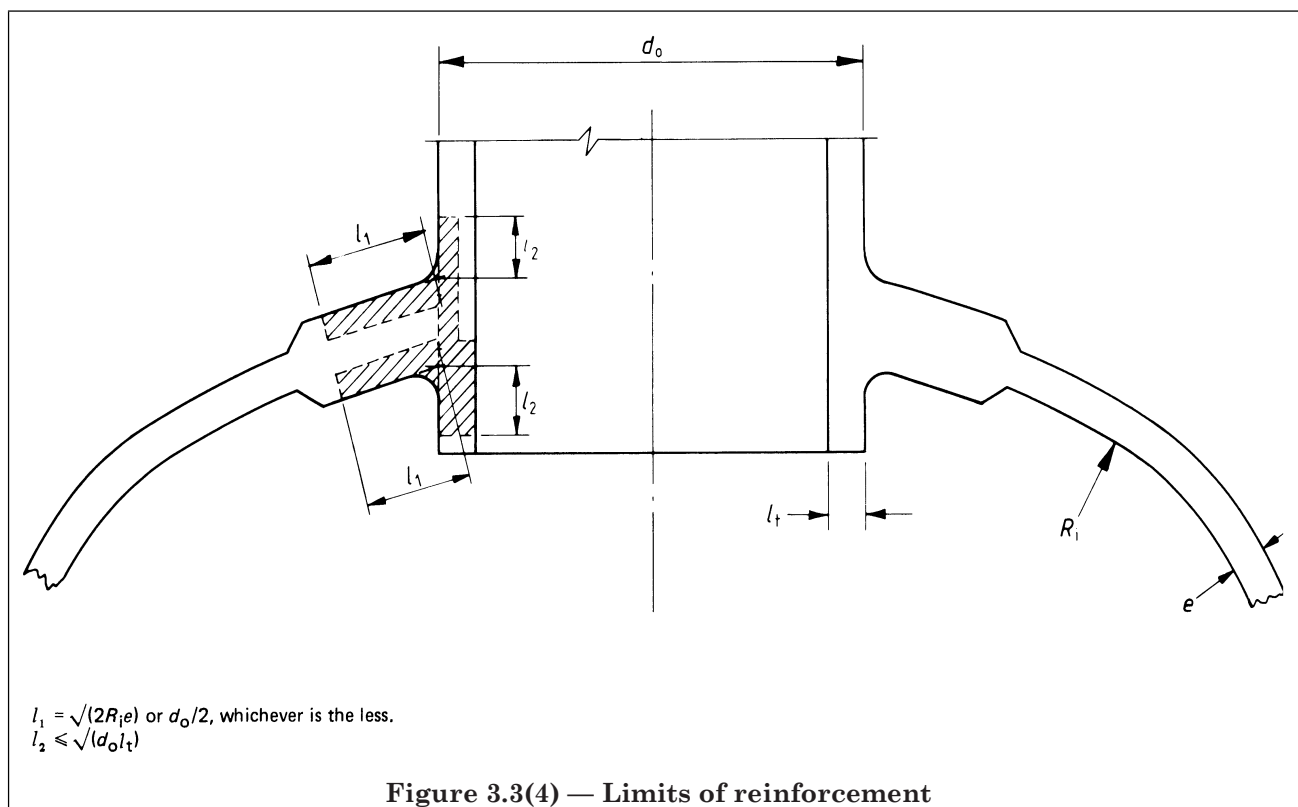
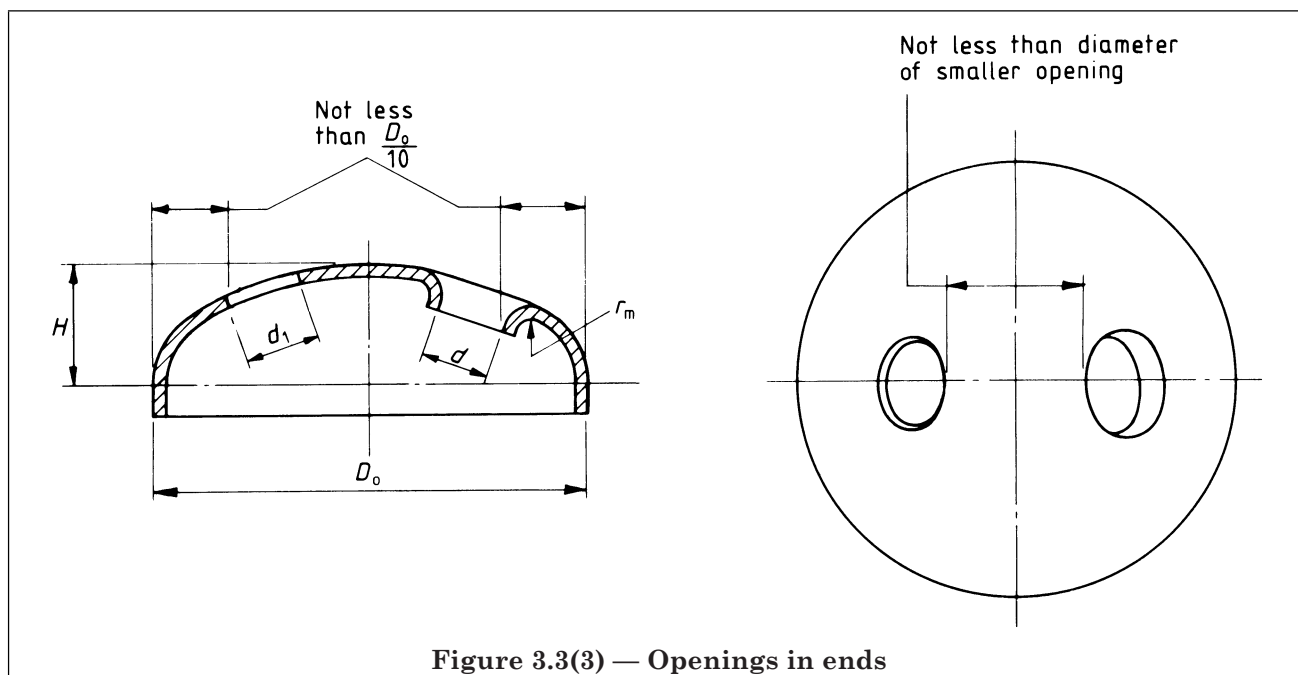
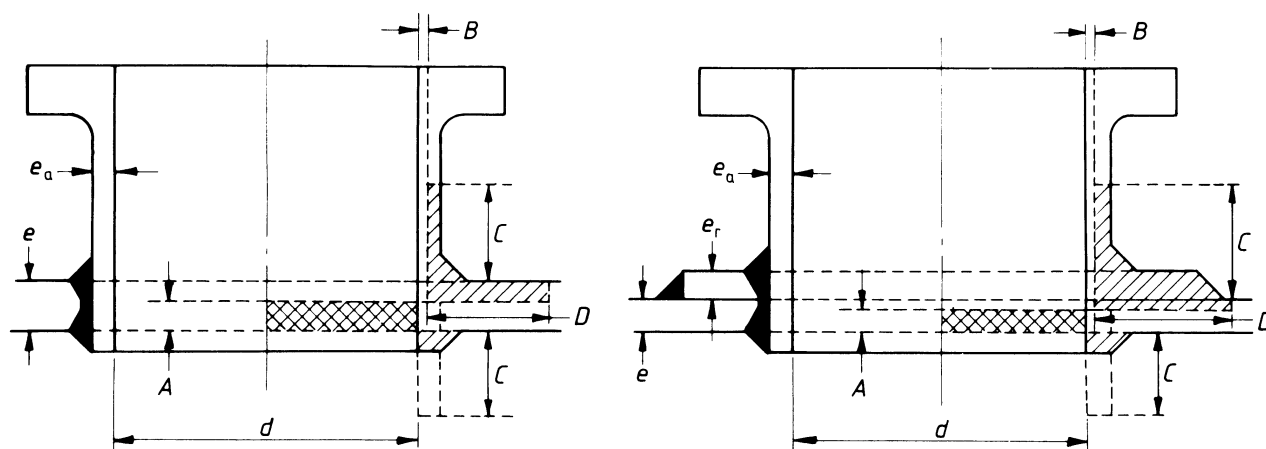


Figure 3.3(2) — Shape factor





(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 $(2.5e_a + e_r)$.

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

X is the area requiring compensation, denoted by 

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 3.4.4 — Compensation of welded branch up to one-third of the diameter of the boiler shell