BRITISH STANDARD

BS 2790:1992

Incorporating Amendment Nos. 1, 2, 3 and 4

Specification for

Design and manufacture of shell boilers of welded construction

ICS 27.060.30

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Pressure Vessel Standards Policy Committee (PVE/-) to Technical Committee PVE/16, upon which the following bodies were represented:

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

This British Standard, having been prepared under the direction of the Pressure Vessel Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 1 January 1992

First published December 1956
Second edition as BS 2790-1 February 1969 and BS 2790-2 August 1973
Third edition August 1982
Fourth edition May 1986
Fifth edition April 1989
Sixth edition January 1992

The following BSI references relate to the work on this standard:
Committee reference PVE/16

ISBN 0 580 20075 2

Amendments issued since publication

Amd. No.	Date	Comments
7437	October 1992	
8435	March 1995	
9346	December 1996	
9551	July 1997	Indicated by a sideline in the margin

Contents

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British Standard, first published in 1956 under the title "*Cylindrical land steam boilers of welded construction*", superseded by BS 2790-1 in 1969 and BS 2790-2 in 1973, and subsequently revised in 1982, 1986 and 1989, has been prepared under the direction of the Pressure Vessel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 This edition supersedes BS 2790:1989 which is withdrawn.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

blank

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 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 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 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/documented 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	490 E
		221 or 223	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
				mm	N/mm^2	N/mm^2	N/mm^2	N/mm^2
Plate	1501-1 (withdrawn)	151 and 161	400 A	⩽ 16 > 16 ⩽ 40 > 40 ⩽ 63 > 63 ⩽ 100	163 155 152 147	136	128	125
			430 A	⩽ 16 > 16 ⩽ 40 > 40 ⩽ 63 > 63 ⩽ 100	180 170 167 161	151	143	139
		164	400 A	⩽ 63	171	152	143	134
		223	460 A 490 A	⩽ 63 ⩽ 63	213 225	195 206	184 193	172 183
Tube	3059-1	HFS CFS ERW	320	— — —	125	100	91	88
	3601	S ERW	320 360 430	— — —	125 145 170	100 122 154	91 111 142	88 109 134
Sections and bars	1502	151, 161 211 and 221	430	⩽ 16 > 16 ⩽ 40 > 40 ⩽ 63 > 63 ⩽ 100	180 170 167 161	151	143	139
Forgings	1503	164	490	⩽ 100	200	180	171	162
		221	410 430 460 490	⩽ 100 ⩽ 100 ⩽ 100 ⩽ 100	157 167 188 197	141 150 165 180	133 144 157 172	129 139 152 166
		223	410 430 460 490	⩽ 100 ⩽ 100 ⩽ 100 ⩽ 100	169 180 197 214	149 160 178 195	139 150 167 184	129 141 157 172

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 m^2) [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.

$t = (t_s + 2e_1)$, or

$t = (t_s + 25)$, 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.

$t = (t_s + 2e_2)$, or

$t = (t_s + 50)$, 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 refractoy 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.

$t = t_s + 4e_2 + 15$

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/mm^2) (see **3.1.4**);

P is the design pressure (in N/mm^2);

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:

a) The ratio of the outside radius to the inside radius does not exceed 1.5.

b) In the case of welded shells, the mid-thickness lines are an extension of each other at each longitudinal joint.

Deviations of alignment due to manufacturing imperfections shall not exceed the values indicated in **5.4.10** and **5.4.11**.

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

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

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

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) ($\geqslant 10e$);
- 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 1.5f.

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

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

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

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

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)]:

$$0.005\,D_o \leqslant e \leqslant 0.08\,D_o$$
$$R_i \leqslant D_o$$
$$r_i \geqslant 0.1\,D_o$$
$$r_i \geqslant 2e$$
$$H \geqslant 0.18\,D_o$$

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

$$0.005\,D_o \leqslant e \leqslant 0.08\,D_o$$
$$H \geqslant 0.18\,D_o$$

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

$$0.005\,D_o \leqslant e \leqslant 0.16\,D_o$$

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.

$$e = \frac{PD_oK}{2f} + C$$

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 mm^2) [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.

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

$\frac{d}{D_o}$ 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:

a) the effective width l_1 of reinforcement shall not exceed $\sqrt{2R_i e}$ or $d_o/2$, whichever is the less;

b) 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.

a) Calculate the sectional area of reinforcement both inside and outside the end plate within the length l_1;

b) 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;

c) add to it the full sectional area of that part of the stern 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/mm^2) (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/mm^2);

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/mm^2) (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/mm^2);

Ri 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/mm^2) (see **3.1.4**);

P is the design pressure (in N/mm^2);

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.

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

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 he 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

a_i is the inner major axis of the compensating plate (in mm);

a_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 mm^2), 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_{rep} or (2.5 e_b + e_{rp}) (in mm);

d_{ib} is the bore of the branch opening (in mm);

D is the greater of the two values: (e_{rep} + 75) or (d_{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:

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

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.

a) 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.

b) 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.

c) 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_{rep}. The depth of the ring h_f shall be not less than $\sqrt{(e_{sr}\,W)}$.

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/mm^2);
- 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/mm^2).

NOTE A design stress value of 50 N/mm^2 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/mm^2) (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/mm^2);

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 1.0.

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/mm^2) (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/mm^2);

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/mm^2 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/mm^2 on the net section, or for parts in shear, a stress of 55 N/mm^2 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
Flat end plate or tube plate attachments to shell	
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 ⩽ 1.6	0.36
> 1.6 ⩽ 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
Reversal chamber or firebox flat tube plate or end plate attachment to wrapper plates	
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
Flat end plate attachment to reversal chamber access tube	
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
Flat end plate attachment to furnaces	
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).

$$\frac{DL_1}{L_2^{\,2}} \leqslant 2.0$$

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).

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

$$e_2 \leqslant b \leqslant 1.7e_2$$

$$b \geqslant 0.7e_1$$

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/mm^2);
- 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/mm^2, 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/mm^2 shall be so designed that the crushing stress on the projected area does not exceed 103 N/mm^2.

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/mm^2) (see **3.1.4**);
- P is the design pressure (in N/mm^2).

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/mm^2.

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/mm^2) (see **3.1.4**);
- P is the design pressure (in N/mm^2).

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:

$$C = \frac{AD_iP}{e}$$

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/mm^2).

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/mm^2);
- R_m is the specified minimum tensile strength at room temperature (in N/mm^2).

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	Values of E
°C	N/mm² × 10³
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.

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

$$P = \frac{1.73E\,(e - C)^{2.5}}{S_2 L d^{1.6}} \quad (2)$$

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.

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

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, less shall be not 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/mm^2);
- P is the design pressure (in N/mm^2);
- 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/mm^2).

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 lead 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/mm^2).

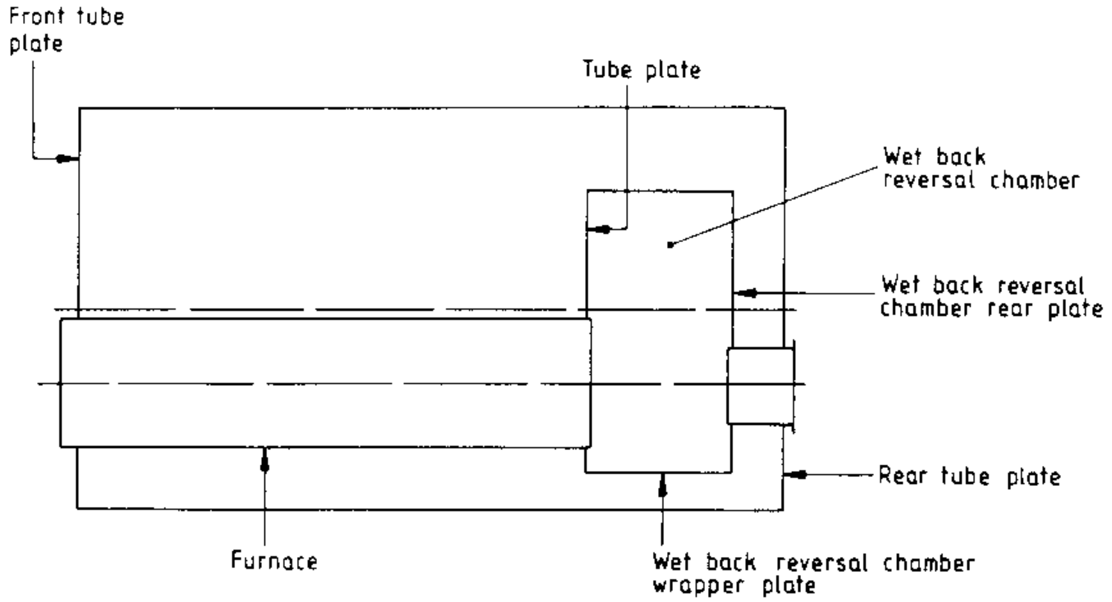
3.10.3.8 *U-rings.* Where a U-ring section is used as shown in Figure 3.10.3(c) the thickness obtained from the equation given in **3.10.3.7** shall be increased by 20 %.

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/mm^2, shall not be less than that given by

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

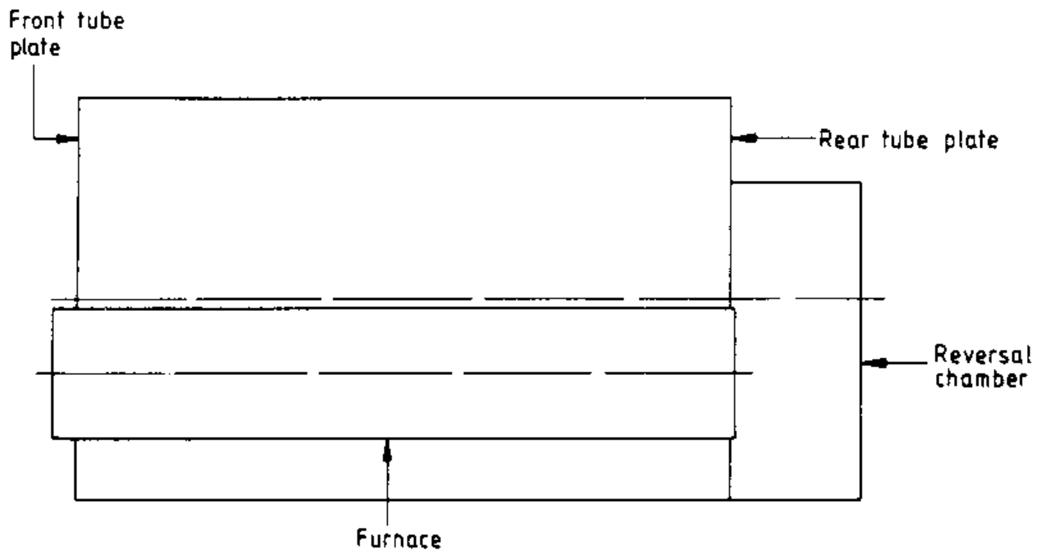
where

- 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/mm^2);
- 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.



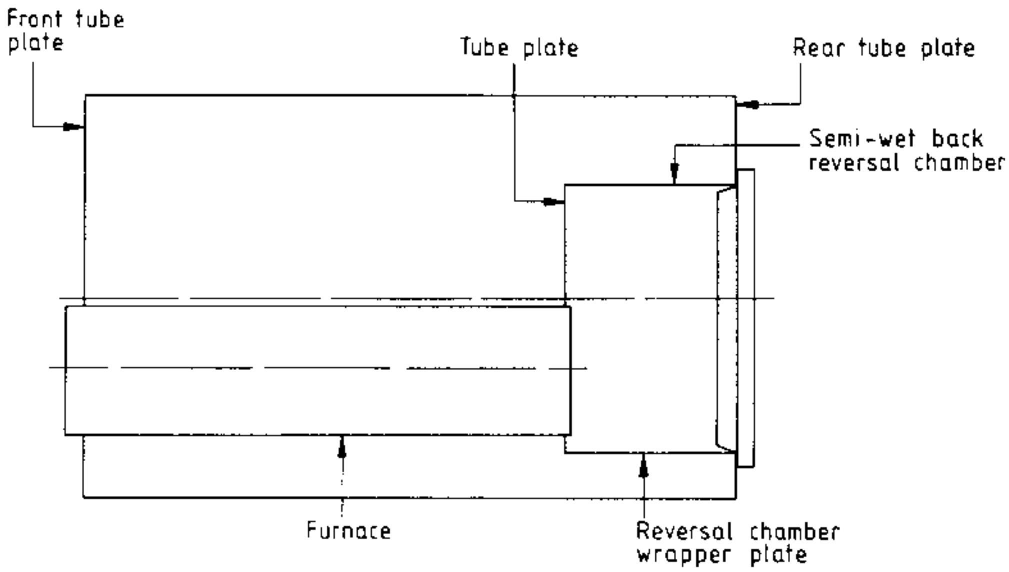
NOTE The radiant heating surface consists of the furnace, the wrapper plate and the wet back rear plate.

Figure 3.1(1) — Wet back boiler



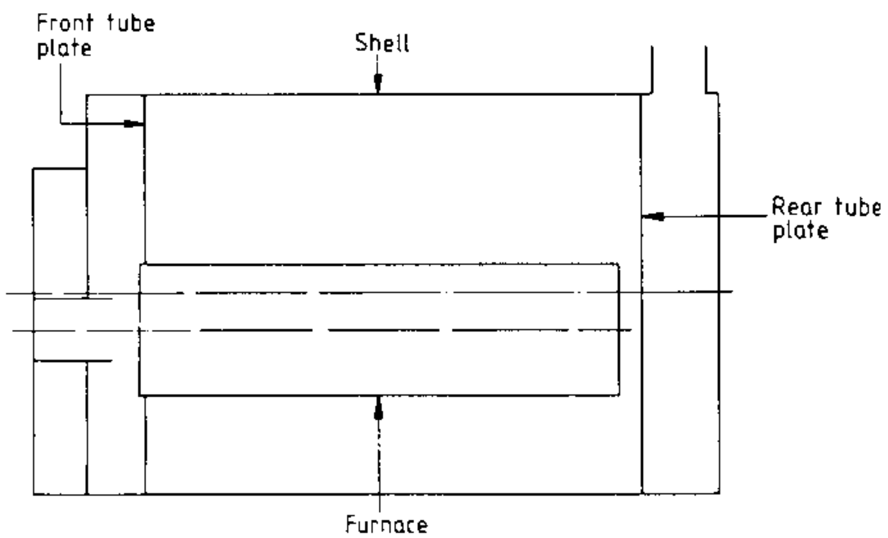
NOTE The radiant heating surface consists of the furnace.

Figure 3.1(2) — Dry back boiler



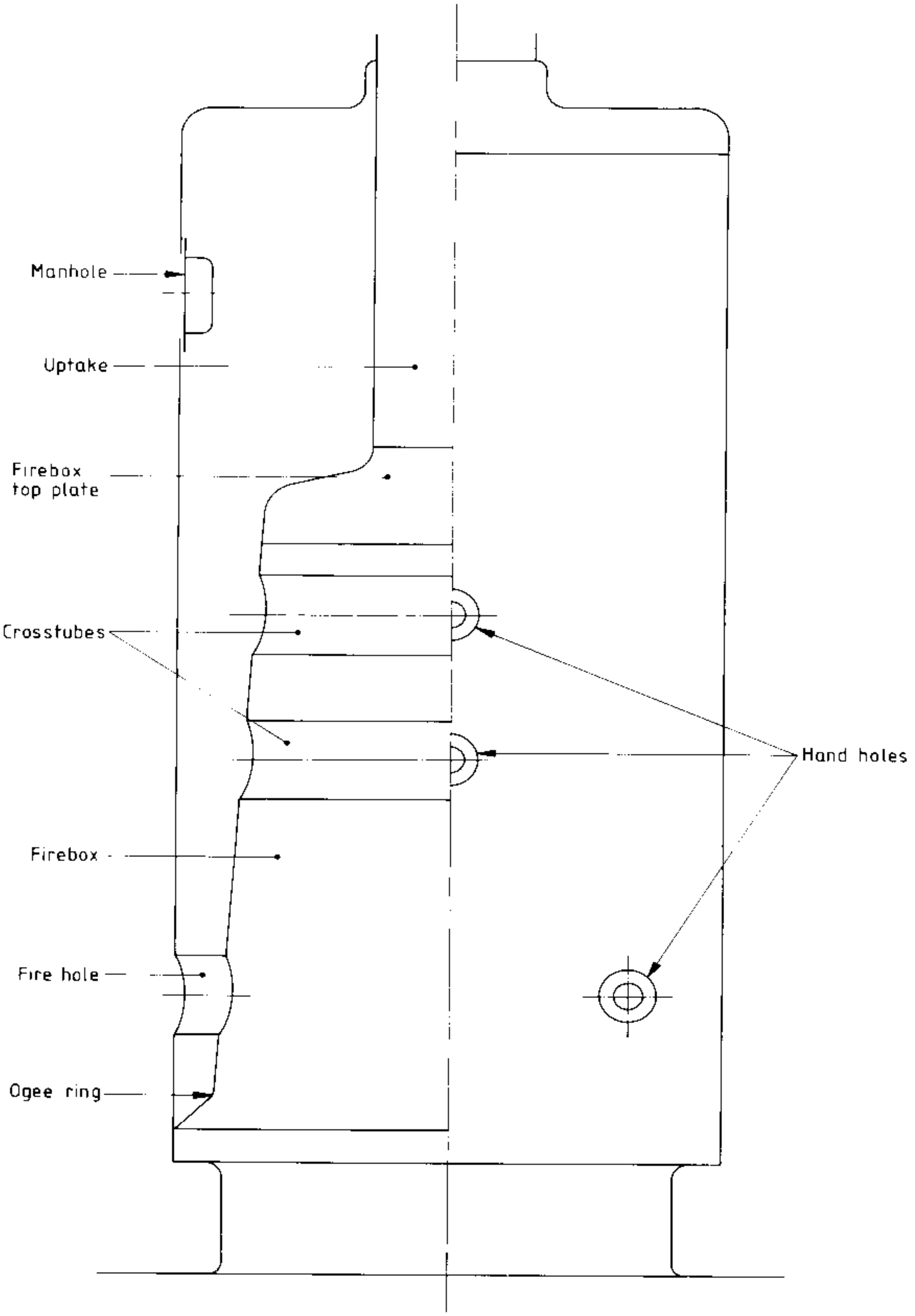
NOTE The radiant heating surface consists of the furnace and the wrapper plate.

Figure 3.1(3) — Semi-wet back boiler



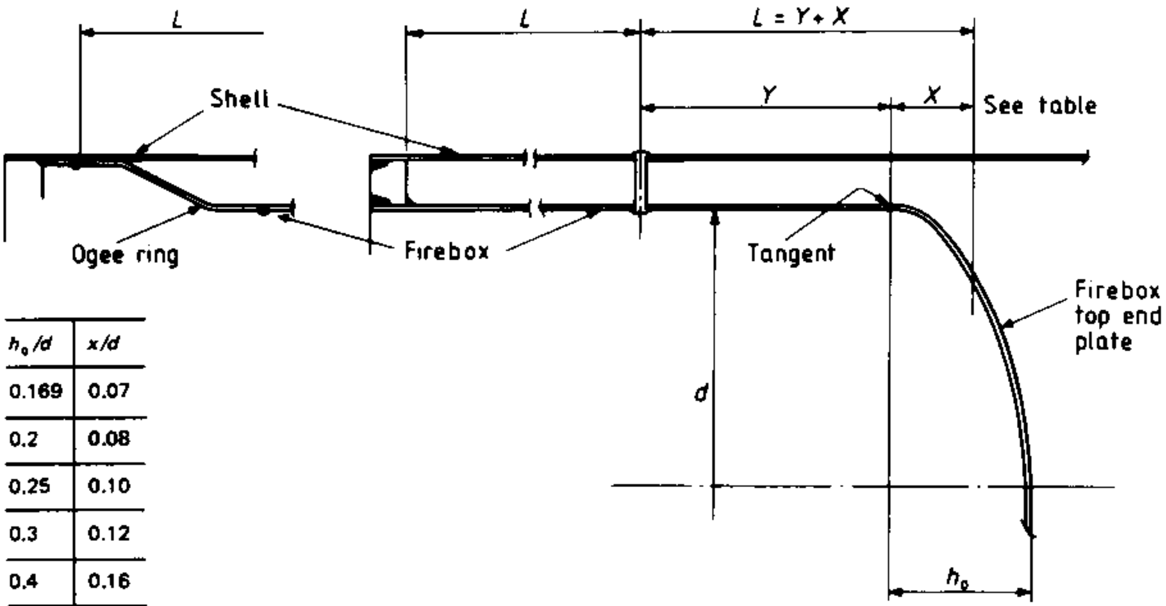
NOTE The radiant heating surface consists of the furnace.

Figure 3.1(4) — Reverse fired boiler



NOTE The radiant heating surface consists of the firebox and the crosstubes.
(a) Part sectional view

Figure 3.1(5) — Vertical boiler



h_o/d	x/d
0.169	0.07
0.2	0.08
0.25	0.10
0.3	0.12
0.4	0.16
0.5	0.20

(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)*

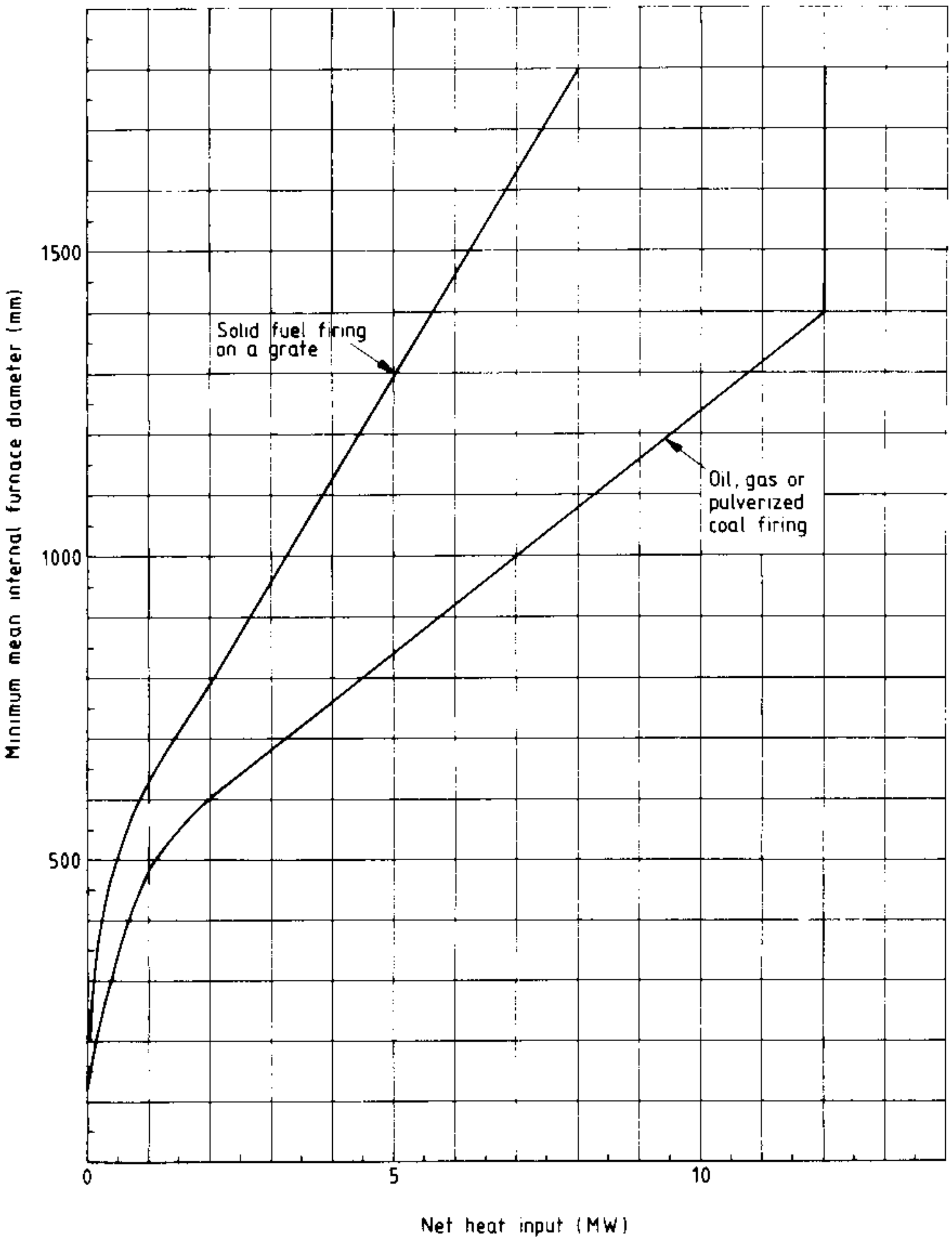
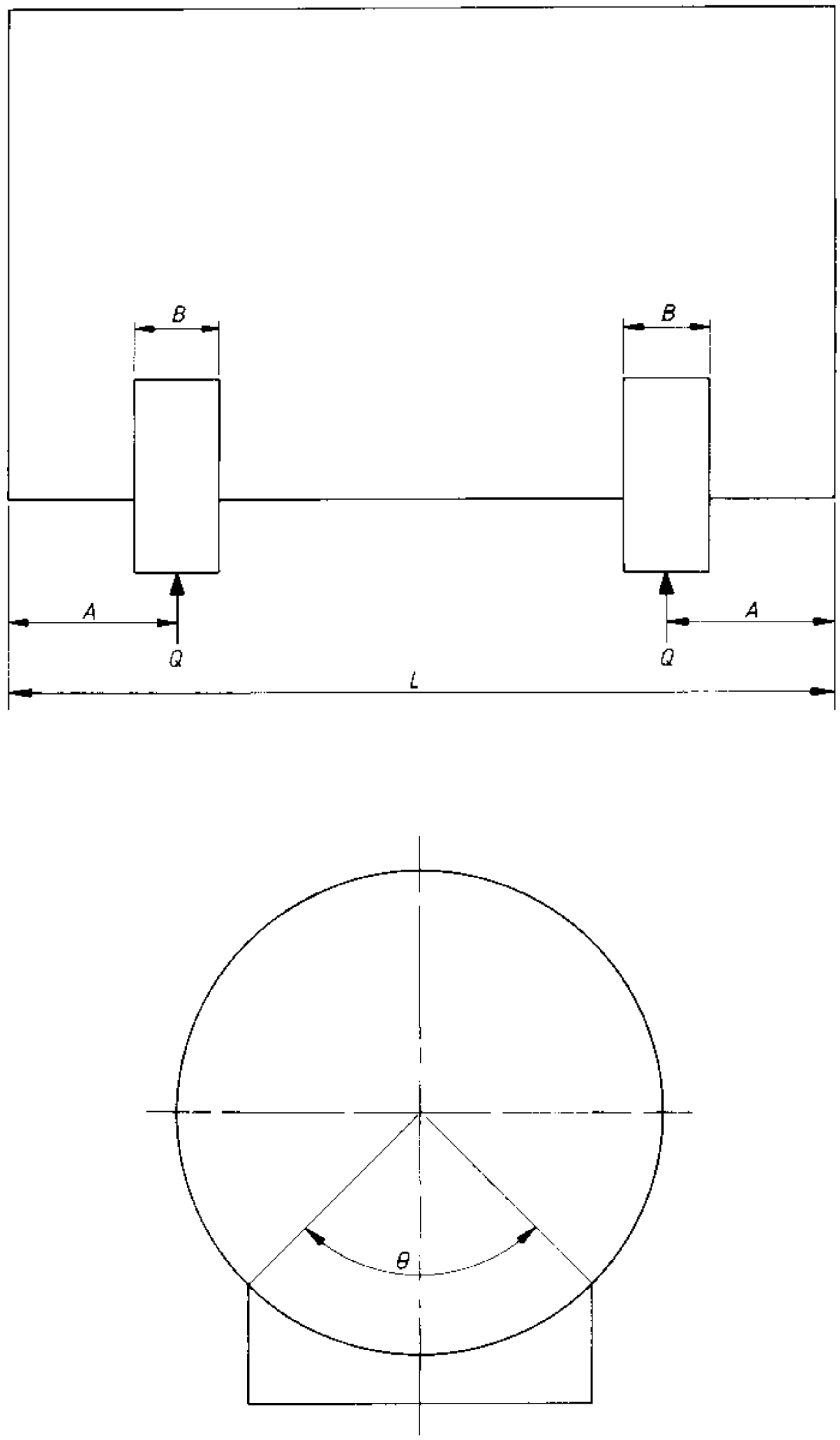
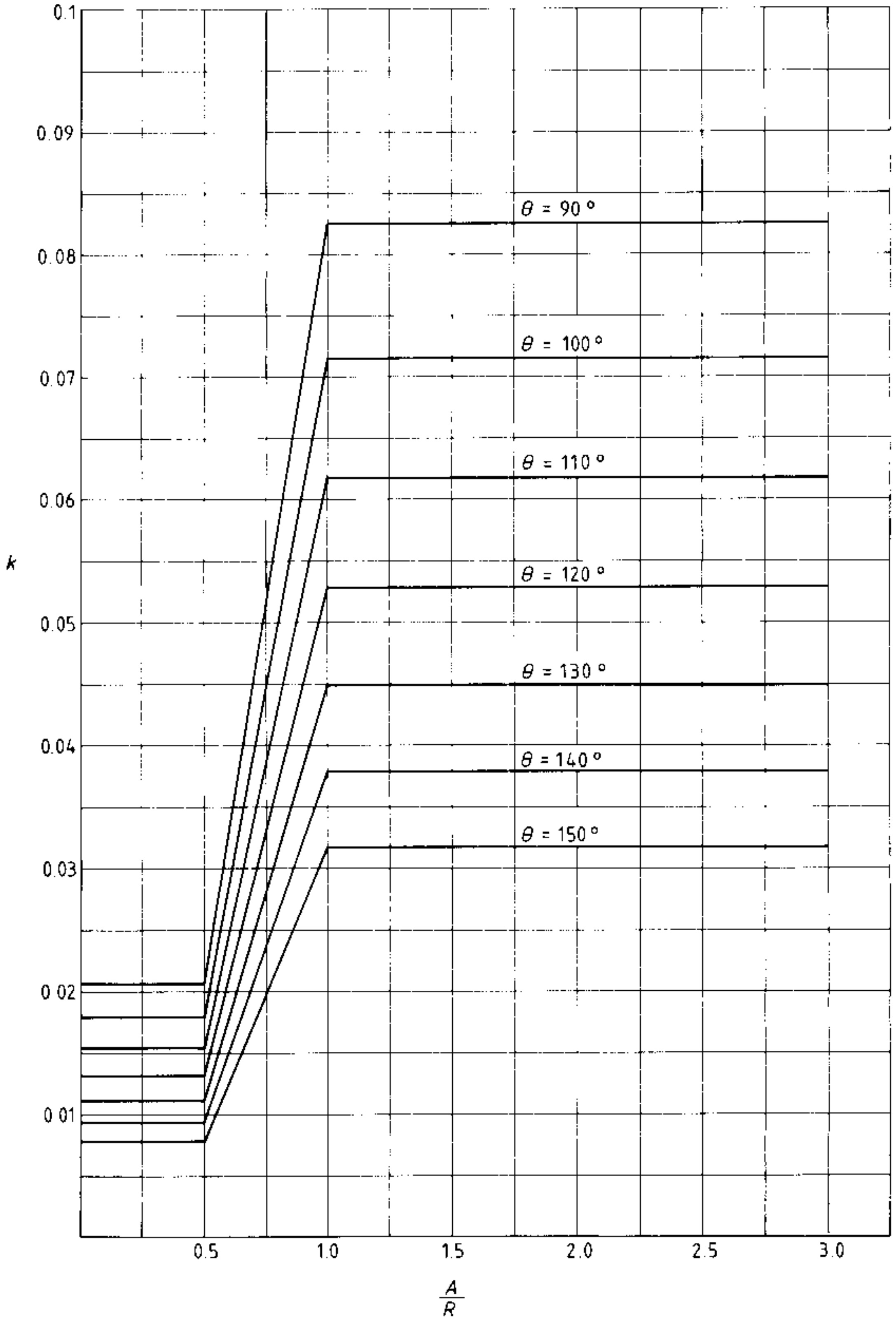


Figure 3.1(6) — Relationship between furnace diameter and permissible heat input



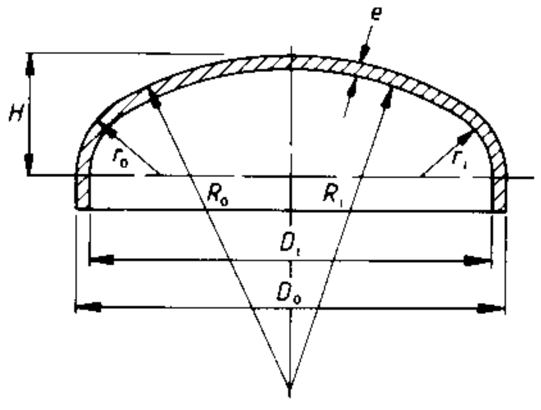
(a) Explanation of notation

Figure 3.2.5.2 — Design of saddle supports

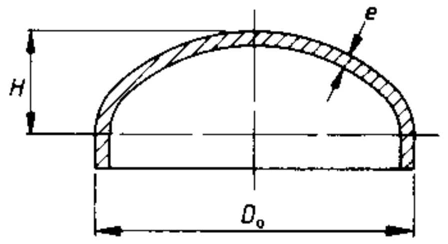


(b) Evaluation of coefficient *k*

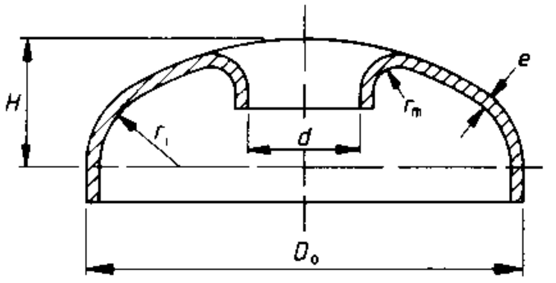
Figure 3.2.5.2 — Design of saddle supports *(concluded)*



(a) Torispherical end



(b) Semi-ellipsoidal end



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

Figure 3.3(1) — Typical dished ends

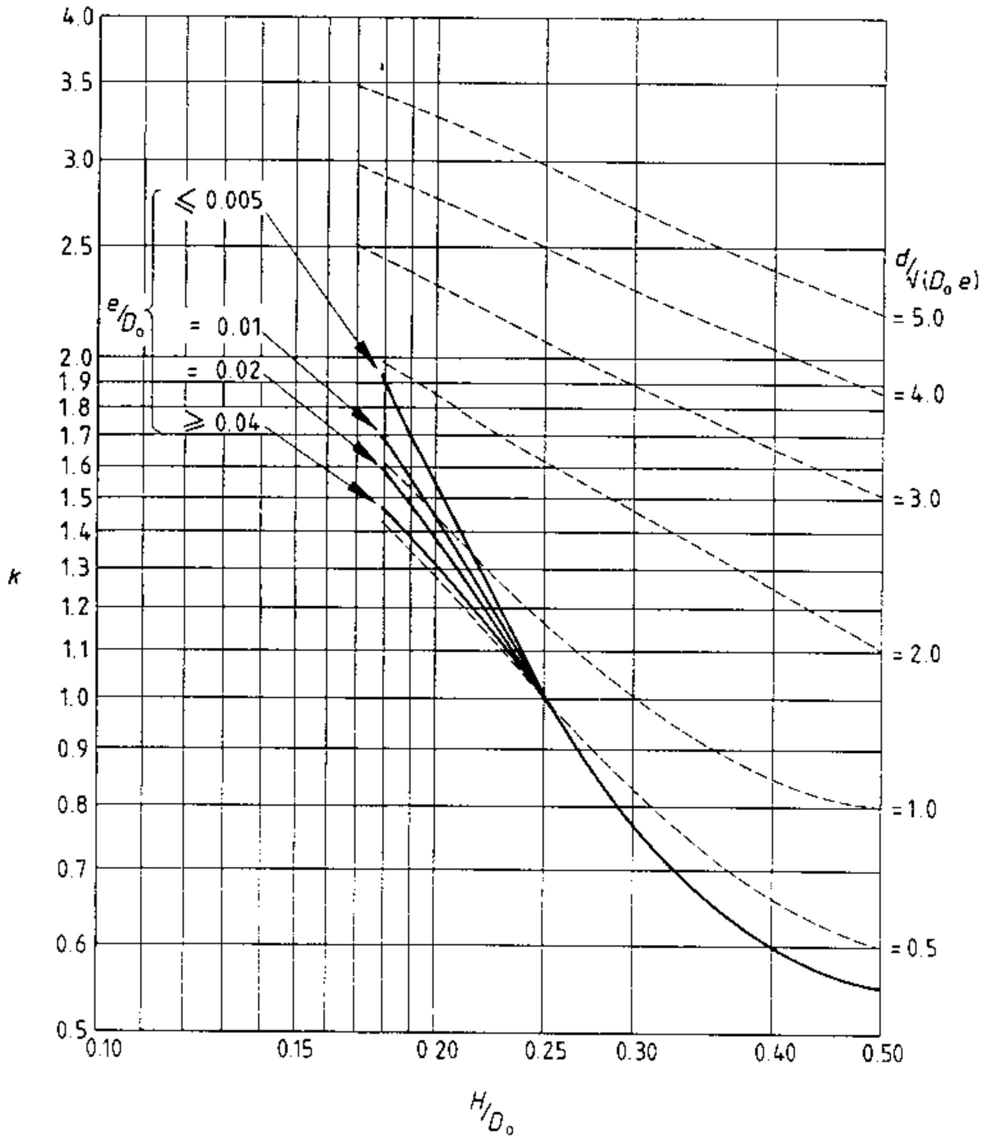


Figure 3.3(2) — Shape factor

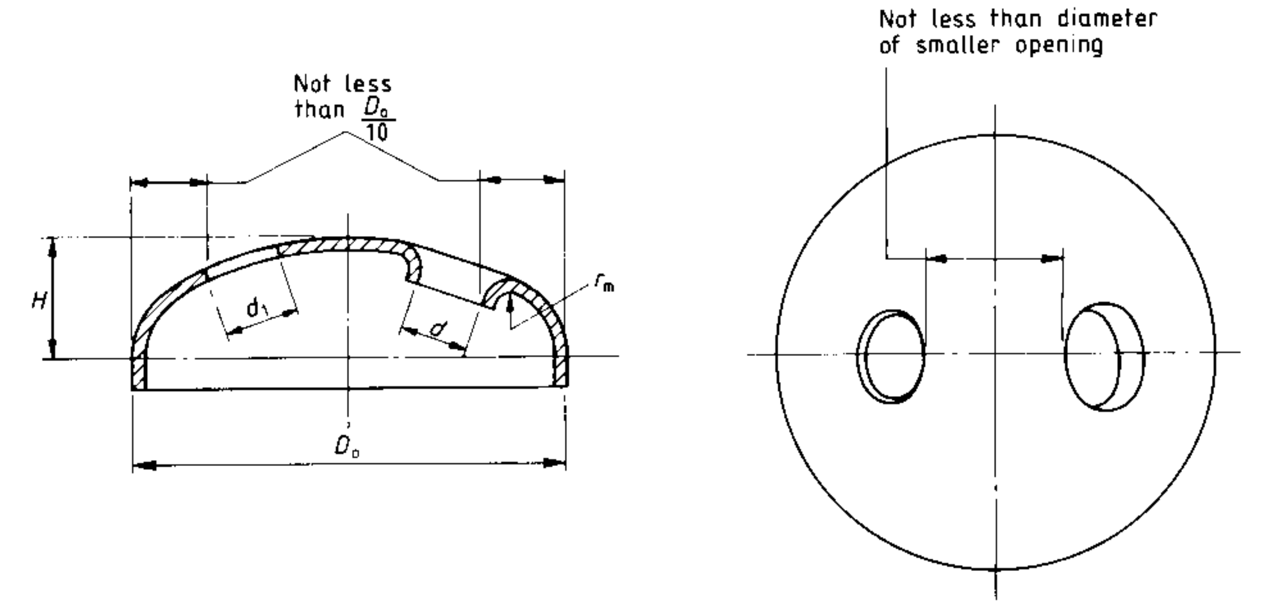
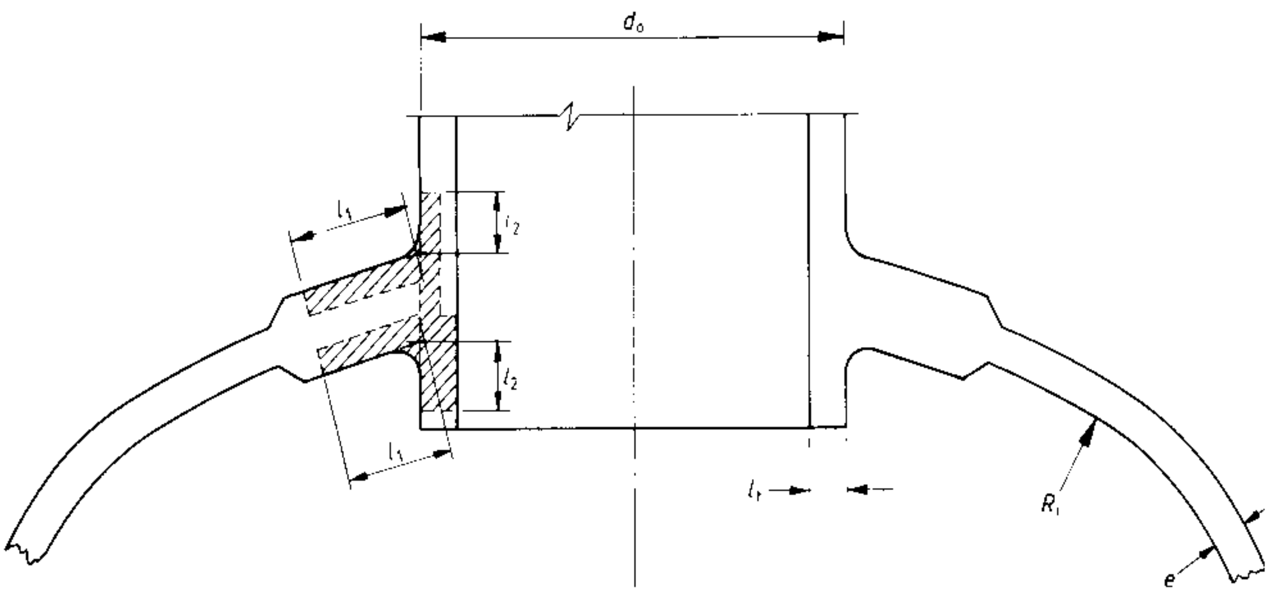
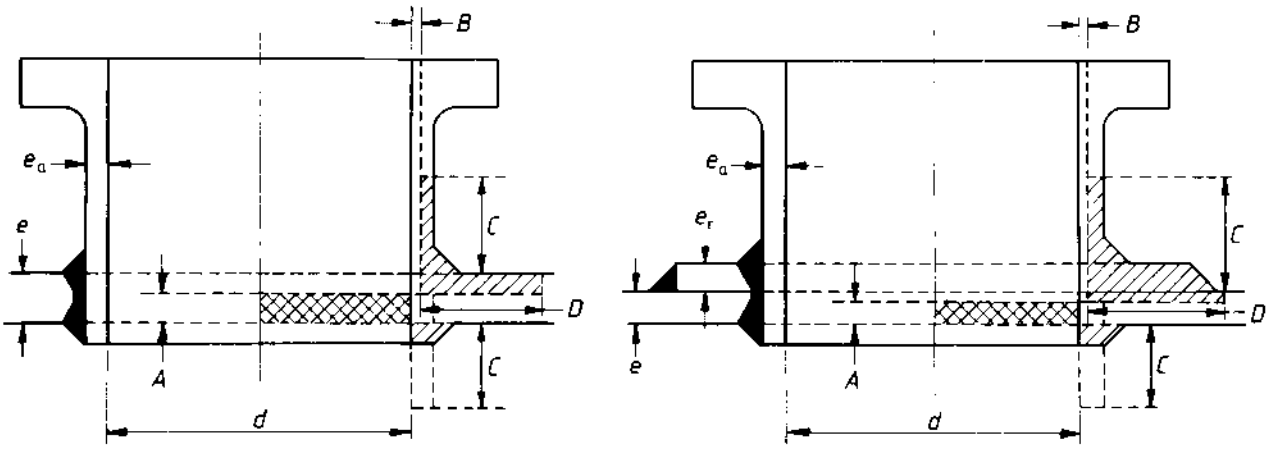


Figure 3.3(3) — Openings in ends



$l_1 = \sqrt{(2R_ie)}$ or $d_o/2$, whichever is the less.
$l_2 \leqslant \sqrt{(d_ol_t)}$

Figure 3.3(4) — Limits of reinforcement



(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: 2.5*e* or $(2.5e_a + e_r)$.

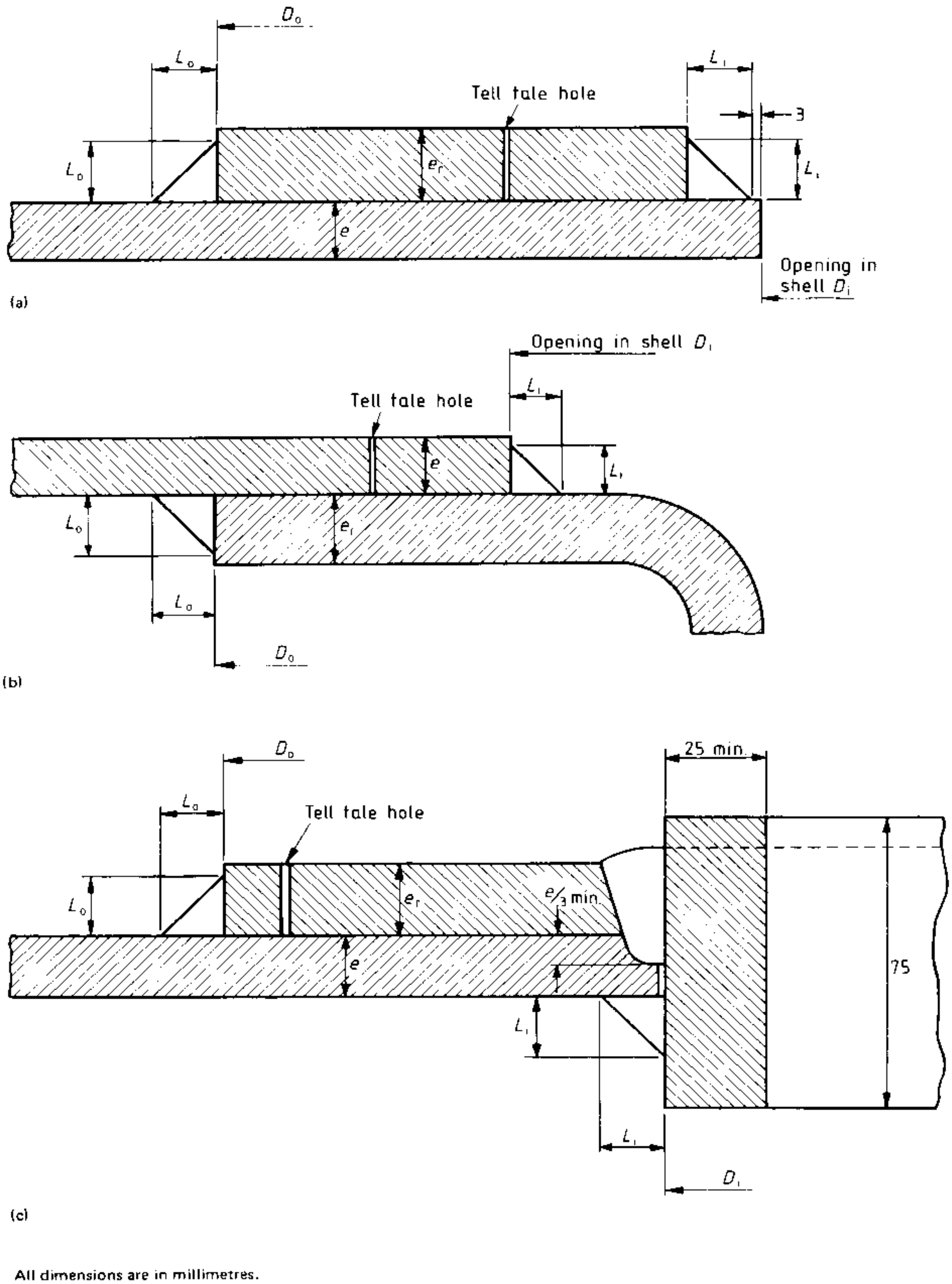
D is the greater of the two values: (*e* + 75 mm) or *d*/2.

X is the area requiring compensation, denoted by [cross-hatched]

Y is the compensating area, denoted by [hatched]

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



NOTE For details of the weld preparation, see the examples given in Appendix B.

Figure 3.5 — Welding of manhole frames and compensating plates

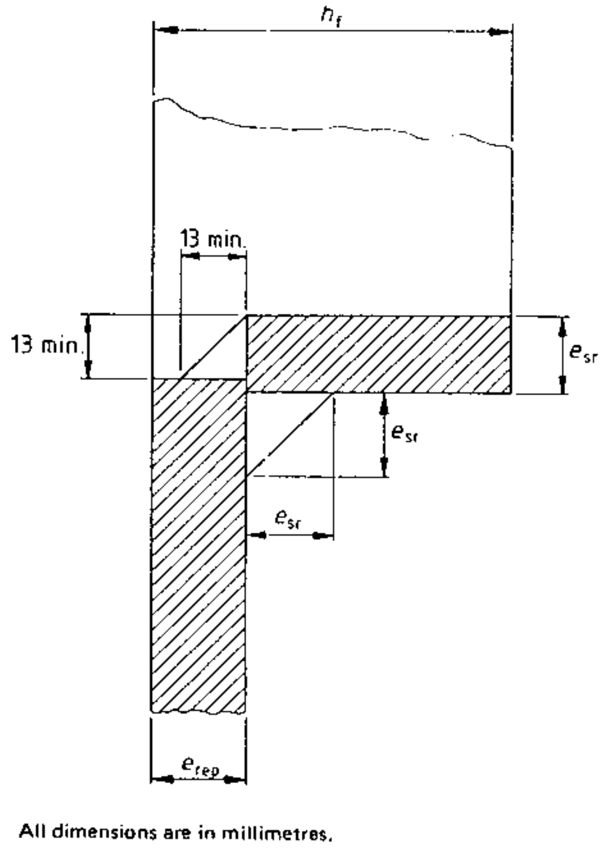


Figure 3.6.1(1) — Welding detail for manhole frame in flat end plate

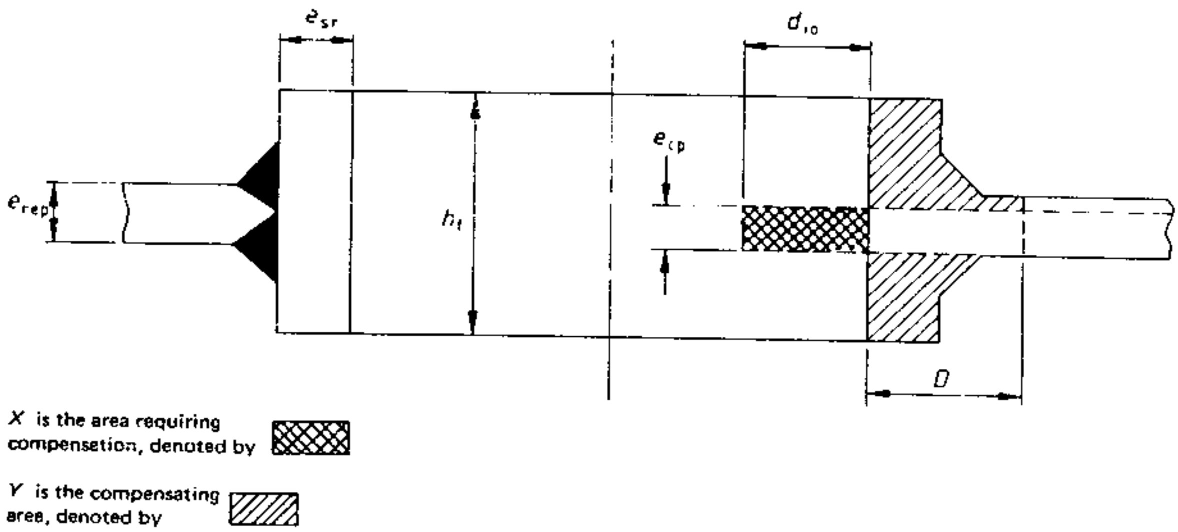


Figure 3.6.1(2) — Compensation for elliptical manholes and inspection openings in flat end plates

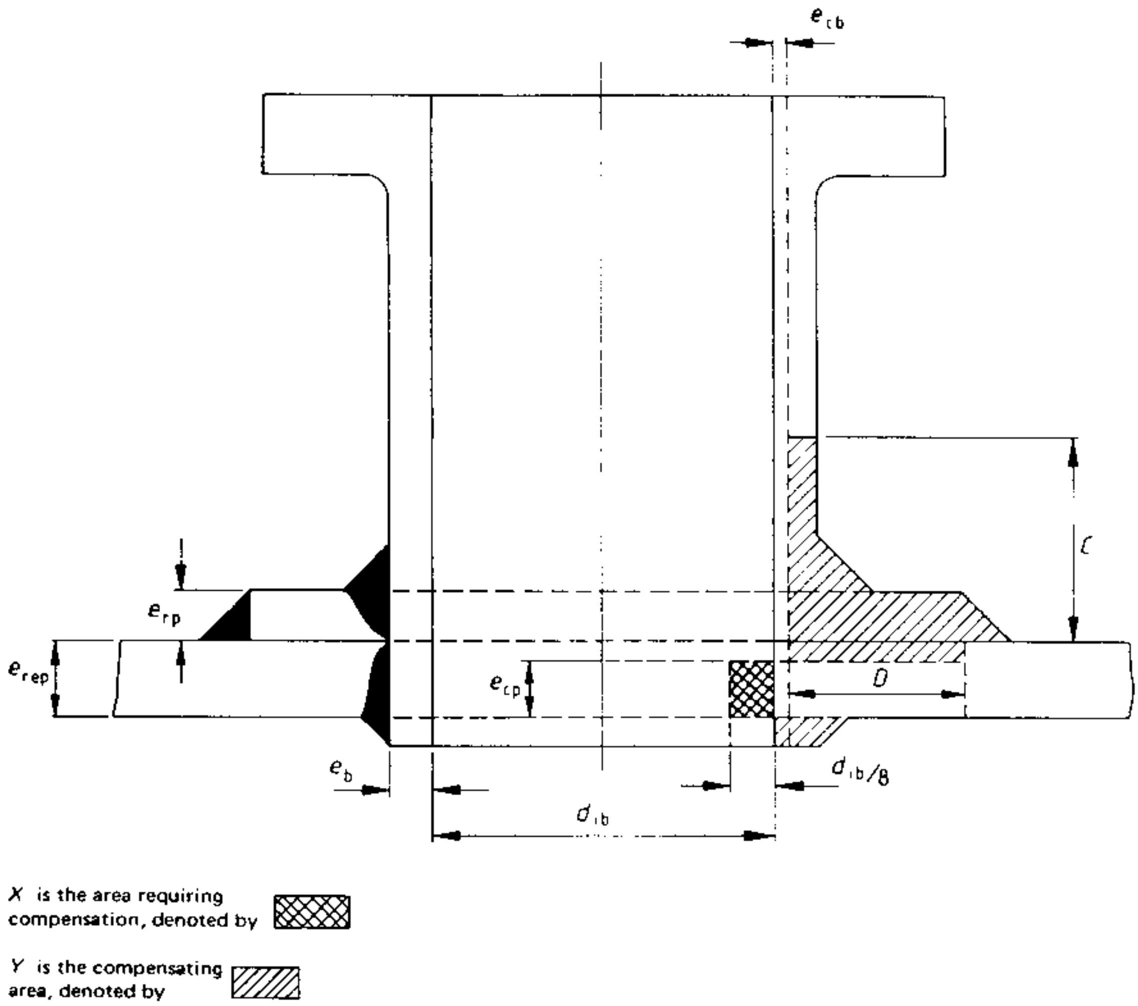
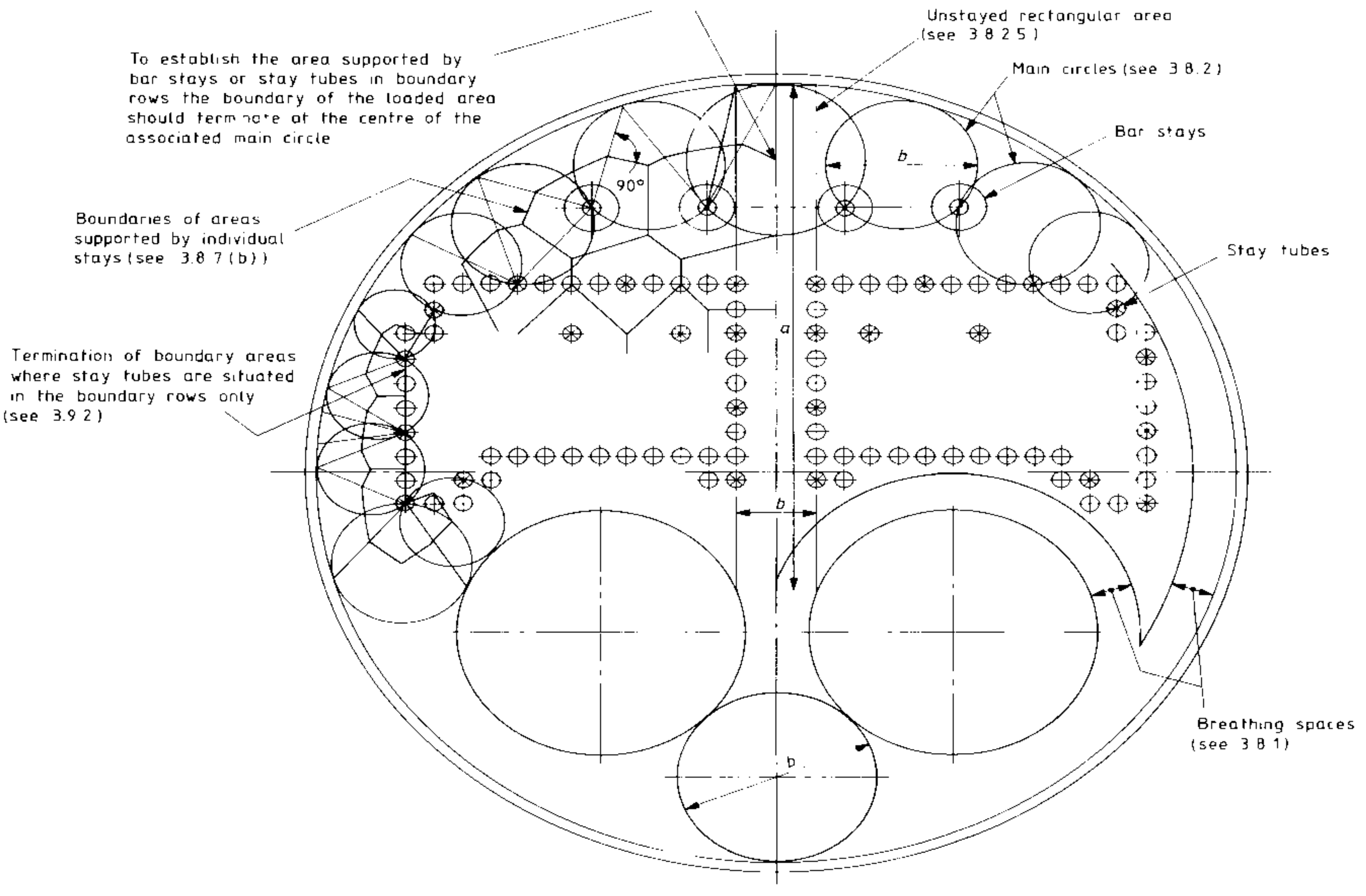


Figure 3.6.1(3) — Compensation for branch in flat end plate



NOTE For dimensions of breathing spaces, see **3.8.1**. If the furnace or end plate is flanged, the breathing space is taken from the commencement of curvature.

Figure 3.8.1(1) — Typical arrangement of end plate on a multitubular boiler

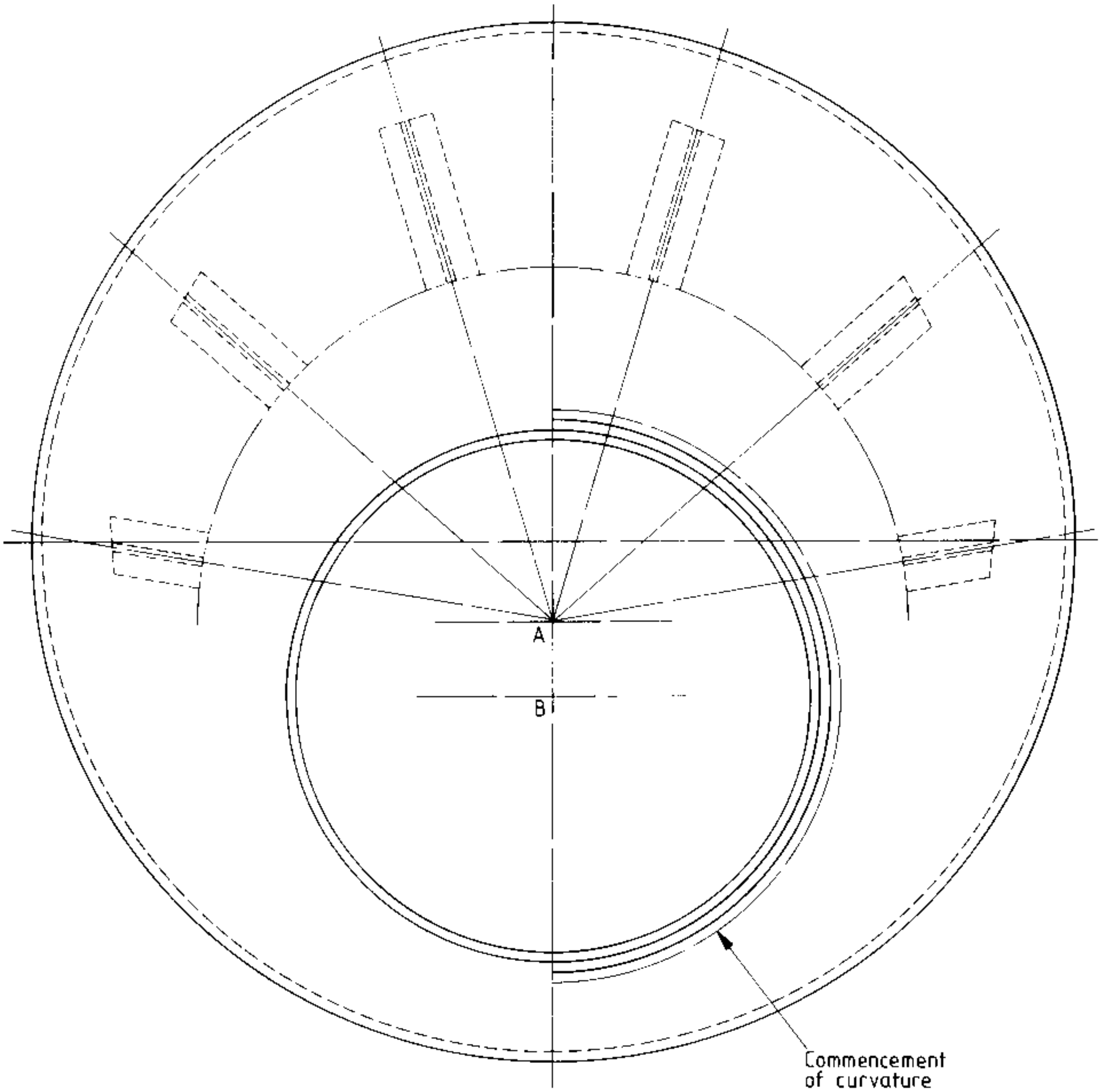


Figure 3.8.1(2) — Typical arrangement of end plate on Cornish boiler

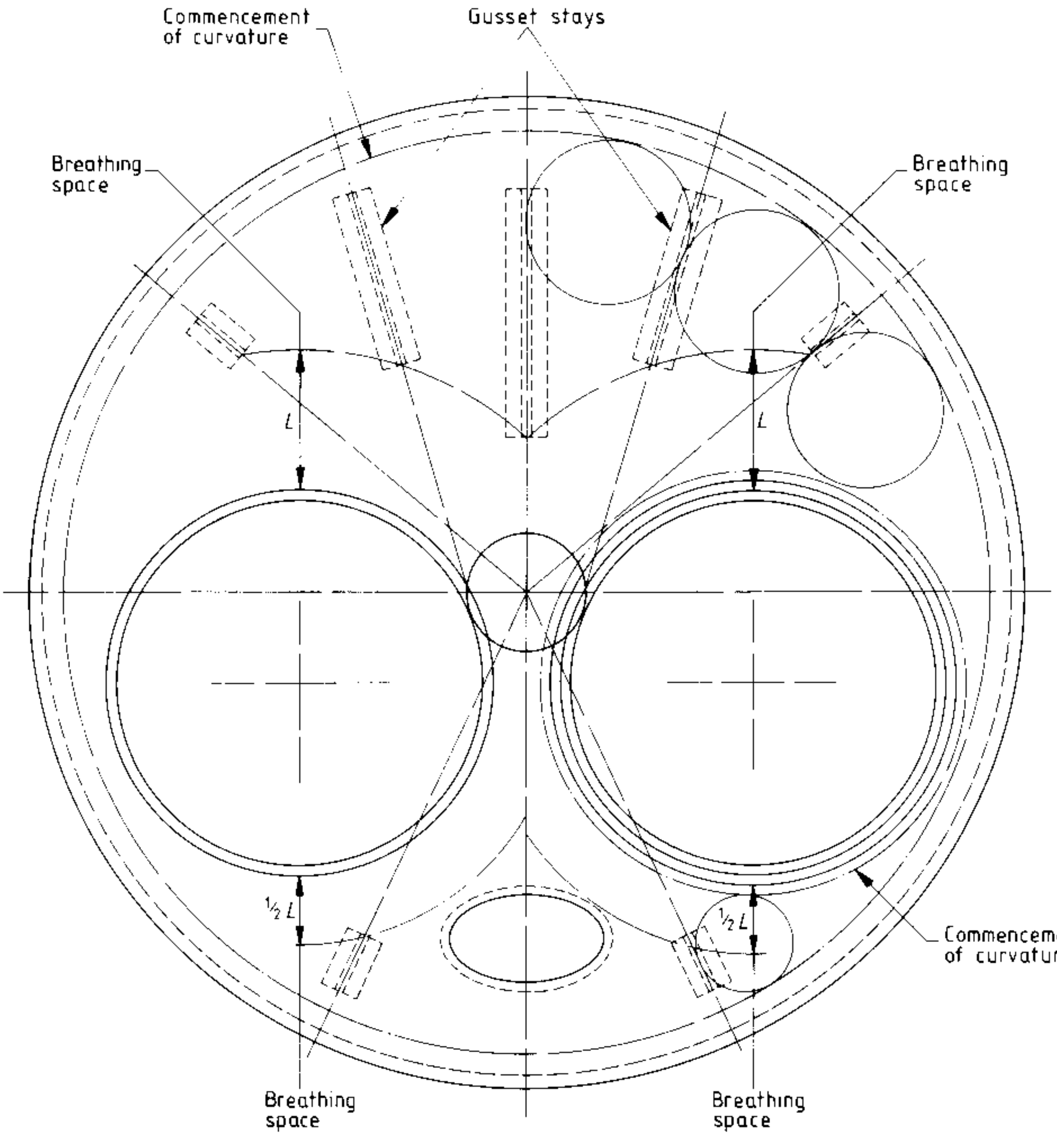


Figure 3.8.1(3) — Typical arrangement of end plate on a Lancashire boiler

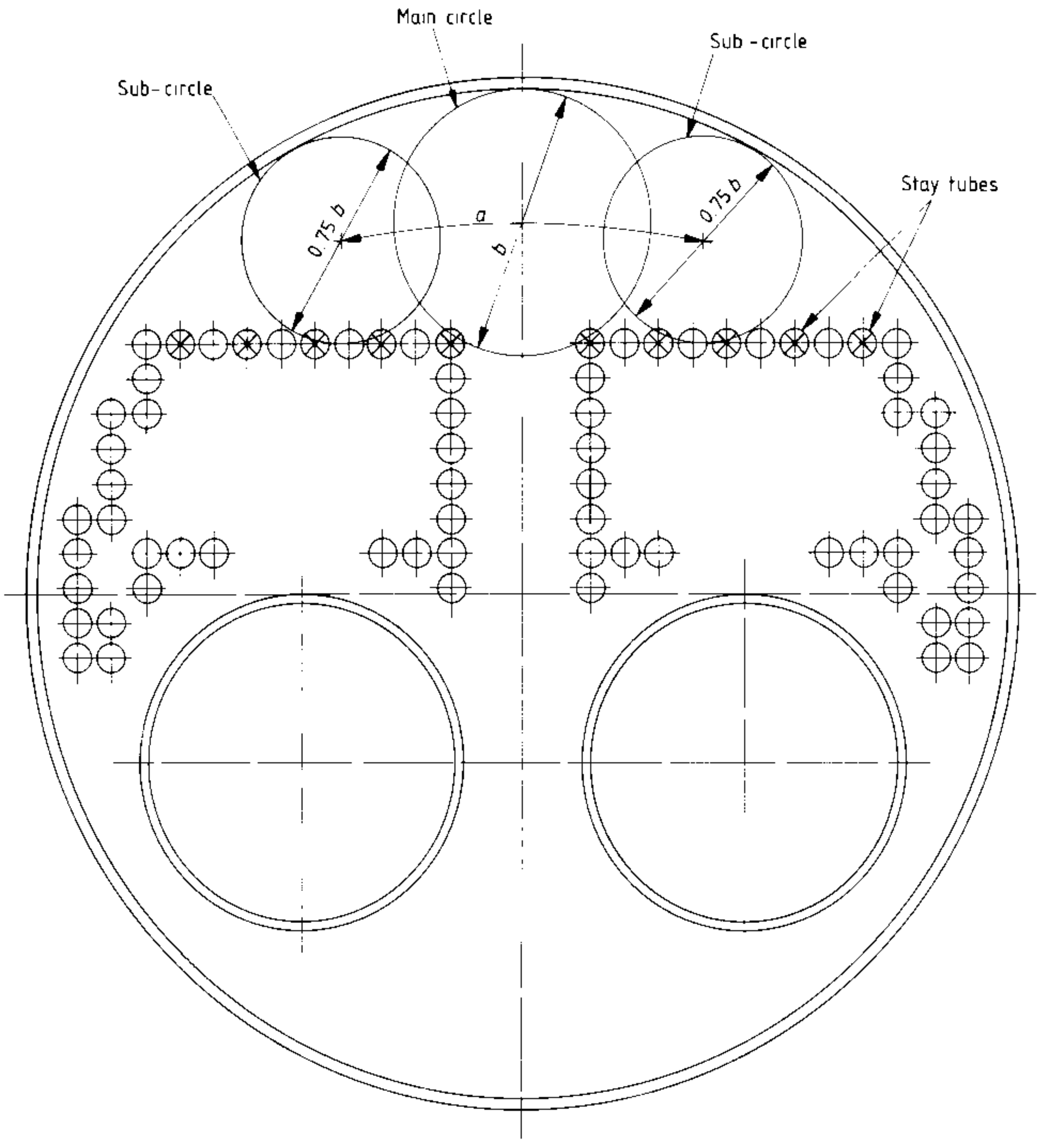


Figure 3.8.2(1) — Use of sub-circles (twin furnace)

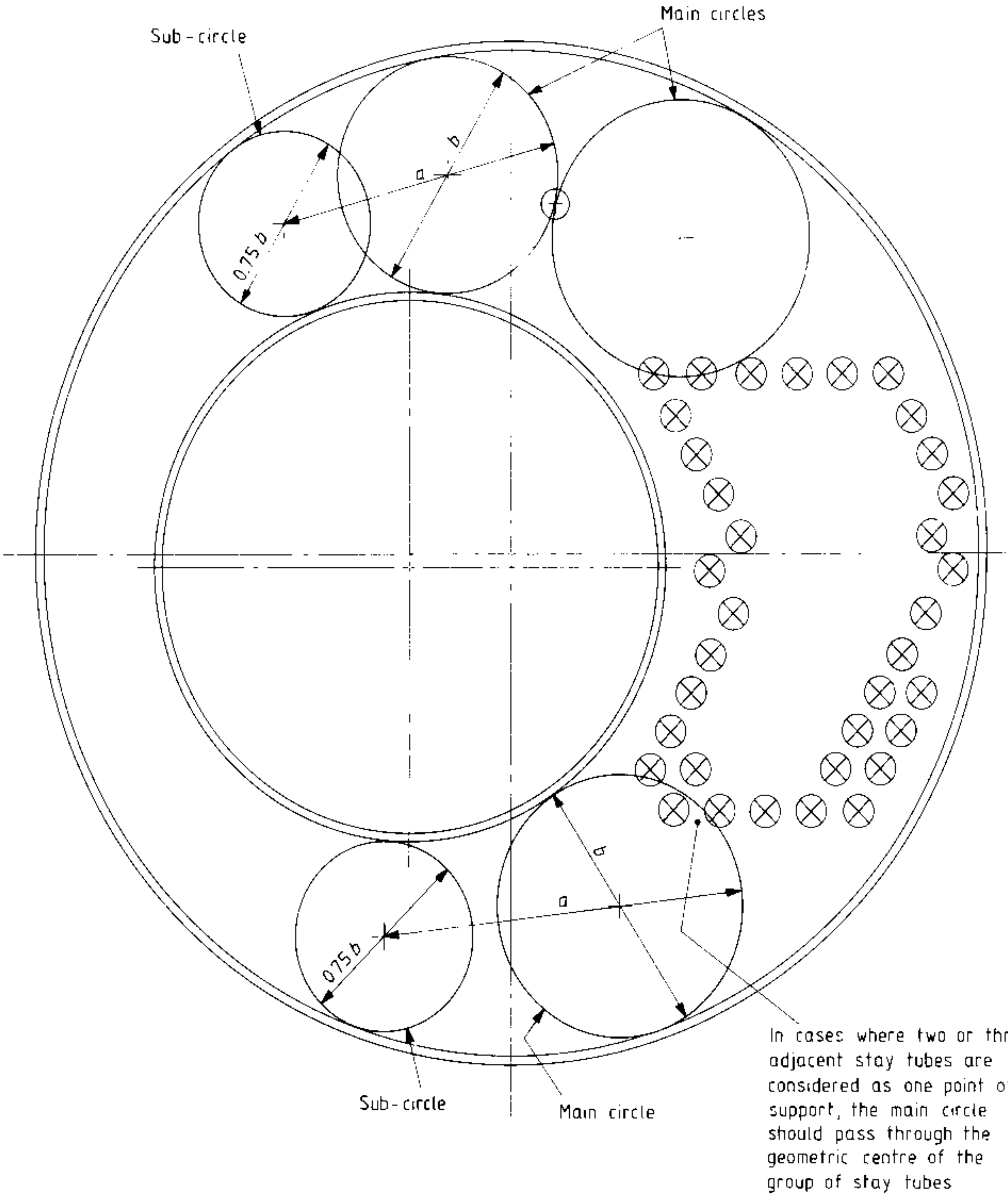


Figure 3.8.2(2) — Use of sub-circles (single furnace)

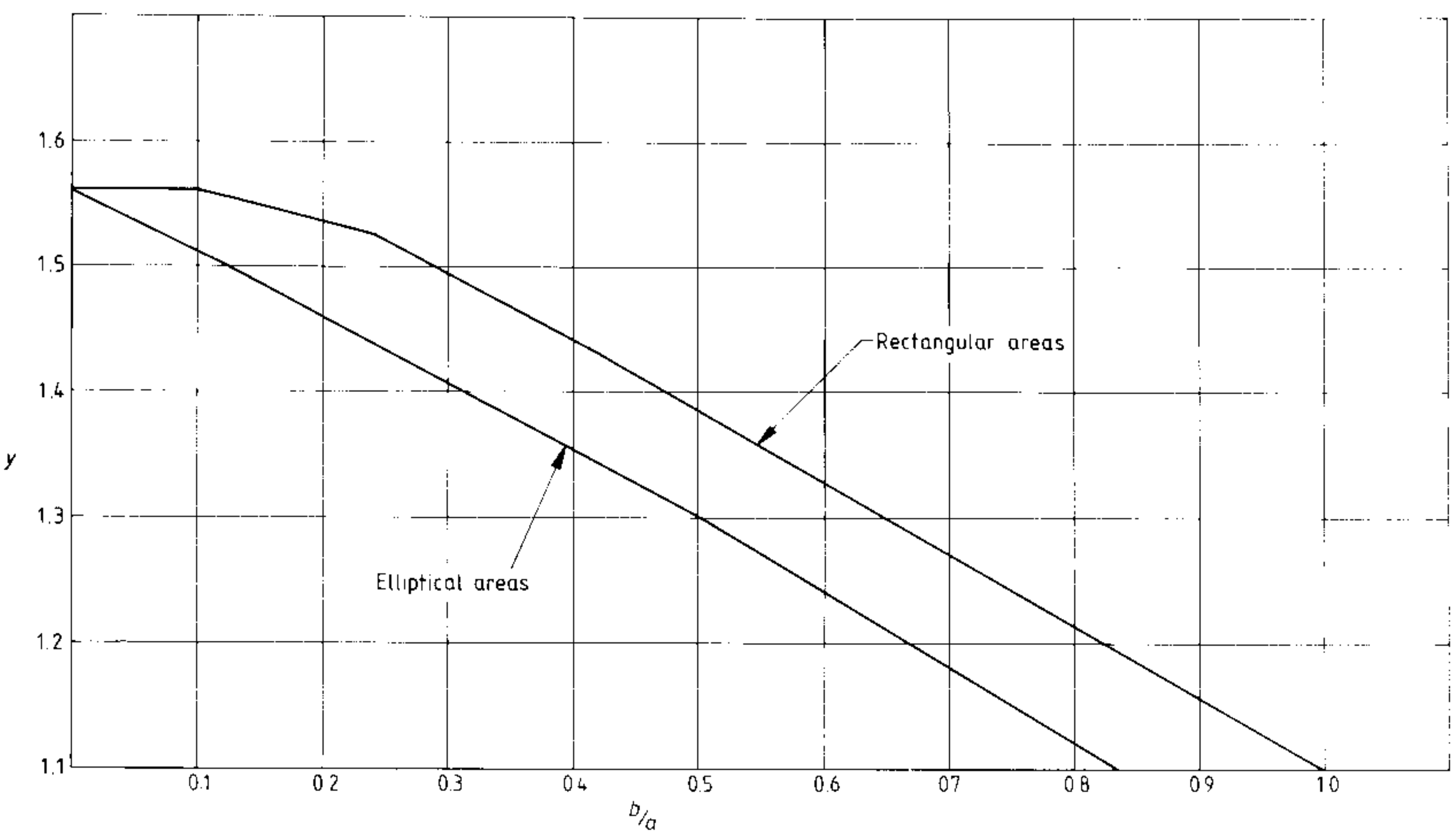


Figure 3.8.2(3) — Determination of factory *y* (see **3.8.2.5**)

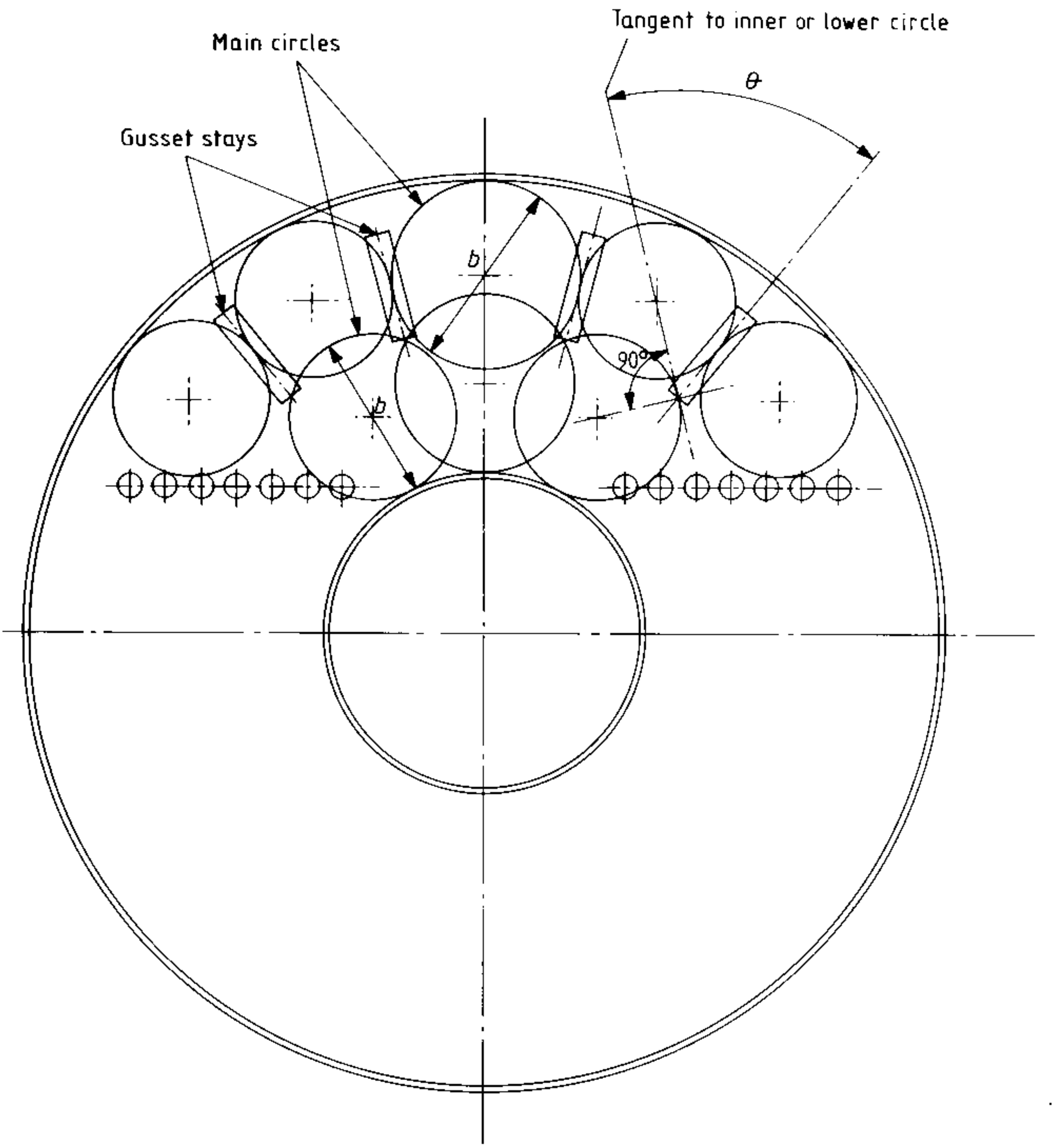
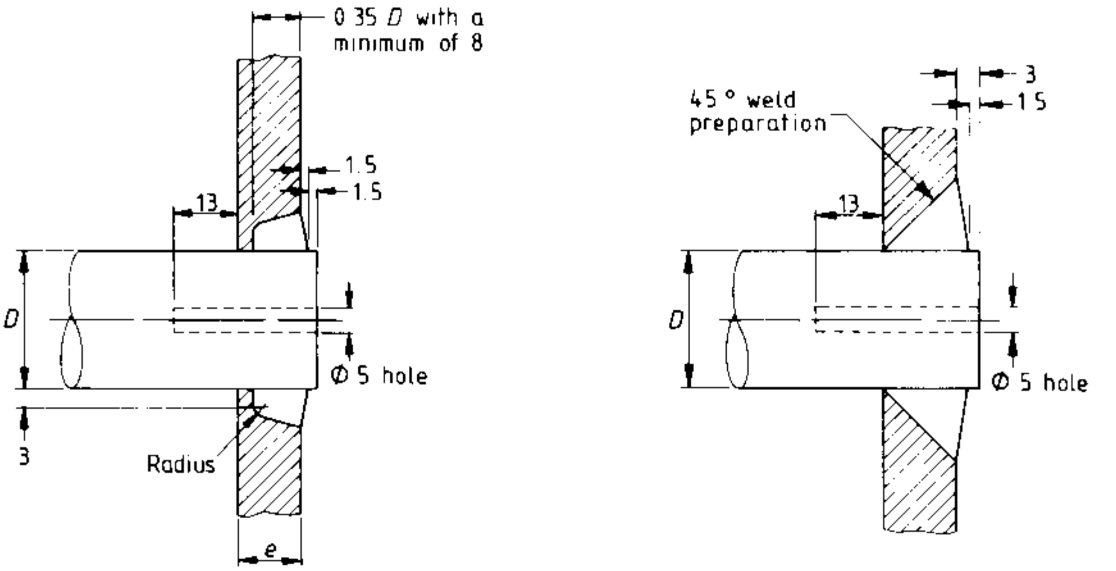


Figure 3.8.2(4) — Example of a gusset stay that impinges on the main circle other than at a tangent

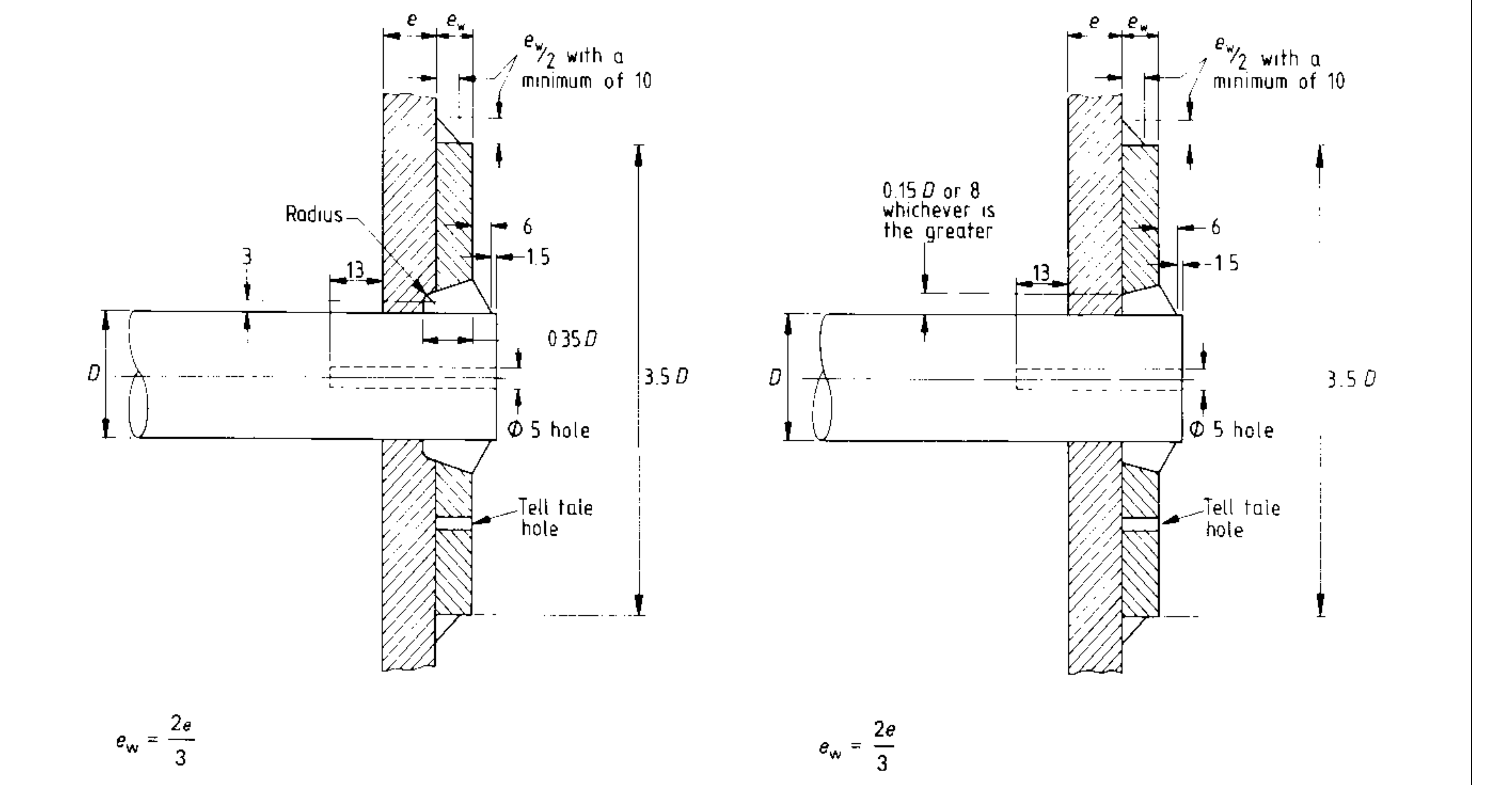


NOTE This form of attachment is also suitable for plain bar stays.

(a) (b)

All dimensions are in millimetres.

Figure 3.8.2(5) — Attachment of firebox and reversal chamber stays



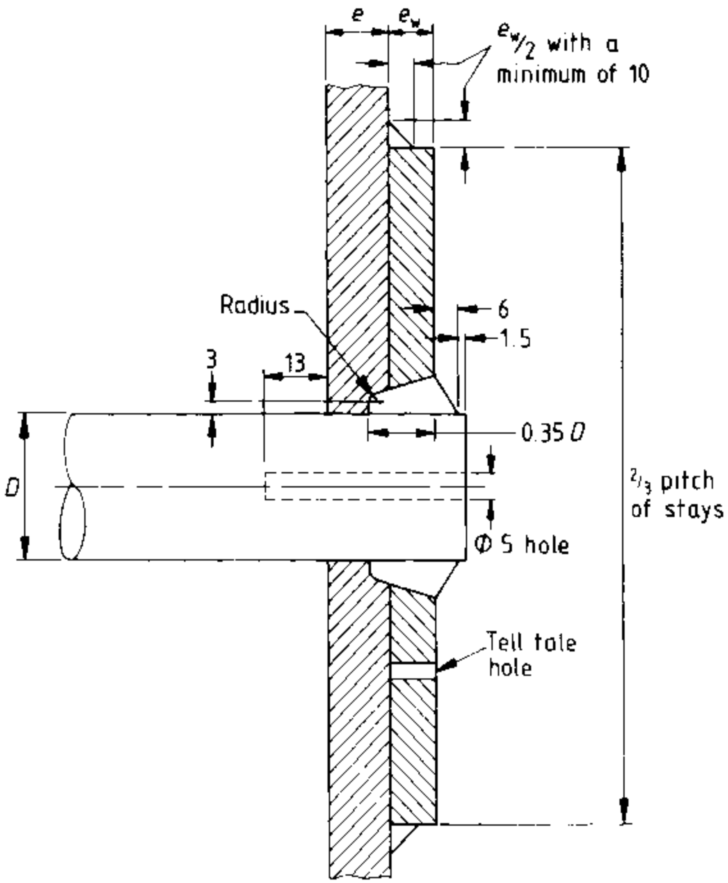
NOTE If e_w is less than $0.35D$, the form of construction shown in Figure 3.8.2(6)(a) is to be used.

(a)

(b)

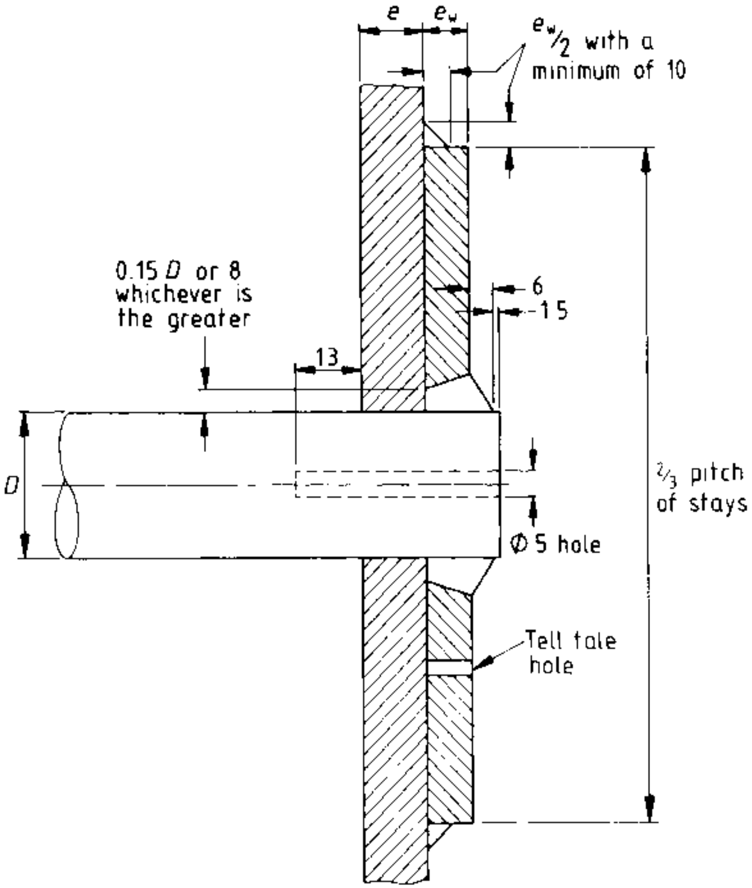
All dimensions are in millimetres.

Figure 3.8.2(6) — Attachment of bar stays with washers



$$e_w = \frac{2e}{3}$$

(c)



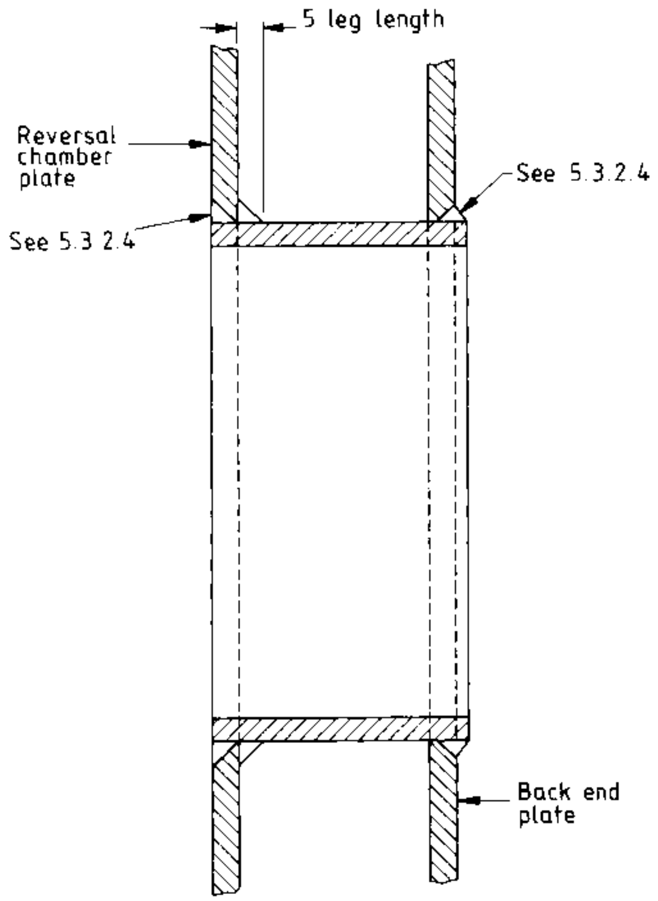
$$e_w = \frac{2e}{3}$$

NOTE If e_w is less than 0.35D, the form of construction shown in Figure 3.8.2(6)(c) is to be used.

(d)

All dimensions are in millimetres.

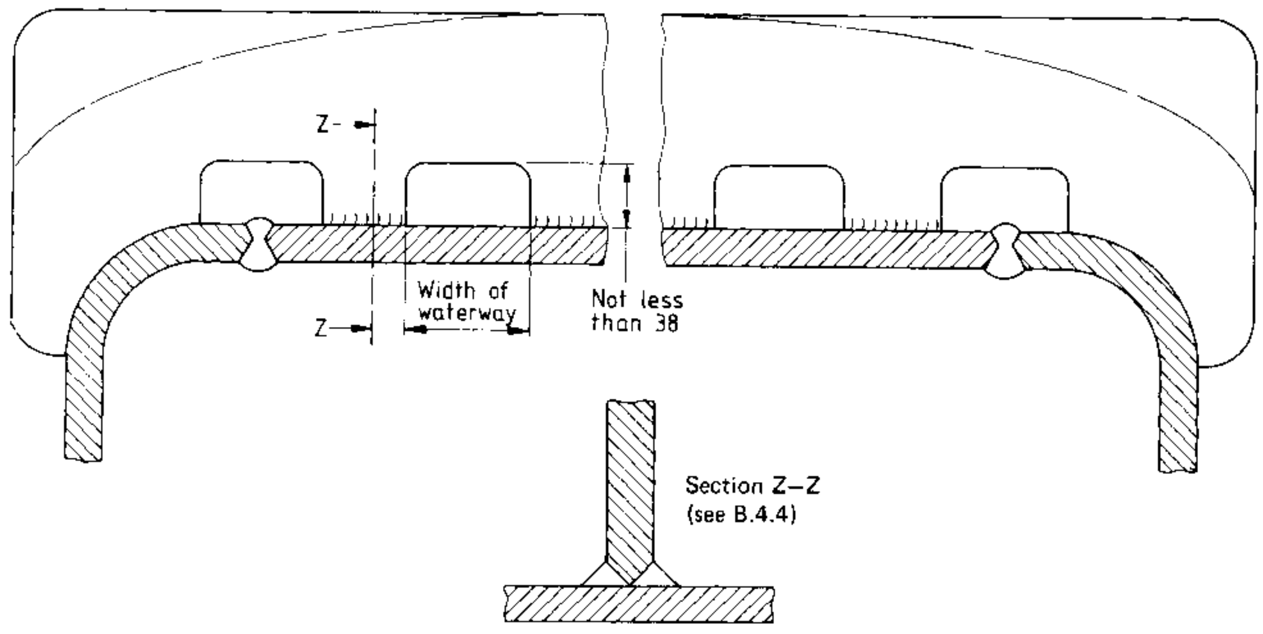
Figure 3.8.2(6) — Attachment of bar stays with washers *(continued)*



See **3.8.2.6** and **B.4.4**.

All dimensions are in millimetres.

Figure 3.8.2(7) — Access opening for wet back boilers

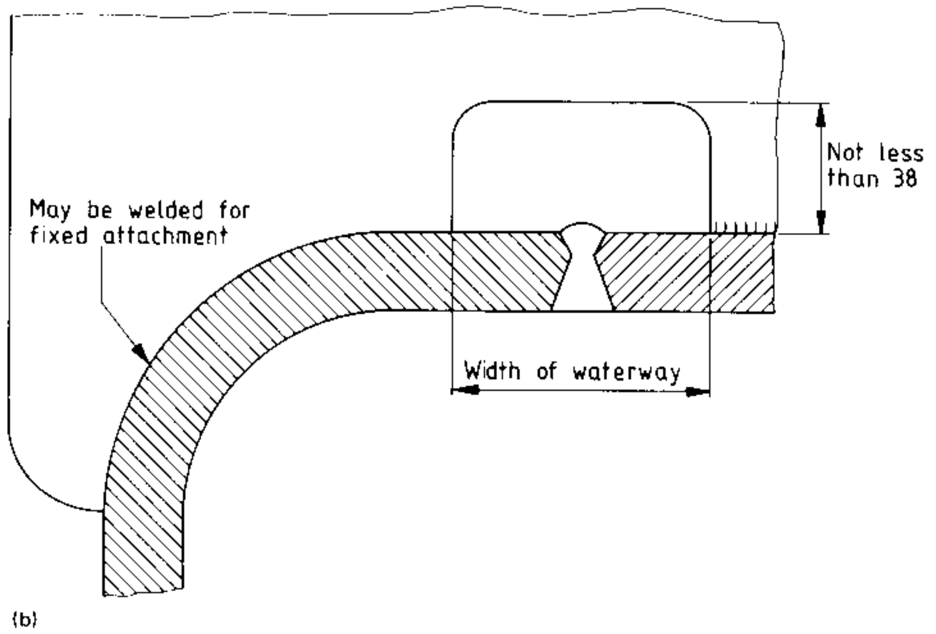


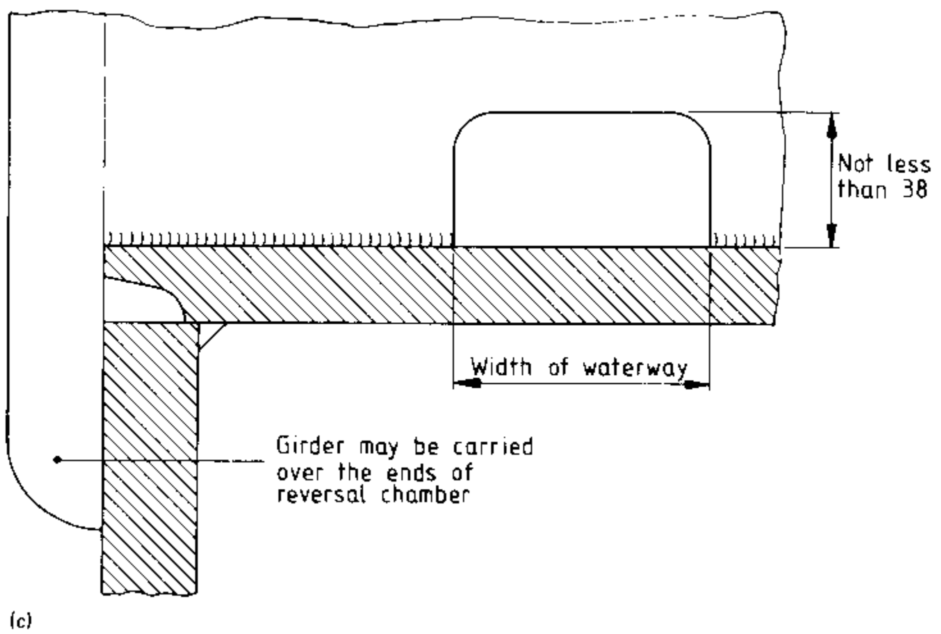
NOTE Girders may be shaped to either the full or the chain dotted lines as shown above.

(a)

All dimensions are in millimetres.

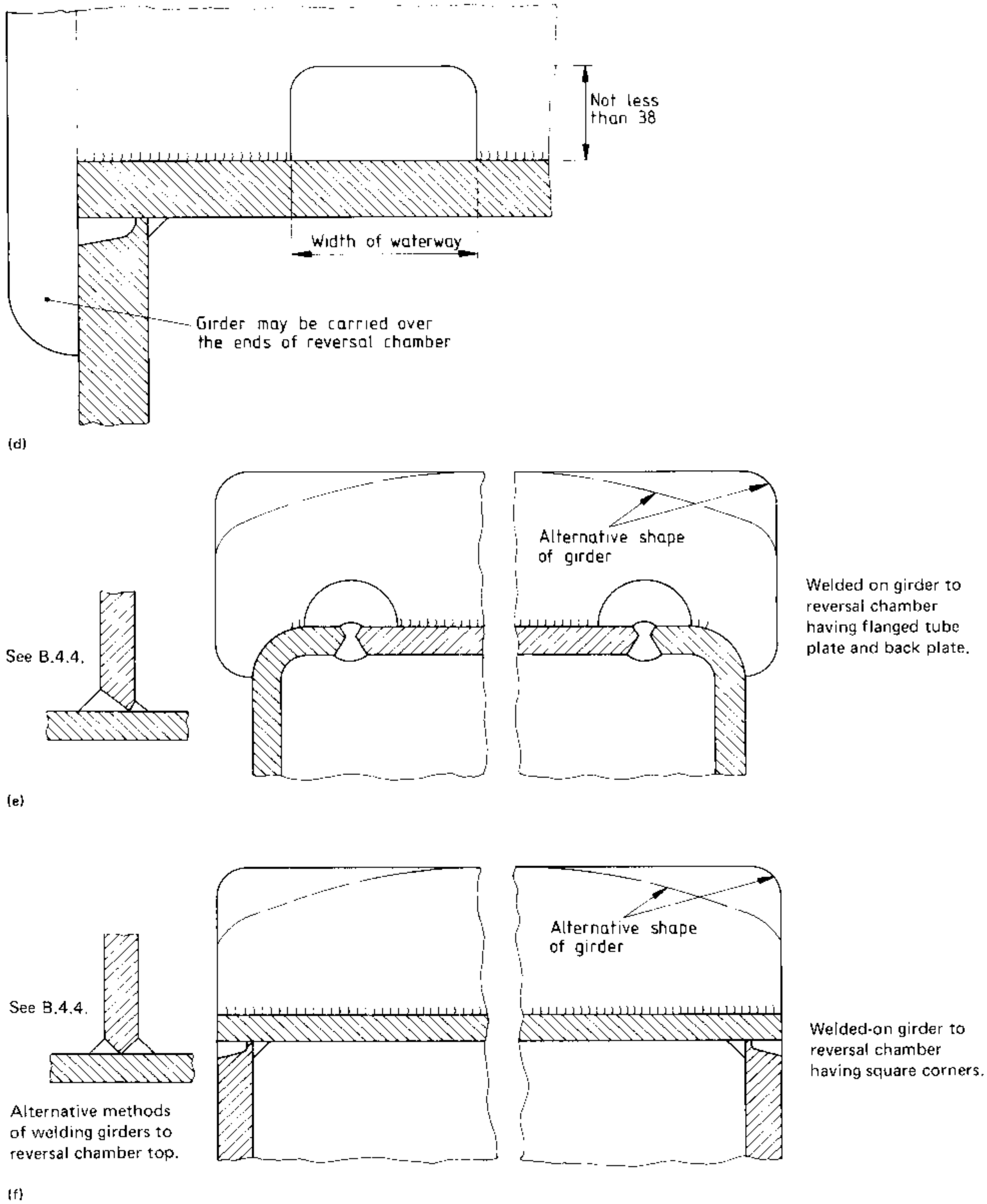
Figure 3.8.2(8) — Typical methods of fitting welded girders to reversal chambers *(continued)*





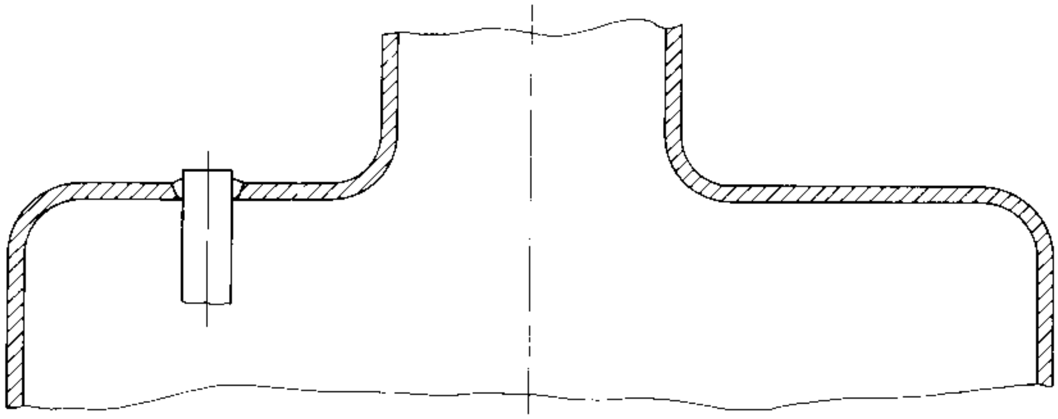
All dimensions are in millimetres.

Figure 3.8.2(8) — Typical methods of fitting welded girders to reversal chambers *(continued)*



Dimension is in millimetres.

Figure 3.8.2(8) — Typical methods of fitting welded girders to reversal chambers *(concluded)*



If stays are fitted, y shall be taken as defined in **3.8.2.5**.

If stays are note fitted, y shall be taken as 1.56.

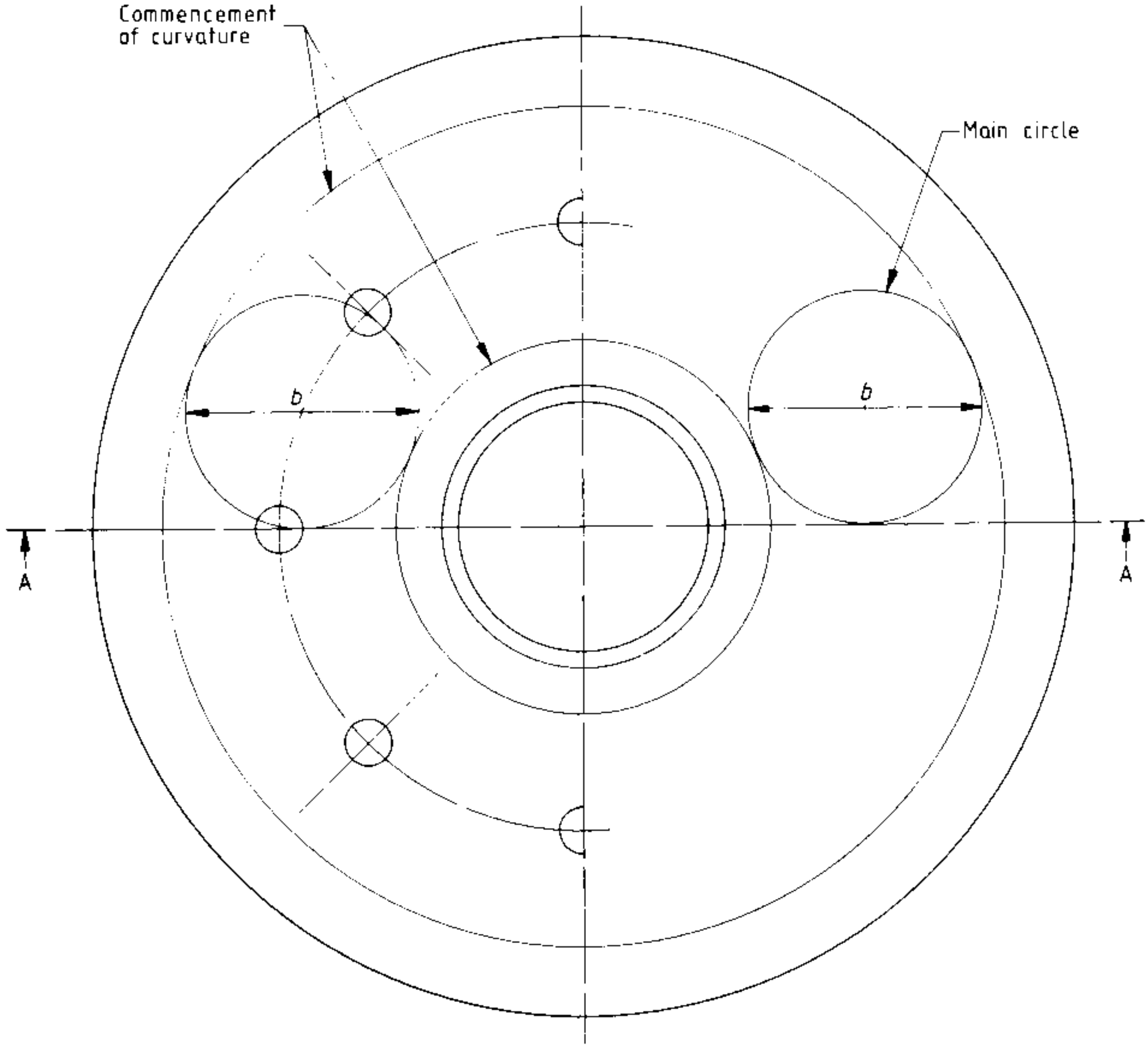


Figure 3.8.3 — Flat end plates of a vertical boiler

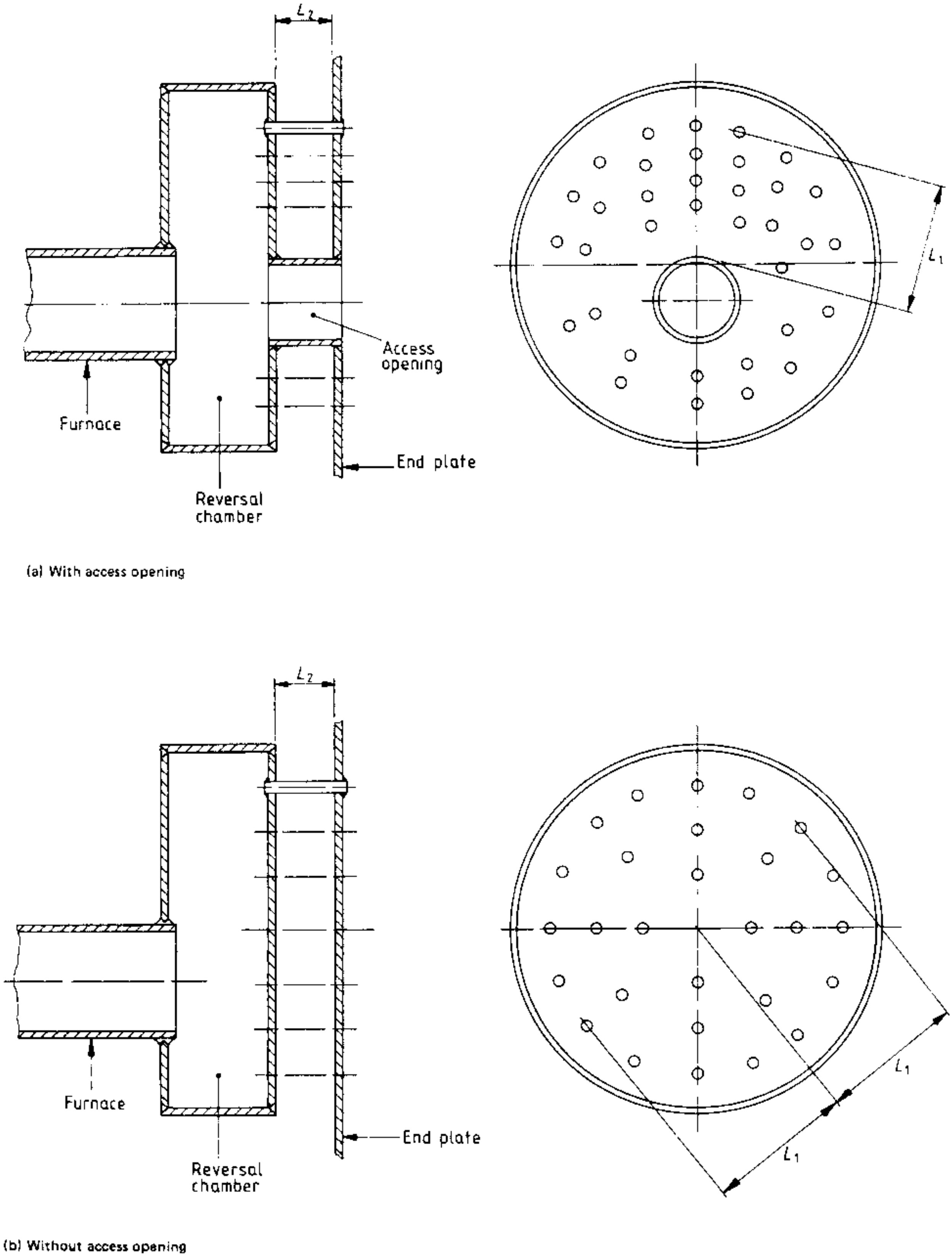


Figure 3.8.5.1 — Bar stays for the rear plate of wet back reversal chambers

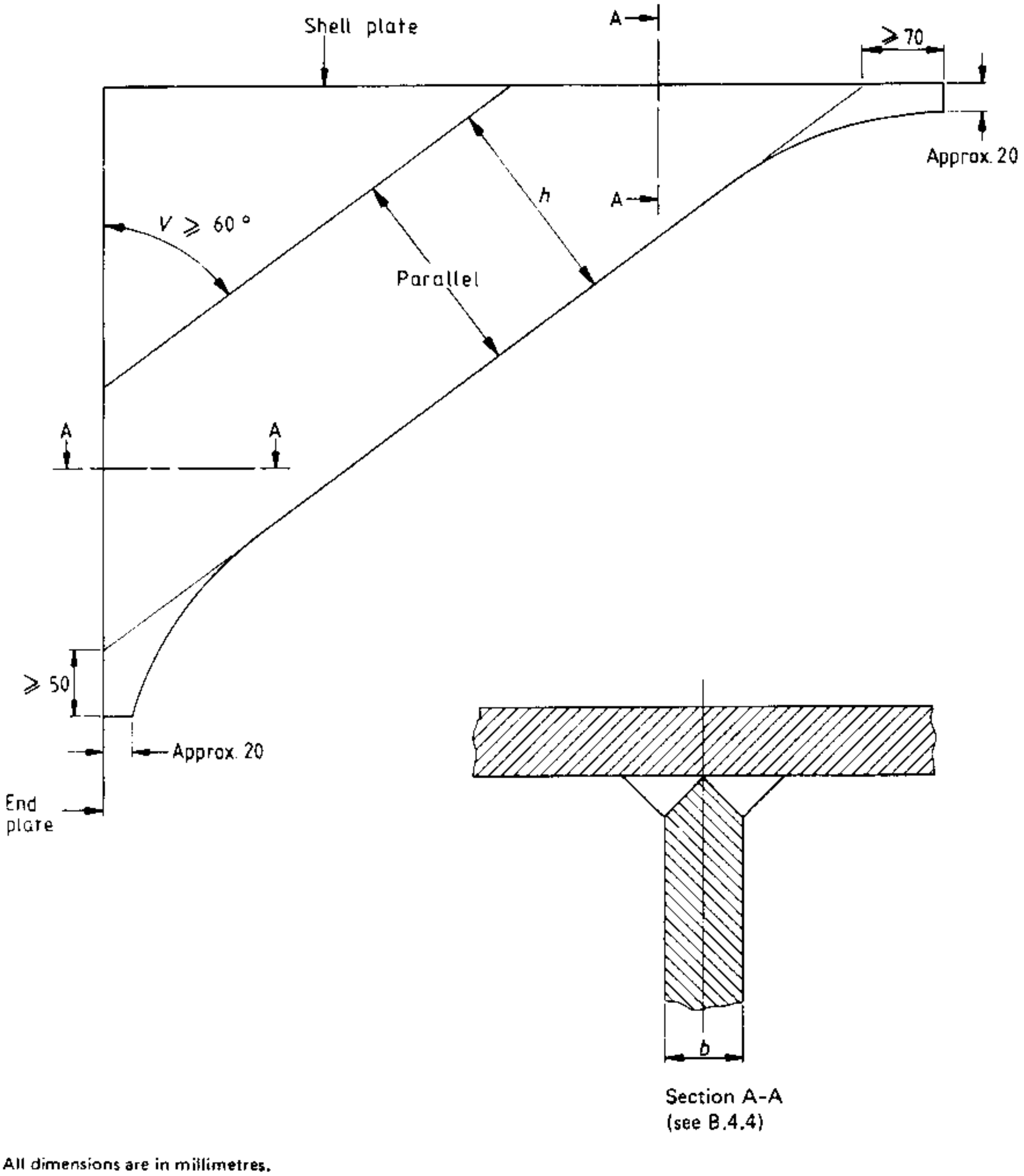


Figure 3.8.8.3(1) — Attachment of welded gusset stays

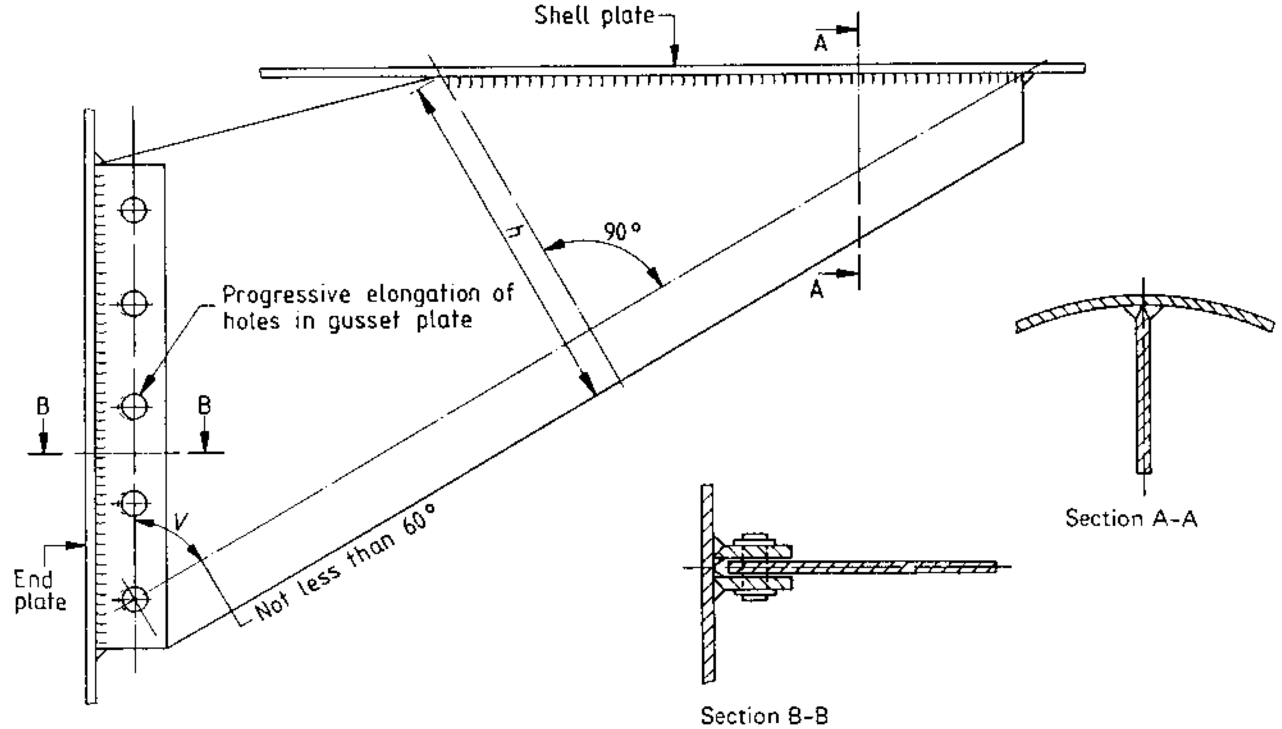
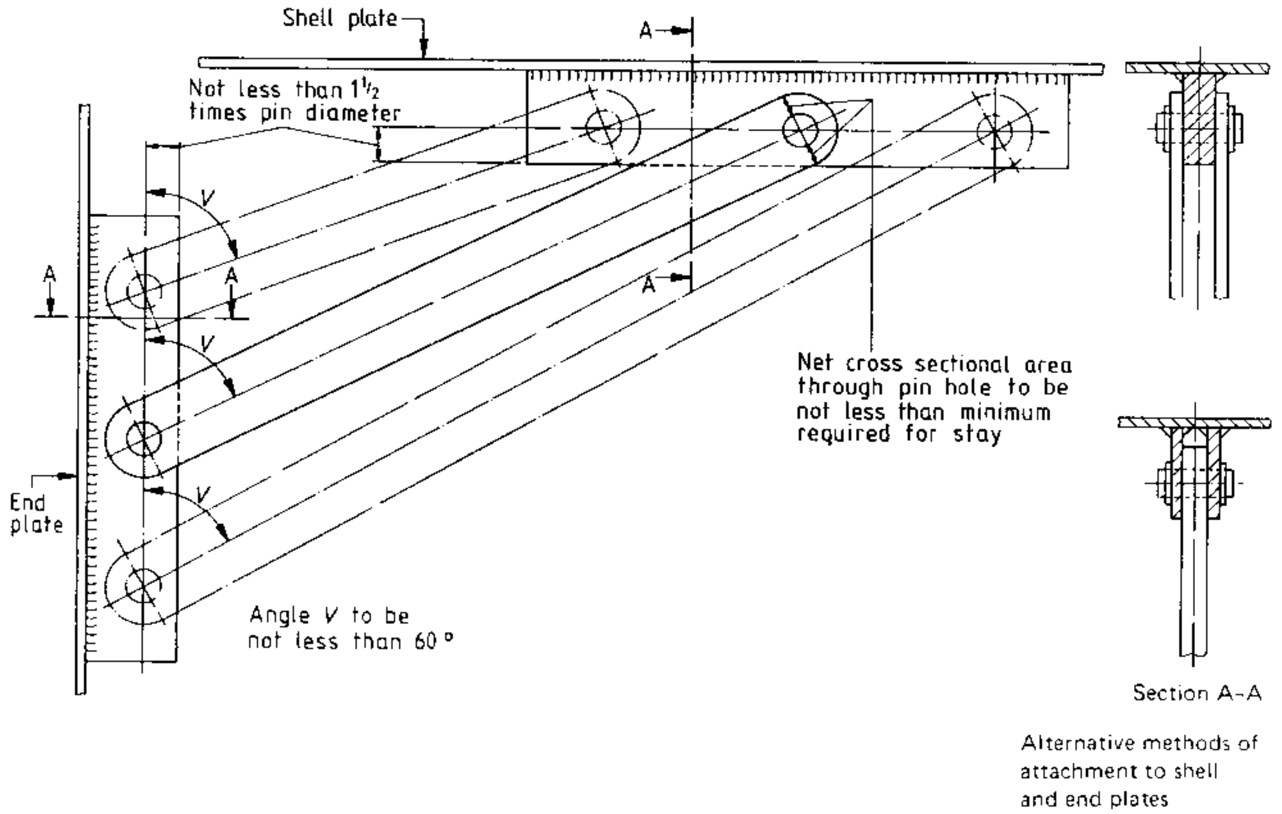
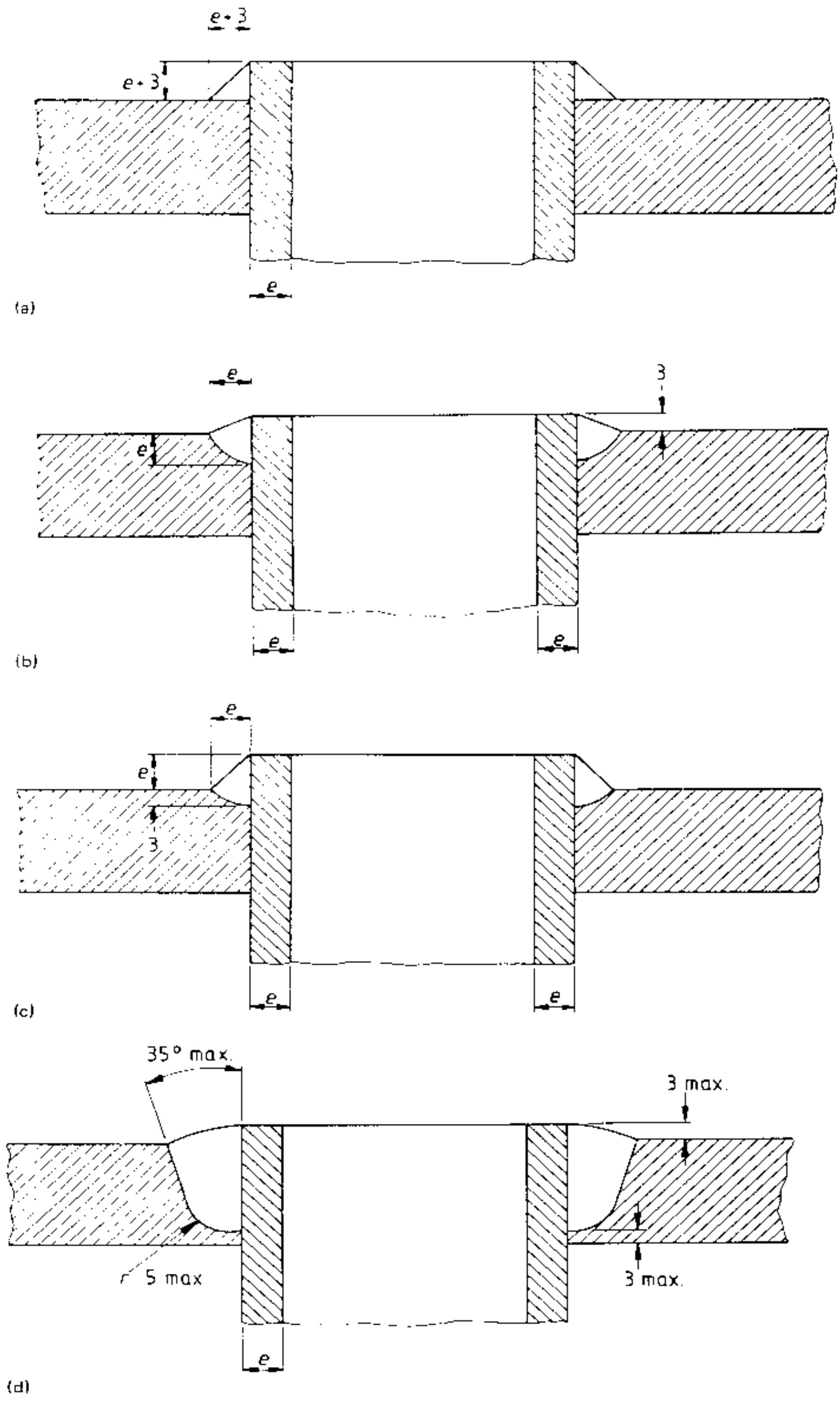


Figure 3.8.8.3(2) — Typical details for welded and pinned gusset stays



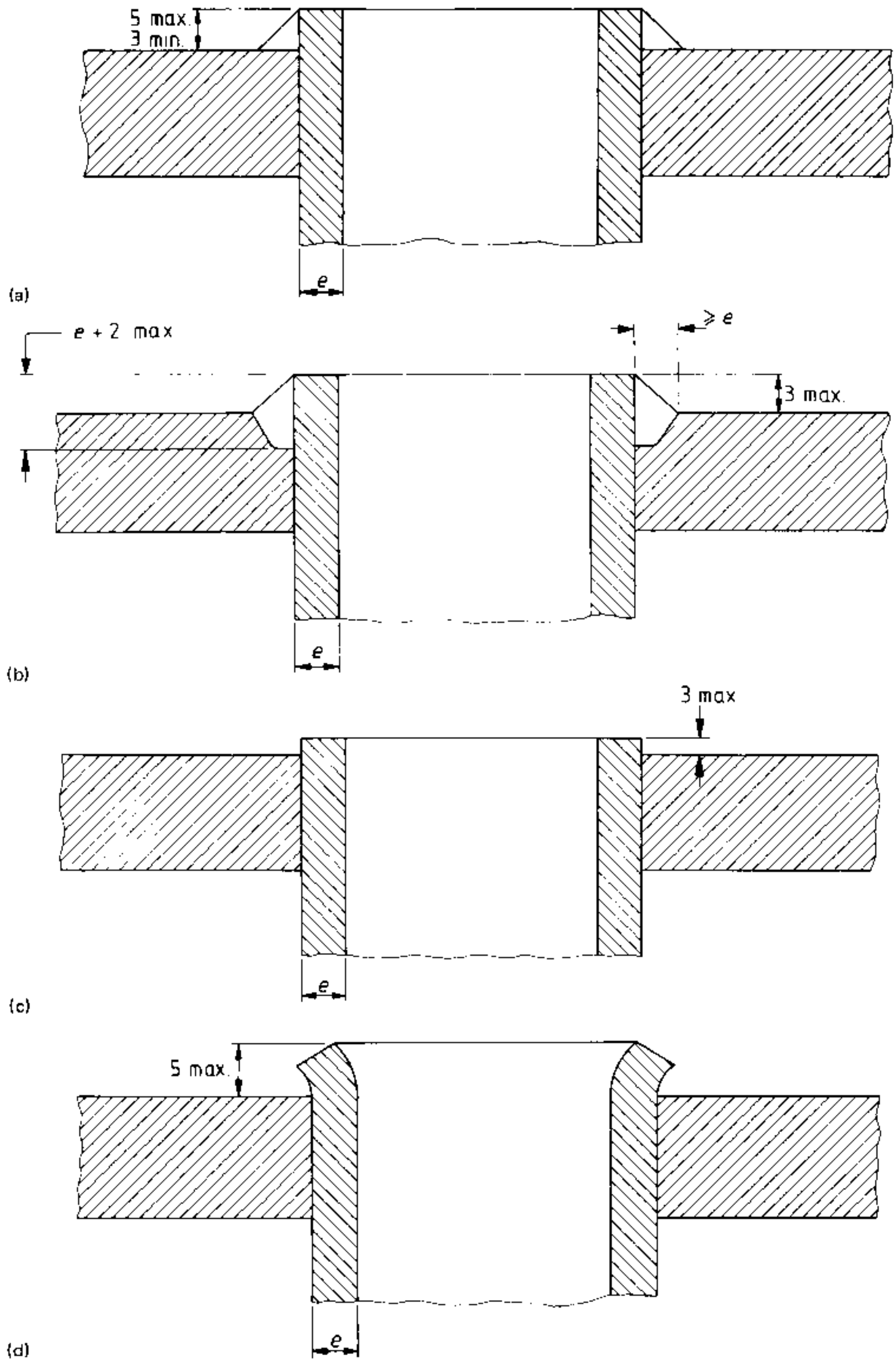
NOTE Broken lines indicate stay with multiple links.

Figure 3.8.8.4 — Typical details for diagonal link stays



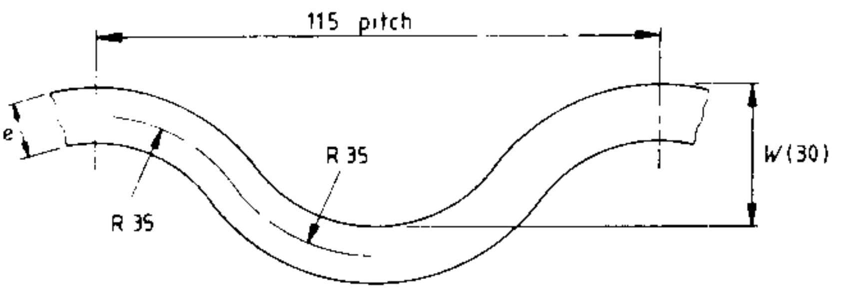
All dimensions are in millimetres.

Figure 3.9.2(1) — Typical attachment of stay tubes



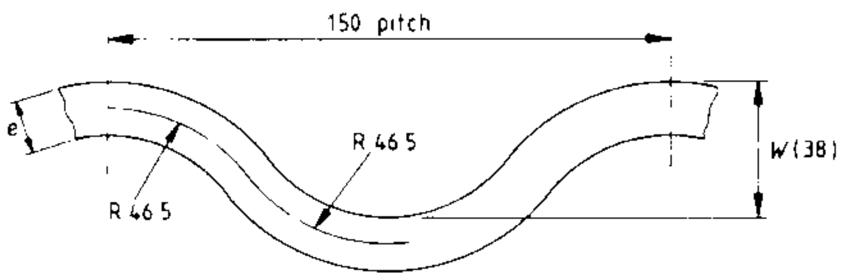
All dimensions are in millimetres.

Figure 3.9.2(2) — Typical attachment of plain tubes



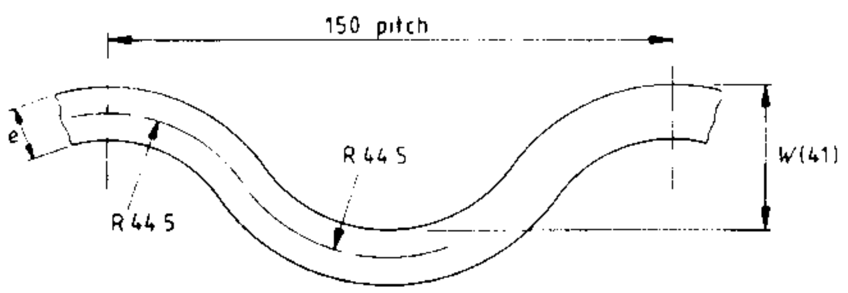
$e - C$	I	F
	mm^4 × 10^4	mm^2 × 10^2
8.25	13.9	11.1
9.25	15.8	12.5
10.25	17.8	13.8
11.25	19.9	15.2
12.25	22.1	16.5
13.25	24.4	17.9

(a) Fox type furnaces (115 mm corrugation and 30 mm depth)



$e - C$	I	F
	mm^4 × 10^4	mm^2 × 10^2
9.25	31.9	16.1
10.25	35.7	17.9
11.25	39.6	19.6
12.25	43.6	21.4
13.25	47.8	23.1
14.25	52.1	24.9
15.25	56.6	26.6
16.25	61.2	28.4
17.25	66.0	30.1
18.25	71.0	31.8
19.25	76.2	33.6
20.25	81.6	35.3
21.25	87.3	37.1

(b) Fox type furnaces (150 mm corrugation and 38 mm depth)

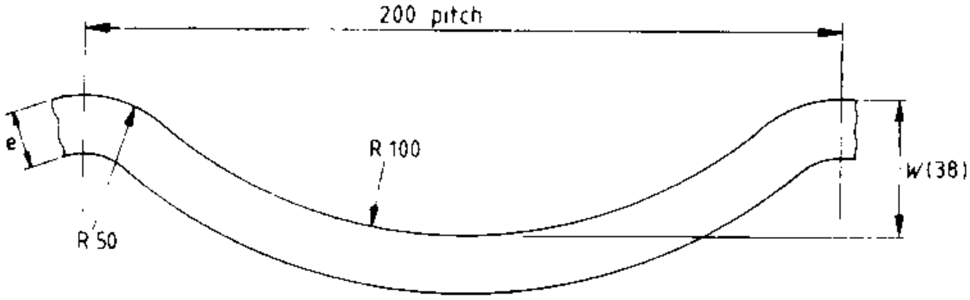


$e - C$	I	F
	mm^4 × 10^4	mm^2 × 10^2
9.25	37.7	16.5
10.25	42.2	18.3
11.25	46.8	20.1
12.25	51.5	21.9
13.25	56.3	23.6
14.25	61.3	25.4
15.25	66.4	27.2
16.25	71.8	29.0
17.25	77.3	30.8
18.25	83.0	32.6
19.25	88.9	34.3
20.25	95.0	36.1
21.25	101.4	37.9

(c) Fox type furnaces (150 mm corrugation and 41 mm depth)

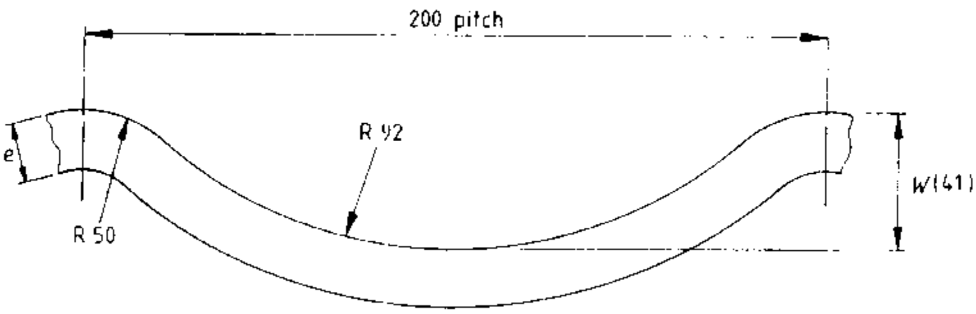
All dimensions in millimetres.

Figure 3.10.1.2 — Second moments of area *I* and cross-sectional area *F*



e – C	I	F
	mm⁴ × 10⁴	mm² × 10²
9.25	38.6	20.2
10.25	43.2	22.4
11.25	47.8	24.6
12.25	52.6	26.8
13.25	57.5	29.0
14.25	62.6	31.2
15.25	67.8	33.4
16.25	73.2	35.6
17.25	78.8	37.8
18.25	84.6	40.0
19.25	90.6	42.1
20.25	96.8	44.3
21.25	103.3	46.5

(d) Morrison type furnaces (200 mm corrugation and 38 mm depth)

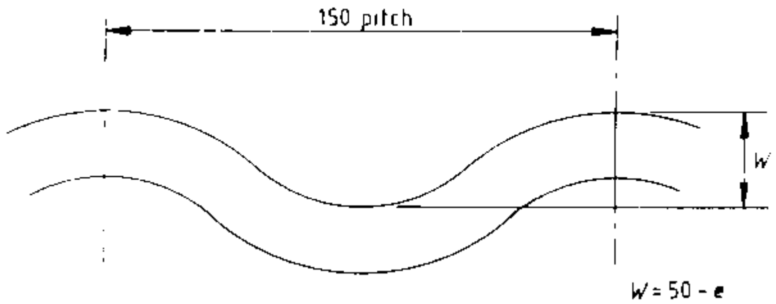


e – C	I	F
	mm⁴ × 10⁴	mm² × 10²
9.25	45.6	20.5
10.25	50.9	22.7
11.25	56.3	25.0
12.25	61.8	27.2
13.25	67.5	29.4
14.25	73.3	31.6
15.25	79.3	33.8
16.25	85.5	36.1
17.25	91.8	38.3
18.25	98.4	40.5
19.25	105.2	42.7
20.25	112.2	44.9
21.25	119.5	47.2

(e) Morrison type furnaces (200 mm corrugation and 41 mm depth)

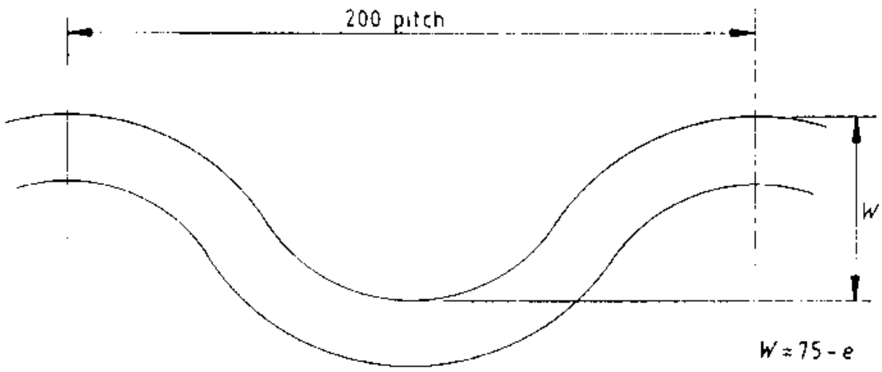
All dimensions are in millimitres.

Figure 3.10.1.2 — Second moments of area *I* and cross-sectional area *F* *(continued)*



(f) Fox type furnaces (150 mm corrugation and 50 mm total depth)

$e - C$	I	F
	$mm^4 \times 10^4$	$mm^2 \times 10^2$
9.25	35.6	16.4
10.25	37.7	18.0
11.25	39.6	19.6
12.25	41.2	21.2
13.25	42.7	22.8
14.25	44.1	24.4
15.25	45.3	25.9
16.25	46.4	27.4
17.25	47.4	28.9
18.25	48.3	30.4
19.25	49.2	31.9
20.25	50.1	33.3
21.25	51.0	34.8



$e - C$	I	F
	$mm^4 \times 10^4$	$mm^2 \times 10^2$
9.25	129.4	23.3
10.25	138.9	25.7
11.25	147.7	28.0
12.25	155.9	30.4
13.25	163.5	32.6
14.25	170.5	34.9
15.25	177.0	37.1
16.25	183.0	39.4
17.25	188.5	41.5
18.25	193.6	43.7
19.25	198.4	45.8
20.25	202.8	48.0
21.25	206.9	50.0

(g) Fox type furnaces (200 mm corrugation and 75 mm total depth)

All dimensions are in millimetres.

Figure 3.10.1.2 — Second moments of area *I* and cross-sectional area *F* *(concluded)*

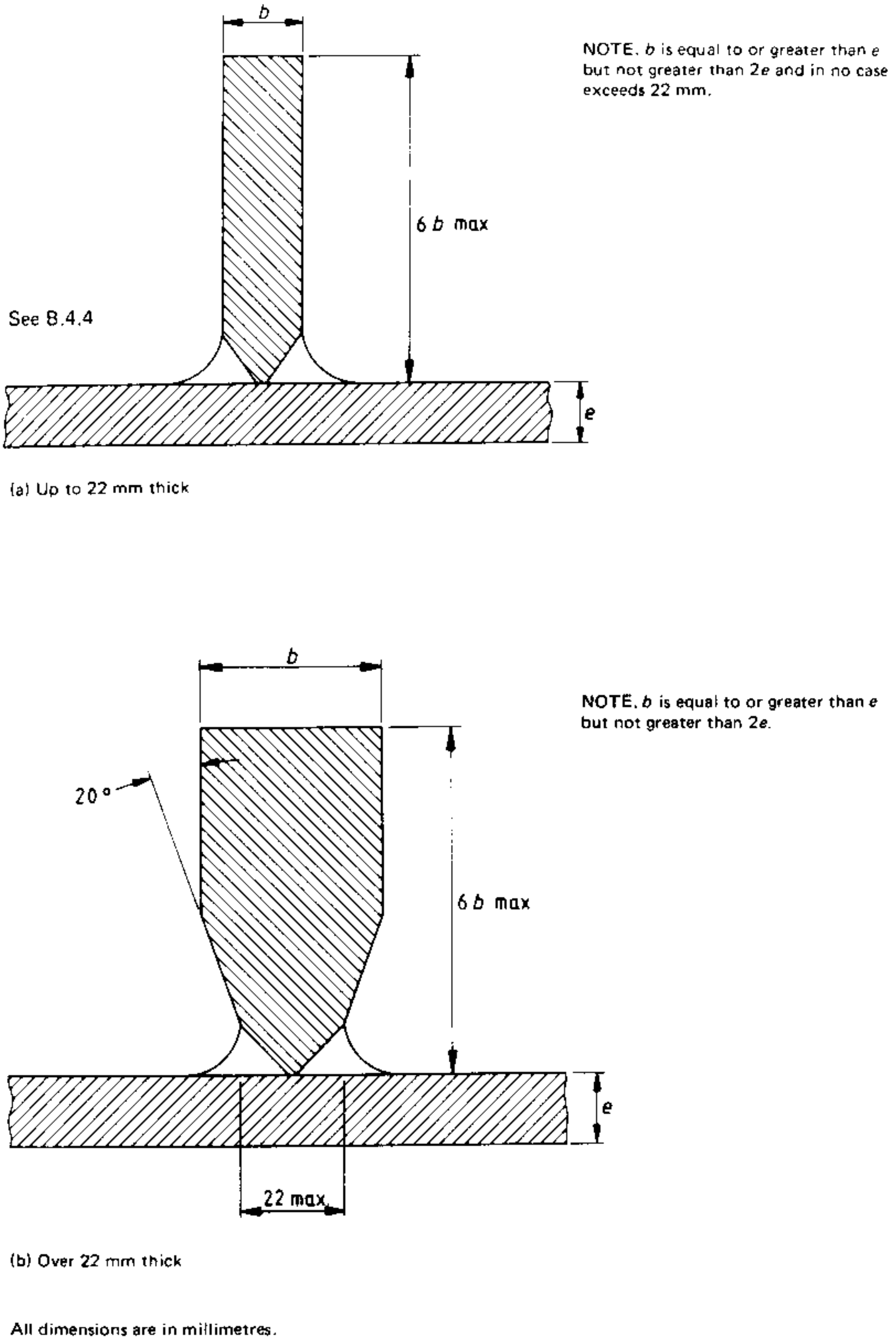
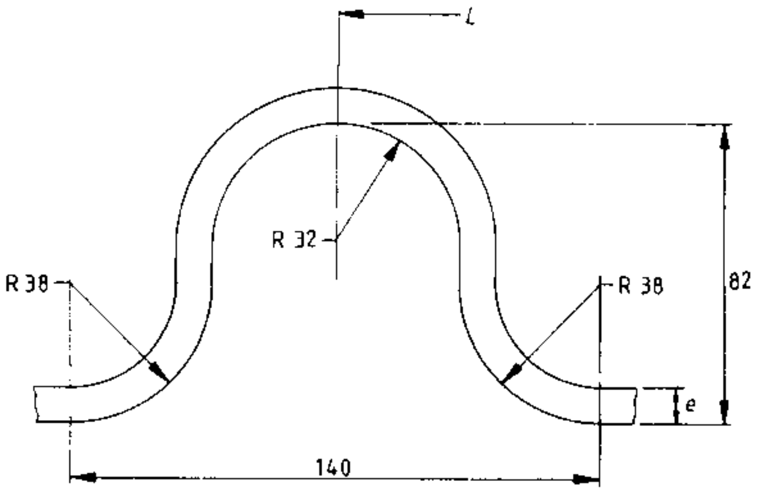
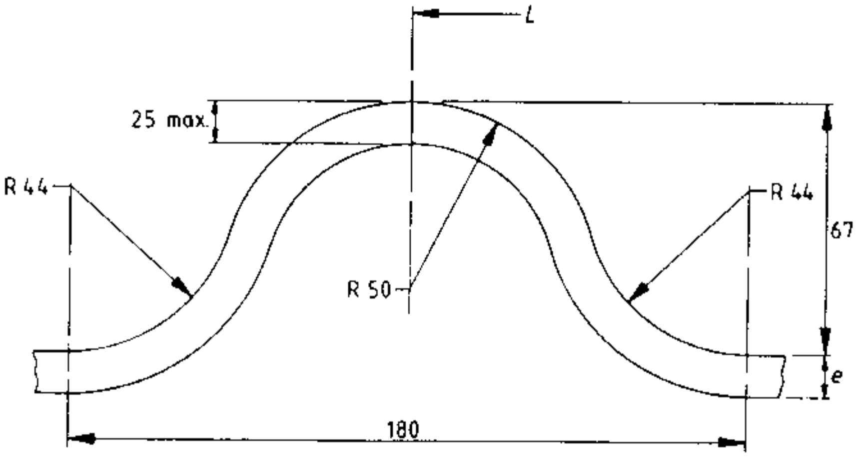


Figure 3.10.1.9.2 — Furnace stiffeners for plain and corrugated sections



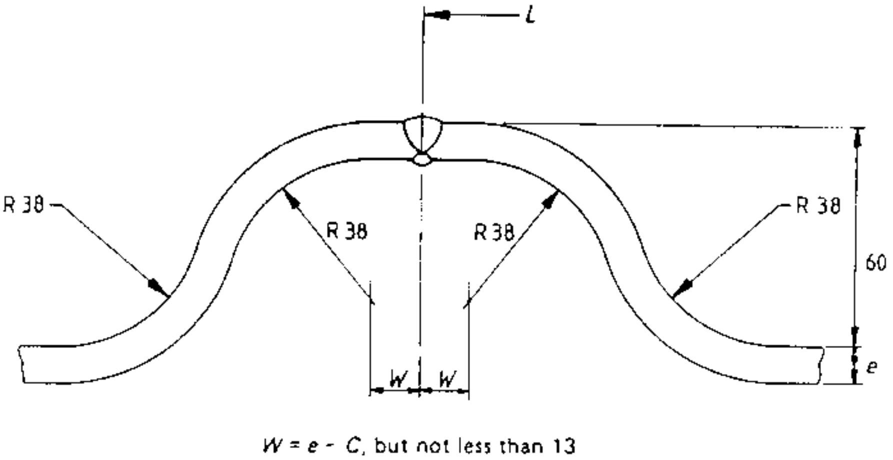
e – C	I
	mm⁴ × 10⁶
9.25	1.9
10.25	2.11
11.25	2.32
12.25	2.53
13.25	2.74
14.25	2.96
15.25	3.18
16.25	3.40
17.25	3.62
18.25	3.85
19.25	4.08
20.25	4.31
21.25	4.55

(a)



e – C	I
	mm⁴ × 10⁶
9.25	1.3
10.25	1.44
11.25	1.59
12.25	1.74
13.25	1.90
14.25	2.04
15.25	2.2
16.25	2.36
17.25	2.52
18.25	2.68
19.25	2.84
20.25	3.01
21.25	3.18

(b)

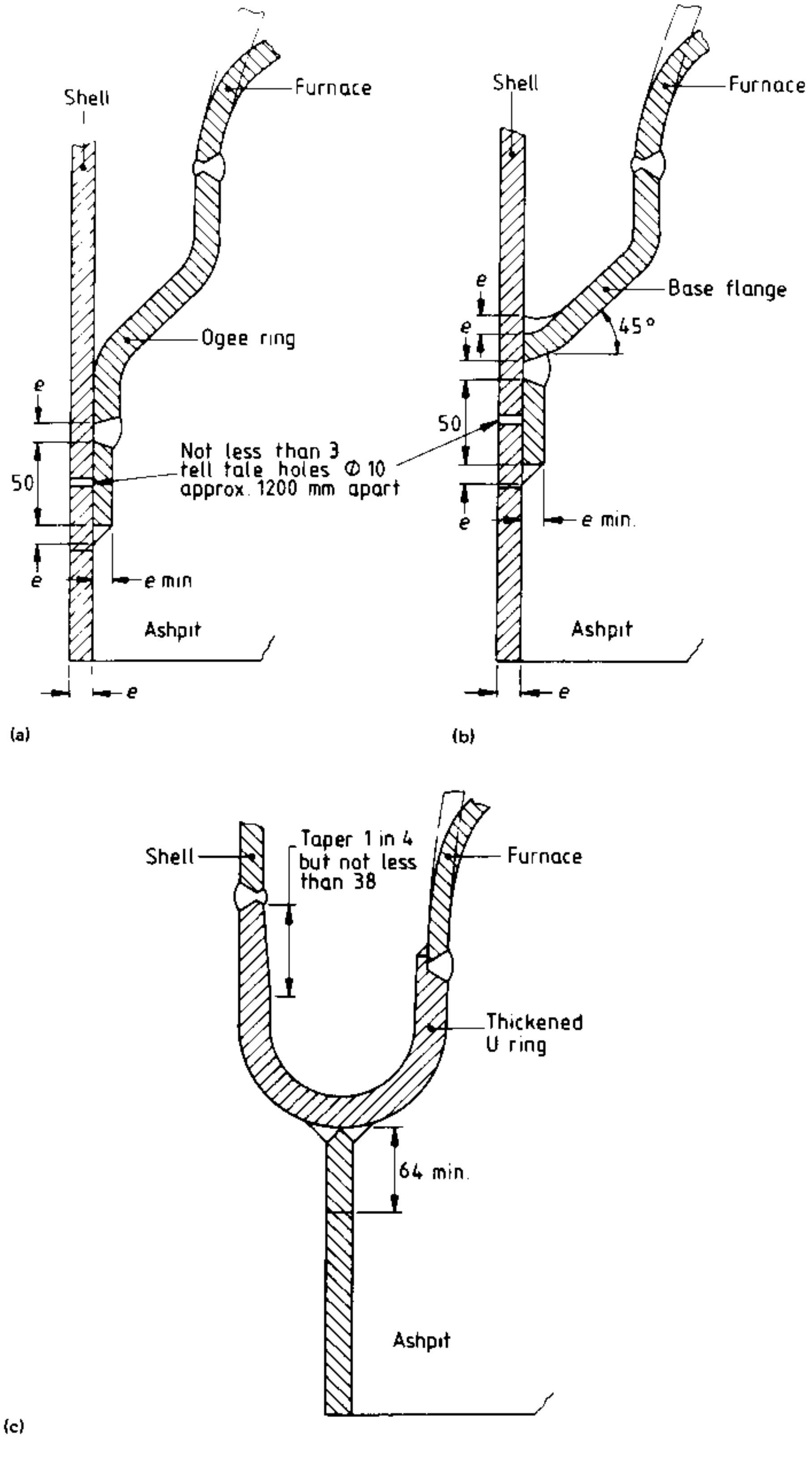


e – C	I
	mm⁴ × 10⁶
9.25	1.14
10.25	1.28
11.25	1.41
12.25	1.55
13.25	1.7
14.25	1.86
15.25	2.04
16.25	2.22
17.25	2.41
18.25	2.6
19.25	2.8
20.25	3.01
21.25	3.22

(c)

All dimensions are in millimetres.

Figure 3.10.1.9.3 — Bowling hoops



All dimensions are in millimetres.

Figure 3.10.3 — Attachment of fireboxes to shells

Section 4. Workmanship and construction in fabrication other than welding

4.1 Plate identification

In laying out and cutting the plates, the plate identification mark shall be located so as to be clearly visible after the pressure part is completed. If the plate's identification mark is unavoidably cut out, it shall be transferred by the pressure part manufacturer to another part of this component to the satisfaction of the Inspecting Authority.

4.2 Cold forming of plate

If the inside radius of curvature is less than ten times the plate thickness, the plate shall be subsequently normalized.

4.3 Cutting of forgings

Forgings shall be cut to size and shape by machining and/or thermal cutting.

4.4 Cylindrical shells

4.4.1 Construction. Each ring shall be formed from not more than two plates, each plate being bent to the correct radius to the extreme ends, except where the design incorporates flat tube plates which form part of the shell.

The bending shall be done entirely by machine. Neither local heating nor hammering shall be used.

The longitudinal seam or seams may be placed in any suitable position(s), but the seams in successive rings shall not fall in line.

Wherever possible, the design shall be such that the longitudinal seams are accessible for inspection.

4.4.2 Shell sections of completed boilers

4.4.2.1 *Straightness.* The maximum deviation of the shell from a straight line shall not exceed 0.3 % of the total cylindrical length and 5 mm in any 5 m length. Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

4.4.2.2 ***Irregularities in profile***

4.4.2.2.1 *Gradual local departures from circularity.* Irregularities in profile (checked by a 20° gauge or a needle gauge) shall not exceed 5 % of the nominal shell plate thickness e plus 3 mm.

This maximum value may be increased by 25 % if the length of the irregularities does not exceed 1 m.

4.4.2.2.2 *Peaking at welded seams.* Where any local departure from circularity is due, either wholly or in part, to the presence of flats adjacent to a welded seam, the peaking shall be measured in accordance with **4.4.2.2.1**. Where a profile gauge is used, its chord shall extend beyond the flats.

The allowable measured peaking δp shall be equal to or less than the smaller of (e/4 + 0.5 mm) and the value calculated in accordance with **4.4.2.2.1**

If this limit is exceeded, the shell shall be rerolled until a satisfactory result is achieved. In this case the seam shall be subjected to magnetic particle inspection (see **4.4.2.4**.)

4.4.2.3 *Out-of-roundness.* The difference between the maximum and minimum diameter of any section of a shell welded longitudinally shall conform to the tolerances of **3.2.3**(c) with a maximum of (D + 1250)/200, where D is the nominal internal diameter in millimetres.

Measurements shall be made to the surface of the parent plate and not to a weld, fitting, or other raised part.

NOTE Shell sections may be measured for out-of-roundness either when lying horizontal or when set up on end.

If the shell section is checked while lying horizontal, the maximum and minimum diameters at any cross section shall be measured. These reference diameters shall be re-measured after rotating the shell through 90° about its horizontal axis.
The mean of the maxima and the mean of the minima from the two sets of measurements shall be used in calculating the out-of-roundness.

4.4.2.4 *Cold rolling.* If cold rolling of a welded shell is used to rectify a small departure from circularity, non-destructive testing in accordance with **5.6** shall be carried out after rolling.

4.5 Reinforcing plates

Reinforcing plates shall bed closely to the plates to which they are to be connected. Any welds in the reinforcing plate are to be on the transverse centre line.

Reinforcing plates and saddles of nozzles attached to the outside of a boiler shall be provided with at least one telltale hole. If reinforcing plates are attached to the inside of the shell, tell-tale holes shall be drilled in the shell [see Figure 3.5(b)].

4.6 End plates and tube plates

4.6.1 Flat or dished ends shall be made in one piece, except that if the diameter is so large that this is impracticable, flat ends shall be made from two plates butt-welded together [see **5.4.11.3** and Figure B(2)]. The weld shall be located preferably between two rows of bar stays or, if there is only one row of bar stays, between this row and the top row of tubes. Dishing and peripheral flanging of end plates shall be done by machine. Such flanging should preferably be done in one operation, but, if this is impracticable, creep machine flanging may be permitted provided that the plate is worked at a suitable temperature and heated to an adequate distance beyond the portion under immediate treatment. Care shall be taken to see that the flanges are cylindrical, of good surface, and free from local irregularities. Plates which have been dished or flanged at non-uniform temperatures or which have been locally heated shall be normalized after forming unless otherwise agreed between the manufacturer and the Inspecting Authority [see **1.7.2.3** e)].

4.6.2 If hemispherical shell top end plates are pressed from one plate, they shall be pressed to form by machine in progressive stages without thinning below the calculated end thickness and shall be normalized on completion, except that normalizing may be omitted in the case of hot formed ends when the forming process is completed at temperatures within the normalizing range.

4.6.3 If dished ends or firebox top end plates are used, they shall be flanged for connection to the shell or the cylindrical portion of the firebox. Flat shell and firebox top end plates of vertical boilers shall also be flanged for connection to the cylindrical portions of the shell or firebox.

4.6.4 The opening in the firebox top end plate of a vertical boiler for the uptake shall be flanged and the connection to the uptake made by means of a circumferential butt weld [see Figure B(1)(a), Figure B(1)(b), Figure B(1)(c) and Figure B(1)(d)].

4.7 Plain tubes and stay tubes

4.7.1 General. Tubes shall be welded or expanded into the tube plate or secured by a combination of both methods.

The extension of tube ends beyond the tube plate shall be in accordance with **3.9.2**. If tubes are welded to the tube plate in accordance with Figure 3.9.2(1)(a), Figure 3.9.2(1)(b) or Figure 3.9.2(1)(c) or Figure 3.9.2(2)(a) or Figure 3.9.2(2)(b), the unwelded portion of the tube within the tube hole shall be in full contact with the tube place except that stay tubes more than 6 mm thick may be welded only, provided that the length of the unwelded land does not exceed four times the tube wall thickness.

NOTE Tubes may be welded after stress relief of the boiler.

4.7.2 Plain tubes. If tubes are expanded only, the process shall be carried out with roller expanders, and the expanded portion of the tube shall be parallel through the full thickness of the tube plate. In addition to expanding, tubes may be belied or beaded (see **3.9.2**).

4.7.3 Stay tubes. Examples of stay tube welding attachments are shown in Figure 3.9.2(1)(a), Figure 3.9.2(1)(b), Figure 3.9.2(1)(c) and Figure 3.9.2(1)(d).

4.8 Access and inspection openings

4.8.1 Materials. Frames and doors shall be of steel complying with the requirements of section 2.

4.8.2 Location. In no case shall the major axis of any opening exceed twice the minor axis of the opening.

NOTE Oval openings should preferably be arranged with the minor axis parallel with the longitudinal centreline of the boiler.

If the manhole is located in or between tube nests in multi-tubular boilers or below the furnaces of twin furnace boilers, the stay tubes in the boundary rows, or gusset stays, as applicable, shall be arranged as close as practicable to the manhole.

4.8.3 Frames. Oval frames of the flanged type shall be formed to fit closely to the shell and provide a mating surface for the door joint. Where practicable, such frames shall be attached to the inside of the shell with the shorter axis parallel to the longitudinal centreline of the boiler.

Oval frames shall be either formed in one piece without welding, or formed from a suitable rolled section fabricated by fusion welding. Welds in fabricated manhole frames shall be positioned so that they are in a plane at right angles to the longitudinal axis of the boiler.

The joint face of manhole frames shall be not less than 17.5 mm wide.

A typical form of manhole frame and attachment is shown in Figure B(30).

4.8.4 Jointing flanges. Faces for gaskets shall be machined on doors and frames. Bearing faces shall be machined for nuts and bolt heads.

4.8.5 Internal doors

4.8.5.1 Doors shall be formed to fit closely to the internal joint surface and shall be fitted with studs, nuts and cross bars.

4.8.5.2 Doors for openings larger than 250 mm × 175 mm shall have two studs. For openings of 250 mm × 175 mm or less, either one or two studs shall be fitted.

NOTE Doors for openings not larger than 125 mm × 90 mm with one stud may have the stud forged integrally with the door.

4.8.5.3 Door studs shall be of welding quality steel having a minimum specified tensile strength of not less than 360 N/mm^2, and those for manholes shall be not less than 30 mm diameter. They shall be attached to the door by one of the following methods:

a) screwed through the plate and fillet-welded on the inside; or

b) fillet-welded each side of the plate with a leg length of not less than 10 mm; or

c) attached to the door by an intermediate plate or lugs so that the strength of the attachment is not less than the strength of the stud, and the studs are prevented from turning.

4.8.5.4 The spigot part or recess of internal manhole, headhole, handhole and sighthole doors shall be as neat a fit as practicable and the spigot depth shall be sufficient to trap the gasket and to ensure that the spigot enters the opening before the gasket comes under compression. The total clearance between the frame and the spigot or recess of such doors shall not exceed 3 mm, i.e. 1.5 mm all round.

4.8.5.5 Nuts shall comply with appropriate British Standards and shall be machined on the seating surface.

4.8.5.6 Cross bars shall be of steel (see section 2) and shall be forged or cut from plate having a minimum specified tensile strength of 360 N/mm^2. The seating surface shall be flat.

4.9 Seatings for mountings

4.9.1 Flanged mountings, bolted or studded

4.9.1.1 Except as stated in **4.9.1.2**, flanged mountings shall be carried on suitable forged, cast or fabricated steel seatings in the form of short nozzles, branches, forged pads or pads cut from plate or round bar. Typical examples of the attachment of seatings to boiler plates are shown in Appendix B.

4.9.1.2 If flanged mountings up to and including 75 mm bore are to be attached to flat plates, they shall be either carried on seatings as described in **4.9.1.1** or attached directly to the flat plate and secured by studs. If the studs are screwed through the plate, nuts of full thickness shall be fitted on the inside of the boiler.

4.9.1.3 If seatings are fabricated by fusion welding and require stress-relieving in accordance with **5.5**, they shall be stress-relieved before attachment unless the whole boiler is to be heat treated on completion.

4.9.1.4 If flanged nozzles or branches are used, the flanges shall be machined or thermal cut by machine on the edges and shall be machined on the jointing and bolting surfaces.

4.9.1.5 If pads are used, the jointing surfaces shall be machined. The pads shall have sufficient thickness to allow drilling of the stud holes for mountings without the inner surface being pierced and the length of the screwed portion of the stud in the pad shall be not less than the diameter of the stud.

4.9.2 Screwed mountings directly connected to the boiler shell or end plates. Mountings with screwed ends shall be used only where the internal diameter does not exceed 25 mm and where the design pressure does not exceed 1.2 N/mm^2. The screwed portion of any such mounting shall be an integral part of it. The mountings shall be screwed directly into the plate, with nuts on the water side.

4.9.3 Screwed mountings fitted to screwed branches

Screwed mountings not exceeding 80 mm bore shall be fitted to suitably screwed branches welded to the boiler. The screwed portion of the mounting shall comply with BS 21. The mounting shall be suitable for the operating pressure and temperature of the boiler.

4.9.4 Bolts and nuts. All bolt and stud holes shall be drilled. Bolts and nuts shall be machined where in contact with flanges.

4.10 Horizontal cylindrical furnaces

4.10.1 Horizontal cylindrical furnaces shall be constructed in one of the following ways.

a) In sections from not more than two plates, in which case the longitudinal seam shall be butt-welded in accordance with section 5.

b) From carbon steel pipes complying with the requirements of the following British Standards.

BS 3602-1: HFS or CFS, grade 430

BS 3602-2: LAW, grade 430 and 490

BS 3601: S, grade 430

The tensile strength and minus tolerances on thickness given in those standards shall be taken into account. If LAW pipe is used, the longitudinal seam shall be non-destructively tested in accordance with **5.6.2.2.1**.

4.10.2 Out-of-roundness as defined in **3.10.1.8** shall not exceed 1.0 % for corrugated furnaces or 1.5 % for plain furnaces with a maximum variation in diameter of any cross section of 6.5 mm or half the thickness, whichever is the greater. Any departure from circularity shall be gradual.

4.10.3 The longitudinal welds shall break joint in successive sections by at least 150 mm.

4.10.4 If the furnace sections are flanged hot for circumferential joints, the flanging shall be carried out at one heat. Subsequently, sections shall be normalized unless flanging be carried out within the normalizing temperature range. If the furnace sections are flanged cold, they shall be subsequently normalized and the flanges shall be subjected to surface crack detection on both sides of the plate by the magnetic particle method. Cold spinning of furnace sections is not permitted.

4.10.5 Edges of all furnace flanges shall be machined or thermal-cut by machine.

4.10.6 If stiffeners are required, they shall be attached by means of continuous full penetration welding in accordance with Figure 3.10.1.9.2.

4.10.7 The projection of furnace plates beyond end plates or reversal chamber tube plates shall not exceed 3 mm. The end of the furnace plate corner exposed to flame or hot gas shall be ground to produce a radius of not less than $e/2$. The cylindrical portion of the flanged end plates connected to furnace plates shall be not less than 50 mm long. Typical examples of connections are shown in Figure B(5), Figure B(5)(a), Figure B(5)(b), Figure B(5)(c) or Figure B(6).

4.11 Fireboxes and reversal chambers

4.11.1 Plain circular fireboxes. The cylindrical portion shall preferably be formed from one plate in a similar manner to the shell plates. The maximum permissible variation in diameter at any cross section shall not exceed 6.5 mm for fireboxes up to 900 mm diameter, or 9.5 mm for fireboxes over 900 mm diameter, or half the thickness of the plate, whichever is the greater.

Vertical fireboxes shall preferably be tapered, a taper of 1 in 8 on diameter being recommended. The water space at the bottom between the firebox and the shell shall be not less than 50 mm for boilers up to and including 750 mm diameter and not less than 63 mm for boilers over 750 mm diameter.

The method of welding shall be in accordance with section 5.

Flats formed in the firebox for the insertion of water tubes shall have an ample radius at the junction of the flat and the curved surfaces and shall be free from sharp corners or tool marks. The plate shall not be thinned below the calculated thickness.

An ogee flange, whether integral with the firebox or made as a separate ring, shall preferably be formed at one heat by suitable machinery and shall be allowed to cool gradually to avoid internal stresses. Rings for firehole openings or foundation rings shall be made of steel in accordance with the requirements specified in section 2. *Z* sections shall not be used for foundation rings.

Methods of attachment of the firebox to the shell shall be in accordance with Figure 3.10.3(a), Figure 3.10.3(b) or Figure 3.10.3(c). Typical methods of attachment of firehole openings are shown in Figure B(10).

4.11.2 Hemispherical fireboxes. Hemispherical fireboxes shall meet the requirements of **4.6.2**.

4.11.3 Water-cooled reversal chambers. Where reversal chamber tube plates or end plates are flanged for attachment to wrapper plates the cylindrical portion shall be not less than $2e$ or 38 mm long, whichever is greater. Flat plates connected to wrapper plates shall have an internal fillet weld with a minimum leg length of 6 mm (see **5.3.2.4**). Typical examples of connections are shown in Figure B(4)(a) to Figure B(4)(e).

Access opening frames shall be attached as shown in Figure 3.8.2(7).

4.11.4 Uptakes. Uptakes shall be formed from seamless or longitudinally welded tube, or butt-welded plate, and shall be butt-welded to the upward flange of the opening in the firebox top end plate.

The depth of the flange of the firebox top end plate opening from the commencement of the curvature of the flange shall be not less than twice the plate thickness with a minimum of 25 mm.

The uptake shall be attached to the shell top end plate as indicated in Figure B(5)(a), Figure B(5)(b), Figure B(5)(c) or Figure B(6).

If the vertical seam of the uptake is butt-welded the welding shall comply with the requirements of section 5 and the weld shall be arranged so that it is directly facing the manhole.

NOTE The uptake should be fitted with an internal cast iron liner extending below the low-water level.

4.12 Cross tubes and stays

4.12.1 Cross tubes. Cross tubes shall be made from seamless steel tubes (see section 2). The tube shall be fusion-welded in position as shown typically in Figure B(8).

4.12.2 Stays. All bar stays or firebox stays shall be made from solid rolled bar without welds in the length, except those attaching them to the plates they support. Bar stays which have been hot-worked shall be subsequently normalized.

NOTE 1 When a stay is in position in the boiler, its axis should be normal to the plate it supports.

A tell-tale hole shall be drilled along the axis of all bar and firebox stays.

NOTE 2 The diameter of the holes should not exceed 5 mm and the drilling should extend 13 mm beyond the water surface of the plate.

4.12.3 Bar stays. Bar stays shall be secured to the plates they support by one of the following methods.

a) Plain bars passing through clearance holes in the plates and welded [see Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b)].

b) Plain bars passing through clearance holes in the plates and fitted with washers on the outside, the stay and washers being welded to the plates in accordance with any one of the methods shown in Figure 3.8.2(6)(a) to Figure 3.8.2(6)(d).

Clearance holes shall be cylindrical having a diameter not exceeding that of the bar stay by more than 3 mm.

4.12.4 Firebox stays. Firebox stays shall be secured to the plates which they support by welding [see Figure 3.8.2(5)(a) and Figure 3.8.2(5)(b)].

4.12.5 Gusset stays. Gusset stays shall be flat and perpendicular to the end plates.

4.12.6 Girder stays. The attachment of girder stays welded directly to the crown plates shall be by means of full penetration welds, and shall comply with the details shown in Figure 3.8.2(8)(a) to Figure 3.8.2(8)(f). Each girder shall be of sufficient strength to support its due proportion of the load on the top end plate independently of the crown plate, and the attachment welds shall have sufficient cross-sectional area to carry the applied load (see **3.8.8.6**)

Section 5. Workmanship and construction in welding

5.1 General

5.1.1 The rules in this section are applicable to boilers and boiler parts that are fabricated by welding and shall be used in conjunction with the specific requirements that pertain to the class of materials used.

5.1.2 The welding shall be executed in conformity with the approved welding procedure in accordance with **5.4.3**.

5.1.3 The welder shall be approved in conformity with the welder's competence tests as specified in **5.4.4**.

5.1.4 The manufacturer of a boiler or boiler part constructed in accordance with this clause shall be responsible for the welding done for this purpose by his workmen. He shall conduct the tests required to approve the welding procedure he uses and the competence of the welders who apply this procedure. No production work shall be undertaken until both the welding procedure and the welders have been approved.

5.1.5 The manufacturer shall maintain a record of the results obtained in welding procedure approvals and competence tests, which shall be witnessed by an Inspecting Authority. These records shall be certified by him and give an accurate description of all the particulars of the materials and procedure concerned and shall be accessible to the inspecting authority.

5.1.6 Each weld shall be identified with the welder by means of a stamp showing the welder's identity or else some other appropriate record shall be made. If hard stamping is employed only low stress stamps shall be used. (Low stress stamps have radiused edges or are made of a series of dots.)

5.2 Materials

The welding consumables to be used shall either:

a) comply with the requirements of the British Standard for the consumables; or

b) in the absence of a relevant British Standard, be agreed between the purchaser, the manufacturer and the Inspecting and/or Regulating Authority [see **1.7.2.3** f)].

5.3 Design

5.3.1 General. The requirements of **5.3** apply to the design of boilers and boiler parts that are manufactured by welding and shall be used in conjunction with section 3 of this standard.

NOTE Typical examples of acceptable details of welded connections are indicated in Appendix B.

5.3.2 Design of welded joints

5.3.2.1 The design of welded joints shall provide access for the deposition of weld metal adequate to comply with the requirements of this standard.

5.3.2.2 Joints where more than two welded seams meet shall be avoided.

5.3.2.3 Where practicable, non-pressure parts shall not be attached by welds which cross existing main welds or nozzle welds, nor shall they be attached such that the minimum nominal distance between the edge of the attachment weld and the edge of existing main welds or nozzle welds is less than twice the thickness of the pressure part or 40 mm (whichever is the smaller).

If such welds cannot be avoided, they shall cross the main weld completely rather than stopping abruptly near the main or nozzle weld, in order to avoid stress concentrations in these areas.

5.3.2.4 Only full penetration butt welds are acceptable for longitudinal and circumferential main seams.

Where temporary backing is used to facilitate welding seams of shells from one side of the plate only, it shall be removed after welding and before any non-destructive testing. The surfaces exposed by the removal of the backing shall be dressed smooth and shall be free from cracks or other defects as determined by a suitable inspection method, e.g. magnetic particle inspection.

Circumferential main seams other than butt welds, as indicated in Appendix B, are permitted for shell-to-flat end and shell-to-tube plate connections.

Flat plates attached to reversal chambers of firebox wrapper plates, as shown typically in Figure B(4)(a) to Figure B(4)(e), shall have reverse side fillet welds, with a minimum leg length of 6 mm, inserted for the full circumference of the seam. Flat plates attached to shells and furnace, as shown typically in Figure B(3)(a) and Figure B(3)(b) and Figure B(5)(a) and Figure B(5)(b), shall have reverse side fillet welds, with a minimum length of 6 mm, inserted for the full circumference of the seam, except in the following cases.

a) *Shell-to-end plate seams.* The reverse side fillet weld may be omitted when the shell outside diameter is less than 1 800 mm.

b) *Furnace-to-end plate and reversal chamber tubeplate seams.* The reverse side fillet weld may be omitted when the furnace is less than 750 mm outside diameter and the seam is protected by a refractory lining.

NOTE The above requirements for reverse side fillet welds ere dictated by consideration of accessibility for welding but whenever it is reasonably practicable to insert a fillet weld of the requisite quality then the weld should be inserted for the full circumference of the seam. It is preferable to complete the fillet weld before welding from the other side whenever it is practicable to do so [see **5.6.2.2.2** d)].

In cases where the reverse side fillet weld is omitted from flat plate attachment welds to shells, furnaces or reversal chamber access tubes, special consideration of the welding technique is required to ensure sound root conditions. Slight lack of root penetration up to a maximum of 2.5 mm shall not be cause for rejection.

5.3.2.5 If a cylindrical shell is constructed with plates of different thicknesses, the plates shall be arranged so that their centrelines form a continuous circle. The thicker plate shall be equally chamfered inside and outside over a circumferential distance not less than twice the difference in the thicknesses so that the plates are of equal thickness at the longitudinal weld.

For a circumferential seam, where the difference in the thickness is the same throughout the circumference, the thicker plate shall be reduced in thickness by machining to a taper for a distance not less than three times the offset.
(See also **5.4.10** and **5.4.11**.)

NOTE The width of the weld may be included as part of the taper of the thicker plate.

5.3.2.6 When welding ash drop-out tubes to furnaces and shells from one side where the other side is inaccessible for welding, lack of root penetration or root concavity shall not exceed 3 mm and the opening in the shell shall be reinforced with pad-type compensation [see Figure B(7)].

5.3.2.7 Corner joints with fillet welds only shall not be used.

5.3.2.8 Where practicable, openings in or near welded seams shall be avoided, especially when the seam is not stress-relieved. The minimum distance from the centreline of the welded seam to the nearest point of the weld of the connection or edge of the opening shall be 60 mm or four times the shell plate thickness (whichever is the larger).

If this is not possible, the opening shall cross the welded seam completely and in such a manner that the tangent at the point where the axis of the seam meets the edge of the opening makes an angle with this axis as close as possible to 90°. In this case, the welded seam shall be non-destructively tested for a length of 60 mm or four times the shell plate thickness (whichever is the larger) at each side of the opening.

5.3.2.9 Fillet welds shall only be employed as strength welds for pressure parts within the limitations recommended in Appendix B. Complete fusion at the root of the fillet welds shall be ensured by taking particular care in the lay-out of joints with fillet welds.

5.4 Fabrication and welding approval

5.4.1 General. The methods of welding main seams shall provide full penetration and it shall be demonstrated by approval tests that the welding method can produce a weld that is free from significant defects as described in BS EN 288-3 as supplemented by the requirements of Table 5.4.7(1).

NOTE Existing procedures to BS 4870-1 are considered technically equivalent to BS EN 288-3, when similar types of tests have been carried out. Thus, the bend tests in BS 4870-1 are considered equivalent to those in BS EN 288-3 even though the exact number and bend angle differ. Similarly, visual, radiographic, ultrasonic, surface crack detection, transverse tensile, hardness, macro-examination and impact tests are considered equivalent.

5.4.2 Welding processes. Any process used shall produce satisfactory results when tested in accordance with the procedure approval tests.

NOTE Details of welding processes are not defined in this standard.

5.4.3 Welding procedure approval

5.4.3.1 If a manufacturing firm can furnish proof, satisfactory to the purchaser in conjunction with the Inspecting Authority, that it has previously made successful procedure approval tests or successfully undertaken the manufacture of boiler components in respect of method, parent metal, filler metal and thickness, within a period of three years in accordance with the requirements of BS EN 288-3, such a firm shall be deemed exempt from the necessity of being re-approved under the requirements of this standard within the range covered by the previous tests.

If a firm has not had its procedure so approved or proof is not available, it shall prove by a welding procedure approval test that its organization is capable of welding the materials to be used.

5.4.3.2 Approval testing of welding procedures is to be carried out in accordance with BS EN 288-3, except as otherwise stated in **5.4.7**.

5.4.4 Welder's competence approvals. If a manufacturing firm can furnish proof, satisfactory to the purchaser in conjunction with the inspecting authority, that any welder assigned to manual or machine welding on boilers has previously made competence approval tests for the type of work and procedure concerned, and has been successfully engaged in the manufacture of boiler components within a period of six months, both in accordance with BS EN 287-1, then any such welder shall be exempt from the necessity of being re-approved under the requirements of this standard so long as the welder remains in the employment of the same manufacturer.

If such proof is not forthcoming, welders assigned to manual or machine welding on boilers shall be required to pass approval tests carried out in accordance with BS EN 287-1, except as otherwise stated in **5.4.7**.

NOTE Approval testing of welders should be carried out in accordance with BS EN 287-1. Welders who previously held approvals to BS 4871-1 are considered to be approved to work with the following provisos.

i) the range of approval of the welder is in accordance with BS EN 287-1.

ii) Welder approval tests to BS 4871-1 are considered technically equivalent to BS EN 287-1 except that for all MIG and MAG welding, bend tests should have been carried out. If bend tests for these processes have not been carried out during the BS 4871-1 test, re-approval to BS EN 287-1 should be performed.

iii) The prolongation of a BS 4871-1 approval test can be made at 6-monthly intervals by the employer/manufacturer, in accordance with **10.1** of BS EN 287-1:1992, for the period of two years from the date of effect of EN 287-1, i.e. from 1st May, 1992.

iv) The prolongation of a BS 4871-1 approval test in excess of the initial two years from 1st May, 1992 has to be made in accordance with **10.2** of EN 287-1:1992 in conjunction with an Inspecting Authority.

5.4.5 Acceptance of welding procedures and welders

5.4.5.1 *Welding procedures.* The inspector shall satisfy himself that the welding procedures employed in the construction of a boiler have been approved in compliance with the requirements of **5.4.3**.

5.4.5.2 ***Welders***

5.4.5.2.1 The manufacturer shall certify that the welding on a boiler has been carried out only by welders who have been approved under the requirements of **5.4.4**, and the inspector shall satisfy himself that only approved welders have been used.

5.4.5.2.2 The manufacturer shall make available to the inspector a certified copy of the record of the approval tests of each welder.

The inspector has the right to witness the approval test of any welder. Subsequently, in case of doubt, he has the right to request re-approval of any welder.

5.4.6 Welded production test plates

5.4.6.1 ***Test specimens***

NOTE The number of test specimens should be to Table 5.4.7(1).

5.4.6.1.1 Production test plates are required to represent all butt-welded main seams in boiler cylindrical components, i.e. shells, furnaces and reversal chambers. If the main longitudinal and circumferential butt-welded seams in a component are welded within the essential variables of the same welding procedure, production test plates welded as a continuation of longitudinal seams shall be provided.

If more than one seam in the same boiler is welded within the limits of the essential variables of the welding procedure, one test plate can represent more than one seam. A test plate is required for each 10 m length of longitudinal weld taken from different seams and a further test plate for any additional length less than 10 m, with a minimum of at least one test plate per boiler (except as required by **5.4.6.1.2**).

If there are only circumferential seams, or if the method of welding the circumferential seams differs from that employed for the longitudinal seams, a production test plate shall be welded separately in accordance with the procedure for the circumferential seams. A production test plate is required for each 30 m of circumferential weld and a further test plate for any additional length less than 30 m, with a minimum of at least one test plate per boiler (except as required by **5.4.6.1.2**).

5.4.6.1.2 For boilers which comply with the following conditions, a reduction in the number of welded production test plates specified in **5.4.6.1.1**, shall be permitted.

a) Sufficient boilers shall have been constructed within the range of the same welding procedure to result in at least 20 production test plates complying with **5.4.6.1.1**.

b) The boilers shall be of a similar type and manufactured in the same shop and by the same method of construction.

c) Production welding and construction shall be reasonably continuous.

d) Plate thickness, details of welds and attachments shall be within the limits covered by the welding procedure approval tests.

In that case the requirements of 10 m and 30 m in **5.4.6.1.1** shall be revised to 30 m and 90 m respectively with a minimum of one test plate every three months.

5.4.6.1.3 The material used for the test plates shall comply with the same specification as that used in the construction of the boiler and shall be manufactured by the same steel making process. The plates shall be of the same nominal thickness as the components represented and preferably selected from the same batch of material as that used in manufacturing the boiler.

The dimensions of a welded test plate shall be sufficient to take out the required test specimens for testing and any necessary retesting (see Figure 5.4.6.1.3).

5.4.6.1.4 If weld test plates are provided at both ends of a longitudinal seam, the dimensions of the test plates shall be sufficient to take the required test specimens from one of them and the specimens for any necessary retesting from the other.

5.4.6.1.5 The test plates shall be supported or reinforced during welding in order to prevent undue distortion.

The test plates shall be subjected to the same heat treatment as required for the work piece to which they belong.

If it is desired to straighten test plates that have become distorted during welding, this shall be done at a temperature below the temperature of heat treatment of the shell to which they belong and before final heat treatment.

5.4.6.2 *Non-destructive testing.* The welds in production test plates shall be subjected to the same non-destructive testing procedure (see **5.6**) and acceptance criteria (see **5.7**) as for the seam they represent.

If any defects in the weld of a test plate are revealed by non-destructive testing, their position shall be clearly marked on the plate and test specimens shall be selected from such other parts of the test plate as may be agreed upon between the manufacturer and the Inspecting Authority.

The cause of such defects in the production test plate shall be ascertained.

5.4.7 Destructive tests for procedure, welder and production control testing

5.4.7.1 *Test method.* The tests shall be carried out in accordance with BS EN 287-1 or BS EN 288-3 and Table 5.4.7(1) as appropriate, except where otherwise stated in **5.4.7**.

5.4.7.2 *Test temperatures.* The tests shall be conducted at room temperature.

5.4.7.3 ***All-weld tensile test***

5.4.7.3.1 The all-weld tensile strength R obtained shall be not less than the minimum specified tensile strength of the plate material. The elongation A % obtained shall be at least equal to that given by the following equation:

$$A = 45 - 0.046\,R$$

where

R is the tensile strength (in N/mm^2).

In addition, this elongation shall be not less than 80 % of the equivalent elongation specified for the parent material.

5.4.7.3.2 The reduction in area shall be not less than 35 %.

5.4.7.4 *Transverse bend test* (for plate $\leqslant$ 10 mm thick) [see Figure 5.4.7.4 and Table 5.4.7(2)]. Face bend tests shall be conducted with the surface of the test plate corresponding to the outer surface of the boiler in tension. Root bend tests shall be conducted with the surface of the test plate corresponding to the inner surface of the boiler in tension.
On completion of the test, no crack or other defect at the outer surface of the test specimen shall have a dimension greater than 1.5 mm. Slight tearing at the edges of the test specimen shall not constitute failure to comply with this standard.

5.4.7.5 *Side bend test* (for plate exceeding 10 mm thick) [see Figure 5.4.7.5 and Table 5.4.7(2)]. On completion of the test, no crack or other defect at the outer surface of the test specimen shall have a dimension greater than 3 mm Slight tearing at the edge of the test specimen shall not constitute failure to comply with this standard.

Table 5.4.7(1) — Number of test specimens for weld procedure approval and production control tests

Test specimen see Figure 5.4.6.1.3, Figure 5.4.7.4, Figure 5.4.7.5 and Figure 5.4.7.7)		**Double-sided butt joints**	**Single-sided butt joints**	**Fillet welds in plate**	**Branch attachment welds**
Macro-examination		1	2	2	4
Hardness survey		1	1	1	1
Transverse tensile	see BS 709	1	2	—	—
All-weld tensile	see BS 709	1	1	—	—
Root bend	for plate ⩽ 10 mm thick	1	3	—	—
Face bend	for plate ⩽ 10 mm thick	1	1	—	—
Side bend (for material > 10 mm thick)		2	1	—	—
Fillet weld fracture		—	—	3	—
Impact tests (class I boilers only)		3	3	—	—

NOTE 1 When more than one specimen of a particular type is required the specimens are to be taken as far apart as possible.
NOTE 2 The hardness survey is to be made on a macro-examination test specimen.
NOTE 3 For plates having a thickness exceeding 10 mm, side bend tests are to be substituted for root and face bends.
NOTE 4 Rout bend tests are always required when testing single-sided welds.
NOTE 5 For welder approval testing, see BS EN 287-1.

Table 5.4.7(2) — Bend test requirements

Steel	**Diameter of former**	**Free space between supports at end of test**
Carbon steels $R_m < 430\ N/mm^2$	2*e*	4.2*e*
Carbon steels $R_m = 430$ to $530\ N/mm^2$	3*e*	5.2*e*
Carbon-manganese steels $R_m > 530\ N/mm^2$	4*e*	6.2*e*

NOTE *e* is the thickness of the test specimen (see BS 709).
Bending angle required = 180°.

5.4.7.6 *Macro-examination.* The specimen for macro-examination shall be taken from material that has not been affected by flame cutting operations. The weld shall be sound, i.e. free from cracks and substantially free from discontinuities such as slag inclusions and porosity, to an extent equivalent to that given in BS EN 288-3 for procedure tests, BS EN 287-1 for welder test and **5.7** for production control tests. If there is any doubt as to the condition of a weld as shown by macro etching, the area concerned shall be examined microscopically.

5.4.7.7 ***Impact tests (class I boilers only)*** (see Figure 5.4.7.7)

5.4.7.7.1 Three notched bar impact test specimens shall be taken transversely to the weld parallel to the plate surface and as near as possible to the face side of the last pass of the weld with the axis of the notch perpendicular to the surface of the plate. The impact tests shall be carried out by the Charpy V-notch method and where the thickness of the material permits, the dimensions of the specimens, each of square section 10 mm × 10 mm, shall be in accordance with BS EN 10045-1. Where the thickness of the material does not permit the preparation of 10 mm wide test pieces the width (along the notch) shall be machined to 7.5 mm or 5 mm as appropriate. The greatest width of test piece that can be obtained from the section of the material shall be selected.

5.4.7.7.2 The average value obtained from the three impact test specimens shall be not less than 27 J for 10 mm × 10 mm specimens, 21.5 J for 10 mm × 7.5 mm specimens and 19 J for 10 mm × 5 mm specimens (see **5.4.7.2**).

One individual value may be below the specified value provided that it is not less than 70 % of that value.

5.4.7.8 ***Retests***

5.4.7.8.1 *Tensile tests.* Where a tensile test specimen fails to meet the requirements, two retests shall be made.

5.4.7.8.2 *Bend tests.* Where a bend test specimen fails to meet the requirements, two retests shall be made.

5.4.7.8.3 *Impact tests.* If the average of the three impact values is less than the specified value or if any one value is lower than 70 % of the specified value, three additional test pieces shall be taken from the same sample and tested. The average value of the six test results shall be not less than the specified value. Not more than two of the individual values shall be lower than the specified value and not more than one may be lower than 70 % of this value.

5.4.7.8.4 *Failure of retest specimens.* If any of the retest specimens fail to meet the specified requirements, the welded seams represented by these tests shall be deemed not to comply with the requirements of this standard. If any retest specimen fails during weld procedure approval tests then the cause of failure shall be established and the whole procedure test shall be repeated.

5.4.8 Cutting, fitting and alignment prior to welding

5.4.8.1 *Cutting.* Plates shall be cut to size and shape by thermal cutting and/or machining, or, for plates not greater than 15 mm in thickness, cold shearing. If cold shearing is used, the edges shall be examined (visually or otherwise) and found suitable for welding.

Preheating may be required particularly in the case of thick steel plates, in order to ensure satisfactory results when thermal-cutting.

Any material damaged in the process of cutting plates to size or forming the edge or end preparation shall be removed by machining, grinding, chipping or thermal-cutting back to sound metal. Surfaces that have been thermal-cut shall be cut back by machining or grinding so as to remove all burnt metal, harmful notches, slag and scale, but slight discoloration of machine thermal-cut edges on mild steel shall not be regarded as detrimental.

5.4.8.2 *Preparation for welding.* Welding preparations and openings of the required shape may be formed by the following methods.

1) Machining, chipping or grinding; chipped surfaces that will not be covered with weld metal shall be ground smooth after chipping.

2) Thermal cutting and gouging, provided that the edges are left smooth and in a condition suitable for welding.

After the edges of the plates have been prepared for welding they shall be given a thorough examination for flaws, cracks, laminations, slag inclusions or other defects. When plates are thermal-cut, the edges should be examined before further work is carried out. Care shall be taken to see that the weld preparations are correctly profiled.

5.4.8.3 ***Fitting and alignment***

5.4.8.3.1 Plates that are being welded shall be fitted, aligned and retained in position during the welding operation.

5.4.8.3.2 Bars, jacks, clamps, tack welds, or other appropriate means may be used to hold the edges to be welded in line. Tack welds shall be removed unless they are to be completely fused into the weld.

5.4.8.3.3 The edges of butt joints shall be held during welding so that the tolerances of **5.4.10** and **5.4.11** are not exceeded in the completed joint. If fitted circumferential joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be adjusted until the errors are within the limits specified. If fillet welds are used, the pieces shall fit closely.

5.4.8.3.4 Correction of irregularities shall not be carried out by hammering.

5.4.9 Surface condition before welding

5.4.9.1 *Cleaning of surfaces to be welded.* The surfaces to be welded shall be clean and free from foreign material such as grease, oil, lubricants, and marking paints, for a distance of at least 25 mm from the welding edge.

Oxide shall be removed from the weld metal fusion area. If weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel, air chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

5.4.9.2 *Assembly alignment tolerance.* Before any welding is commenced, it shall be ascertained that the edges prepared are aligned in accordance with the welding procedure.

5.4.10 Middle line misalignments. For longitudinal joints, the middle lines of the plates shall be in alignment within 10 % of the thickness of the thicker plate with a maximum misalignment of 3 mm.

5.4.11 Surface alignment tolerances

5.4.11.1 *Longitudinal joints.* The misalignment at the surface of the plates shall not exceed the values given in the following table.

Thicker plate thickness, b	Maximum misalignment
$b \leqslant 12$ mm	$b/4$
12 mm $< b \leqslant 48$ mm	3 mm
$b > 48$ mm	$b/16$ but not greater than 10 mm

If this misaligment would otherwise be exceeded, the surface of the thicker plate shall be tapered with a slope of 1 : 4.

5.4.11.2 *Circumferential joints.* The misalignment at the surface of the plates shall not exceed the values given in the following table.

Thicker plate thickness, *b*	Maximum misalignment
$b \leqslant 20$ mm	$b/4$
20 mm < $b \leqslant 40$ mm	5 mm
40 mm < $b \leqslant 50$ mm	$b/8$
$b > 50$ mm	$b/8$ but not greater than 20 mm

If this misalignment would otherwise be exceeded, the surface of the thicker plate shall be tapered with a slope of 1 : 3.

5.4.11.3 *Tube plate joints.* If tube plates are constructed from plates of different thickness the surface of the thicker plate shall be tapered with a slope of 1 : 4.

5.4.12 Finished longitudinal and circumferential joints. Welds shall have a smooth finish without valleys and shall merge into the plates without significant under-cutting or abrupt irregularity.

Undercutting shall be considered significant if the depth exceeds 0.5 mm.

To ensure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining plate, weld metal may be built up as reinforcement on each side of the plate. This reinforcement shall not exceed the following thicknesses.

Thicker plate thickness, *b*	Maximum reinforcement thickness
$b \leqslant 12$ mm	2.5 mm
12 mm < $b \leqslant 25$ mm	3 mm
$b > 25$ mm	5 mm
NOTE The reinforcement need not be removed except to the extent that it exceeds the permissible thickness, or if required by **5.4.14.4** and **5.6.3.5**.	

5.4.13 Fillet welds. Fillet welds shall be made in such a manner that there is no significant undercutting, as defined in **5.4.12**, or other harmful defects, and the deposition of weld metal shall be such as to ensure fusion with the parent metal at the root of the weld. Sufficient weld metal shall be deposited to meet the specified requirements. Not less than two weld runs shall be employed when making fillet welds.

If internal fillet welds are present in flat unflanged end plate or tubeplate joints to shells, furnaces and reversal chamber wrapper plates, the profile of the fillet weld shall be such as to minimize notch effects.

5.4.14 Miscellaneous welding requirements

5.4.14.1 The reverse side of joints that are welded from both sides shall be cleaned back to sound metal before applying weld metal from the reverse side.

NOTE This requirement is not intended to apply to any process of welding by which proper fusion and penetration are obtained by other means and by which the base of the weld remains free from impurities.

5.4.14.2 If the welding is stopped for any reason, extra care shall be taken on restarting to obtain the required penetration and fusion.

NOTE For submerged arc welding, chipping out a groove in the crater is recommended.

5.4.14.3 If joints welded from one side only are used, particular care shall be taken in aligning the components to be joined so as to ensure complete penetration and fusion at the bottom of the joint for its full length, except if otherwise stated in this standard.

5.4.14.4 *Plates welded prior to hot or cold forming.* If it is necessary to butt-weld plates together prior to hot forming, the welded joint shall be non-destructively tested throughout its length by ultrasonic or radiographic methods after hot forming.

Cold forming of welded plates shall only be carried out under the following conditions.

a) *Forming precaution.* Before cold forming the weld reinforcement shall be ground smooth and the manufacturer shall take precautions, where necessary, to avoid crack formation in the weld metal or the heat-affected zone.

b) *Limiting thicknesses:*

1) up to 20 mm thickness for coarse grained steels;

2) up to 25 mm thickness for fine grained steels.

c) *Forming.* If the inside radius of curvature after forming is less than 10 times the thickness, an appropriate heat treatment shall be applied as agreed between purchaser, manufacturer and Inspecting and/or Regulating Authority [see **1.7.2.3** g)].

d) *Control.* After cold forming, the welded joints shall be visually examined and non-destructively tested throughout their length by ultrasonic or radiographic methods, and on both sides by magnetic particle or penetrant methods.

NOTE For the purposes of this standard, coarse and fine grained steels are defined according to their McQuaid Ehn grain size, coarse grained having a grain size of 1 to 5 and fine grained having a grain size of 5 to 8 (see BS 970-1 and BS 4490).

5.4.14.5 Only small departures from circularity of a welded shell shall be rectified by cold rolling.

5.4.14.6 In cases where post weld heat treatment of a completed boiler is required by this standard (see **5.5.2**), the attachment of nozzles, pads, branches, pipes and non-pressure parts shall be carried out before heat treatment unless this is manifestly not practicable, e.g. when smoke boxes are welded to pressure parts or in other exceptional circumstances. In such cases, the following requirements shall be complied with in addition to all the other appropriate requirements of section 5.

a) Hydrogen controlled welding electrodes dried to at least scale B of BS 5135 shall be used or, alternatively, a process giving such potential hydrogen levels shall be used, e.g. TIG welding.

b) The weld metal shall blend smoothly with the component material and shall be dressed if so required by the non-destructive testing technique.

c) After completion of all welding and dressing, welds with throat thicknesses exceeding 6 mm shall be examined over their full length by magnetic particle methods.

5.4.14.7 ***Attachments***

5.4.14.7.1 Lugs, brackets, stiffeners, and other attachments shall be contoured to fit the curvature of the surface to which they are to be attached.

5.4.14.7.2 Temporary attachments welded to the pressure parts shall be kept to a practical minimum.

5.4.14.7.3 Temporary attachments shall be removed (see **5.4.14.8**) prior to the first pressurization unless they have been designed to the same standard as permanent attachments.

5.4.14.7.4 The welding of all attachments shall be carried out by approved welders and according to an approved procedure.

5.4.14.8 ***Removal of attachments***

5.4.14.8.1 If construction attachments are to be removed, the technique used shall be such as to avoid damaging the pressure part. Such removal shall be by chipping, grinding, or thermal cutting followed by chipping or grinding.

5.4.14.8.2 The areas from which temporary attachments have been removed shall be dressed smooth and be examined by an appropriate non-destructive test to the satisfaction of the parties concerned.

5.4.15 Repair of weld defects

5.4.15.1 Any repair to a weld carried out by the manufacturer shall be reported to the Inspecting Authority.

If the repair is made as a consequence of a radiographic examination, the films of the original defects shall be made available. If the defects form a continuous line, the manufacturer and the Inspecting Authority shall agree either to repair the defective part of the weld or to remove and reweld the entire weld [see **1.7.2.3** h)].

NOTE If the whole seam or an appreciable part of the seam has to be rewelded, the purchaser or Inspecting Authority may require that the original test plates be similarly treated or that new test plates of the same quality and thickness of material be attached to the end of the seam and welded with it.

5.4.15.2 Except for local repairs made by manual welding, all repairs or rewelding referred to in **5.4.15.1** shall, where practicable, be carried out by the same process as was used for the original weld. An alternative process shall only be used with the full knowledge and approval of the purchaser and Inspecting and/or Regulating Authority, and if approved in accordance with **5.4.3**.

5.5 Heat treatment

5.5.1 Preheating

5.5.1.1 To avoid hard zone cracking in the heat-affected zones of thermally-cut surfaces and welds, consideration shall be given to preheating the parent metal prior to the commencement of thermal-cutting or welding, including tack welding.

NOTE The preheating temperature will depend upon the type of joint, the metal thickness, the composition of the steel, the heat input to each run of weld and the hydrogen potential of the weld metal. Recommendations for preheating temperatures given in Table 5.5.1.1(1) and Table 5.5.1.1(2) should be considered as a general guide to good practice.

Other preheating temperatures are permitted provided that they are proved to be satisfactory by weld procedure approval tests.

Calculations of preheating temperature to suit particular combinations of heat input, material composition and thickness for carbon and carbon manganese steels may be made by reference to the following:

a) BS 5135;

b) Welding steels without hydrogen cracking. F. R. Coe. The Welding Institute, available from the Welding Institute, Research Laboratory, Abington Hall, Abington, Cambs., CB1 6AL.

No welding or tack welding shall be carried out when the temperature of the parent metal within 150 mm of the joint is less than 50 °C.

Table 5.5.1.1(1) — Recommended preheating temperatures for thermal-cutting of plates, sections, bars and forgings

Material type	Material thickness	Minimum preheating temperature
	mm	°C
Carbon and carbon manganese steel, C ⩽ 0.25 %	All	5

5.5.1.2 The manufacturer shall state, in the welding procedure submitted for approval by the Inspecting Authority in accordance with **5.4.3**, the details of any preheating treatment for each type of weld including attachment welds.

The manufacturer shall implement procedures for the measurement and maintenance of the preheating temperature.

NOTE Acceptable methods of temperature measurement include temperature-indicating crayons, contact pyrometers and thermocouples.

5.5.1.3 Where the risk of hydrogen cracking is high, e.g. under conditions of severe restraint, consideration shall be given to the benefits of either maintaining or boosting preheating temperature for a minimum of 2 h after welding (post-heat) or of an intermediate post-weld heat treatment to facilitate hydrogen removal.

5.5.1.4 The temperature shall be checked during the period of application.

5.5.1.5 Where preheating is specified, welding, where practicable, shall be continued without interruption. If continuity of preheating is interrupted, the joint shall be cooled slowly under an insulating blanket. Before recommencement of welding preheating shall be applied.

5.5.2 Post weld heat treatment

5.5.2.1 Post weld heat treatment in accordance with **5.5.2.2** to **5.5.2.5** shall (except as permitted by **5.4.14.6**) be carried out on the completed boiler after completion of all welding, and prior to the pressure test in cases where the thickness at any welded construction exceeds 30 mm.

5.5.2.2 If the welded joint connects parts that are of different thickness, the thickness to be considered in applying the limit given in **5.5.2.1** shall be one of the following nominal thicknesses (no deduction being made for corrosion allowance):

a) the thinner of two adjacent butt-welded plates including dished end-to-shell connections;

b) the thickness of the shell in connections to flat plates which are butt-welded to the shell; the thickness of flat plates where these are inset into the shell;

c) the thickness of the shell or flat plate, as appropriate, in nozzle or pad attachment welds;

d) the thickness of the nozzle neck at the joint in nozzle neck-to-flange connections;

e) the thickness of the pressure part, at the point of attachment, where a non-pressure part is welded to a pressure part.

5.5.2.3 The temperature to which plain carbon and carbon-manganese steels shall be heated for stress relief purposes shall be within the range 580 °C to 620 °C. The holding time within this temperature range shall be 2.5 min/mm, with a minimum of 60 min.

The procedures a) to f), as follows, shall be adopted for application of the heat treatment.

a) The temperature of the furnace at the time the boiler is placed in it shall not exceed 300 °C.

b) The rate of heating above 300 °C shall not exceed the values given in the following table, the limiting thickness *e* being as stated in **5.5.2.2**.

Table 5.5.1.1(2) — Recommended preheating temperatures for welding of plates, sections, bars and forgings

Type	Hydrogen controlled weld metal[a]		Non-hydrogen controlled weld metal	
	Material thickness[b]	Minimum preheating temperature	Material thickness[b]	Minimum preheating temperature
	mm	°C	mm	°C
Carbon and carbon manganese steel, C ⩽ 0.25 %	⩽ 30 > 30	5 100	⩽ 20 > 20 ⩽ 50 > 50[c]	5 100

[a] Hydrogen controlled weld metal as defined in BS 639 contains not more than 15 mL of diffusible hydrogen per 100 g of deposited metal when determined by the method given in BS 6693-2.
[b] The greatest component thickness at the joint.
[c] It is recommended that only hydrogen controlled weld metal is used.

Shell or end plate thickness, *e*	Rate of heating
Up to and including 25 mm	220 °C/h
Over 25 mm	5 500/*e* °C/h or 55 °C/h, whichever is the greater

c) During the heating period, there shall not be a variation in temperature greater than 150 °C within any 4.5 m interval of length. When at the holding temperature, the temperature throughout that portion of the boiler being heated shall be within the range 580 °C to 620 °C.

d) During the heating and holding periods, the furnace atmosphere shall be controlled so as to avoid excessive oxidation of the surface of the boiler. There shall be no direct impingement of the flame on the boiler.

e) The boiler shall be cooled in the furnace to 300 °C at a rate not exceeding the values given in the following table.

Shell or end plate thickness, *e*	Rate of cooling
Up to and including 25 mm	275 °C/h
Over 25 mm	6 875/*e* °C/h or 55 °C/h, whichever is the greater

Below 300 °C, the boiler may be cooled in still air.

f) The temperatures specified shall be the actual temperatures of any part of the boiler as determined by thermocouples in contact with the boiler.

Furnace atmosphere temperatures may be used to indicate metal temperatures provided that evidence exists that such readings correspond to the metal temperatures within close limits and that such limits have been agreed between the manufacturer and the Inspecting Authority [see **1.7.2.3** i)].

A sufficient number of temperatures shall be recorded continuously and automatically to ensure that all the requirements of **5.5.2.3** are complied with.

5.5.2.4 *Check of post weld heat treatment.* The inspector shall satisfy himself that post weld heat treatment has been correctly performed and that the temperature readings comply with the requirements.

5.5.2.5 *Methods of heat treatment.* Heat treatment shall be effected where required by one of the following methods.

a) By heating the boiler as a whole in an enclosed furnace.

b) By heat treatment of an end plate, or a course of a shell having welded-on attachments, before the end or course is attached to the remaining parts. Where this is done, further stress-relieving may be necessary on completion.

c) By heat treatment of a shell in sections in an enclosed furnace. Where this method is adopted, the heated sections shall overlap by at least 1 500 mm and the portion outside the furnace shall be sufficiently shielded so that there shall be no harmful temperature gradient.

5.5.2.6 *Heat treatment of test specimens.* Test plates welded in accordance with **5.4.6** shall receive the same heat treatment where applicable as the shell they represent.

Where the shell is given a primary heat treatment in every way similar to that to be given to it on completion, the test plates shall be heat treated attached to or lying inside or alongside the shell.

Where the shell is not given a primary heat treatment, or is given a primary treatment that is not identical with the final treatment, the test plates may be heat treated with another shell which is to be heat treated in accordance with this standard. The heat treatment shall take place in a furnace in which the drum or shell to which the test plates relate will receive its final treatment. In such cases temperature-time records shall be provided to show that the test plates and the parts to which they relate have received similar treatment in respect of heating, soaking and cooling.

Where test plates are heat treated independently, the following factors shall be the same for both the test plate and the related shell:

1) rate of heating;

2) maximum temperature;

3) time held at temperature;

4) condition of cooling.

Heat treatment temperatures of separately heated test plates shall be recorded.

5.5.3 Heat treatment of test materials. The pre-heat, interpass temperature, intermediate and post-heat treatments, as applicable, for test materials shall be the same as for production welding, although the pre-heat temperature used during fabrication may be increased by up to 100 °C without requalification.

Subsequent heat treatment of test materials, i.e. normalizing or grain refining, tempering or stress relief, shall be the same for the test as for production welding.

5.5.4 Other heat treatments

5.5.4.1 A normalizing heat treatment, or other treatments according to the type of steel, as agreed between the manufacturer, purchaser and Inspecting and/or Regulating Authority, shall be carried out before or after welding hot-formed parts, unless the process of hot forming is carried out within the appropriate temperature range [see **1.7.2.3** j)].

5.5.4.2 If a normalizing heat treatment is carried out, the part to be normalized shall be brought up to the required temperature slowly and held at that temperature for a period just sufficient to soak the part thoroughly. If the geometry of the part causes insufficiently homogeneous cooling, a stress-relieving heat treatment shall be applied after the normalizing heat treatment.

5.6 Non-destructive testing

5.6.1 General

5.6.1.1 For acceptance purposes, class I and class II boilers shall be subjected to non-destructive testing in accordance with the requirements of **5.6.2** and **5.6.3**.

NOTE 1 For the purposes of this standard the term "non-destructive testing" covers the conventional techniques of radiographic, ultrasonic, magnetic particle and/or liquid penetrant testing as specified in **5.6.2** and **5.6.3**. Visual inspection is also, in principle, a non-destructive method of examination but in this standard is distinguished (see **5.6.1.2**) from the conventional non-destructive testing methods.

NOTE 2 Non-destructive testing is not required for class III boilers for the purposes of this standard.

NOTE 3 Non-destructive testing may also be used by the manufacturer during construction as part of the quality control process.

NOTE 4 Non-destructive testing of tube-to-tube plate and bar stay-to-flat plate welds is not required.

NOTE 5 Non-destructive testing may be carried out before post weld heat treatment.

If during the application of any one of the non-destructive techniques, the results obtained do not permit a final decision to be made in accordance with the acceptance criteria specified in **5.7** another of the techniques shall be applied in order to reach a final decision.

5.6.1.2 In addition to the requirements of **5.6.1.1**, all welds of class I, class II and class III boilers shall be visually inspected in accordance with the recommendations of BS 5289.

5.6.1.3 Non-destructive testing shall be carried out to written procedures provided by the manufacturer and approved by the Inspecting Authority.

5.6.1.4 Non-destructive testing personnel shall hold an appropriate certificate of competence (e.g. CSWIP) which is recognized by the Inspecting Authority; otherwise the Inspecting Authority shall satisfy itself as to the competence of such personnel.

5.6.2 Extent of non-destructive testing

5.6.2.1 *Parent material.* In the case of set-on end plates in accordance with Figure B(3)(c) and Figure B(3)(d) the requirements of quality grades L4 and C4 of BS 5996 shall apply.

To minimize the risk of laminar type defects occurring near welds of set-in plates it is recommended that the edges of shell and furnace plates be ultrasonically tested in areas which will be located adjacent to end plate welds, and that edge discontinuity quality grade E of BS 5996 should be used as a guide to acceptability. Imperfections affecting the plate edges shall only be repaired by welding procedures approved in accordance with **5.4.3**. Repaired areas shall be subjected to repeat ultrasonic tests.

If set-on end plates in accordance with Figure B(3)(c) and Figure B(3)(d) are employed, the plates shall be subjected to 100 % ultrasonic inspection over a 150 mm wide band from the periphery and 100 % ultrasonic inspection of deposited weld metal after intermediate stress relief and machining of weld profile. The plate material so tested shall satisfy edge discontinuity grade ES of BS 5996. The deposited weld metal shall comply with **5.7** of this standard.

The edges of shell and furnace plates adjacent to the welds of set-in end plates shall be ultrasonically tested to the same percentage as that given in Table 5.6.2.2.1 after completion of the welding of the seams. The acceptance level for laminar type defects shall be edge discontinuity grade E of BS 5996. Lamellar tearing shall not be permitted. Plate edge imperfections shall only be repaired by welding procedures approved in accordance with **5.4.3**. Repaired areas shall be subjected to repeat ultrasonic tests.

5.6.2.2 ***Welded seams***

5.6.2.2.1 *Butt-welded seams.* Butt-welded seams shall be subjected to radiographic or ultrasonic testing as given in Table 5.6.2.2.1.

Table 5.6.2.2.1 — Extent of radiographic or ultrasonic testing for butt welds

Component	Type of weld	Weld location	Figure no.	Testing technique	Notes	Percentage of total length of weld to be tested	
						Class I boilers	Class II boilers
Shell	Longitudinal	In shell sections	Figure B(1)	Radiographic or ultrasonic	1 and 2	100	10
	Circumferential	Between shell sections	Figure B(1)	Radiographic or ultrasonic	1,2 and 5	25	10
	Circumferential	Between shell sections and flanged end plates	Figure B(1) and Figure B(2)a	Radiographic or ultrasonic	1,2,4 and 6	25	10
	Circumferential	Between shell sections and set-on end plates	Figure B(3)c and Figure B(3)d	Radiographic or ultrasonic	—	100	100
	T-butt	At junction of shell with set-in end plates	Figure B(3)a and Figure B(3)b	Ultrasonic	2 and 3	10	10
Flat end plates	Butt	Between the two sections in large diameter end plates	Figure B(2)	Radiographic or ultrasonic	2	25	10
Furnaces	Longitudinal	In furnace sections	Figure B(1)	Radiographic or ultrasonic	1 and 2	10	10
	Circumferential	Between furnace sections	Figure B(1)	Radiographic or ultrasonic	1 and 2	10	10
	Circumferential	Between furnace sections and bowling hoops	Figure B(1)	Radiographic or ultrasonic	1 and 2	10	10
	Circumferential	Between furnace sections and flanged and plates	Figure B(6)	Radiographic or ultrasonic	1 and 2	10	10

Table 5.6.2.2.1 — Extent of radiographic or ultrasonic testing for butt welds

Component	Type of weld	Weld location	Figure no.	Testing technique	Notes	Percentage of total length of weld to be tested	
						Class I boilers	Class II boilers
Furnaces	T-butt	Between furnace sections and set-in end plates	Figure B(5)a, Figure B(5)b and Figure B(5)c	Ultrasonic	2 and 3	25	25
	T-butt	Furnace to reversal chamber end plate	Figure B(5)a, Figure B(5)b and Figure B(5)c	Ultrasonic	2 and 3	25	25
	T-butt	Between furnace sections and cylindrical components	Figure B(7), Figure B(19), Figure B(20), Figure B(21), Figure B(22) and Figure B(23)	Ultrasonic	2	25	25
Reversal chambers	Longitudinal	In wrapper plate	Figure B(1)	Radiographic or ultrasonic	2	10	10
	Circumferential	Between wrapper plate and flanged end plate	Figure B(4)a	Radiographic or ultrasonic	1 and 2	10	10
	T-butt	Between wrapper plate and set-in end plate	Figure B(4)b, Figure B(4)c, Figure B(4)d and Figure B(4)e	Ultrasonic	2 and 3	10	10
Reversal chamber access tube	Longitudinal	In access tube	Figure B(1)	Radiographic or ultrasonic	2	10	10
	T-butt	Access tube to boiler and reversal chamber end plates	Figure 3.8.2(7)	Ultrasonic	2 and 3	10	10

NOTE 1 The tests shall include each intersection of longitudinal and circumferential seams. For each longitudinal and circumferential seam there shall be at least one radiograph, or where ultrasonic testing is specified, at least a 200 mm length shall be examined.

NOTE 2 In each case the section of weld to be tested shall be selected at random.

NOTE 3 The position of the tested section of weld shall be marked on the boiler and recorded.

NOTE 4 In class I boilers it is permissible to reduce the percentage of weld tested to 10 when the boiler end plates are stayed to the shell or to each other.

NOTE 5 In class I boilers it is permissible to reduce the percentage of weld tested to 10 when the boiler end plates are fully stayed to each other by bar stays, stay tubes or a combination of bar stays, reversal chamber stays and stay tubes.

NOTE 6 When the flange is thicker than the end plate, the flange shall be machined to a taper and welded as shown in Figure B(2)a.

5.6.2.2.2 *Welds other than those covered by Table 5.6.2.2.1*

a) *General.* When welds are to be examined on the basis of a percentage of their length, the section(s) to be examined shall be selected at random.

b) *Full penetration welds of branches and pads.* For class I boilers, 25 % of the total length of branch welds, including the pad attachment welds that are welded to the same procedure, shall be subjected to non-destructive examination by radiographic or ultrasonic methods where the thickness of the thickest part exceeds 40 mm. If the thickness of the parts being joined is equal to or less than 40 mm, at least 25 % of the total length of weld shall be examined for surface flaws by magnetic particle or penetrant methods.

For class II boilers, it shall be permissible to reduce the amount of non-destructive examination to 10 %.

c) *Gusset and link stay attachment welds.* For class I and class II boilers, the full length of each gusset or link stay attachment weld, when of the full penetration type, shall be ultrasonically examined. When attached by fillet welds, the full length of each weld shall be examined for surface flaws by magnetic particle or penetrant methods.

d) *End plate reverse side fillet welds.* For class I and class II boilers, the reverse side fillet weld of boiler end plate to shell attachments and furnace to end plate and reversal chamber tubeplate attachments shall be examined for surface flaws over their full length, or as far as access permits, by magnetic particle or dye penetrant methods, except when the fillet weld was completed before welding from the other side. In this case, it shall be permissible to reduce the amount of magnetic particle or dye penetrant testing to not less than 10 % of the total length of welding of each seam.

e) *Lifting lug attachment welds.* Lifting lug attachment welds of the full penetration type shall be examined over their full length by the ultrasonic method. When lifting lugs are attached by fillet welds, the welds shall be examined for surface flaws over their full length by magnetic particle or penetrant methods.

f) *Welds of permanent major load carrying attachments.* For class I boilers, the welds shall be examined over 25 % of their length by ultrasonic methods in the case of full penetration welds, and by magnetic particle or penetrant methods in the case of fillet welds.

For class II boilers, it shall be permissible to reduce the amount of non-destructive examination to 10 %.

g) *Fillet welds other than those referred to in (b) to (f).* For class I boilers, 25 % of the total length of fillet welds shall be examined for surface flows by magnetic particle or penetrant methods.

For class II boilers, it shall be permissible to reduce the amount of non-destructive examination to 10 %.

5.6.2.2.3 *Acceptance of spot non-destructive testing.* If a welded seam reveals an unacceptable defect (see **5.7**) the entire seam shall be subjected to non-destructive testing.

5.6.2.2.4 *Non-destructive testing of repaired seams.* After a repair has been carried out to a welded seam, the repaired section shall be fully non-destructively tested by all the techniques specified for the original weld.

5.6.3 Non-destructive testing techniques

5.6.3.1 *Radiographic techniques*

5.6.3.1.1 Radiographic examination shall be in accordance with BS 2600-1, BS 2600-2 or BS 2910, as appropriate. Because several techniques with differing sensitivities are detailed in these standards, it is necessary to specify for each particular application which technique is required to be used. For thicknesses up to 50 mm X-ray techniques shall normally be used. Other techniques may be used provided it can be demonstrated to the satisfaction of the Inspecting Authority that adequate sensitivity can be obtained.

Radiographic sensitivity shall be determined in accordance with Table 7 of BS 3971:1980, which gives attainable values for thicknesses up to 150 mm. The values given in section A of Table 7 of BS 3971:1980 shall be regarded as the maximum acceptable percentage sensitivity values for techniques 1 and 2 of BS 2600-1:1983, equipment groups A, B, C, and D of BS 2600-2:1973 and techniques 1, 7 and 13 of BS 2910:1986.

The values in section B of Table 7 of BS 3971:1980 shall be used for the remaining techniques in these standards.

5.6.3.1.2 *Marking and identification of radiographs.* Each section of weld radiographed shall have suitable symbols affixed to identify the following:

a) the job or work-piece serial number, order number, or similar distinctive reference number;

b) the joint;

c) the section of the joint;

d) arrows, or other symbols, alongside but clear of the outer edges of the weld to identify its position clearly. The symbols, consisting of lead arrows, letters and/or numerals, shall be positioned so that their images appear in the radiograph to ensure unequivocal identification of the section.

If radiographs are required of the entire length of a welded seam, sufficient overlap shall be provided to ensure that the radiographs cover the whole of the welded seam and each radiograph shall exhibit a number near each end. Radiographs of repair welds shall be clearly identified as R1, R2, etc., for the first repair, second repair, etc.

5.6.3.2 *Ultrasonic techniques.* Ultrasonic examination shall be in accordance with level 2B of BS 3923-1 with a maximum transfer value of 6 dB.

5.6.3.3 *Magnetic particle techniques.* Magnetic particle inspection techniques shall comply in all respects with BS 6072. Their use shall be limited to applications where surface flaws are being sought.

Particular care shall be taken to avoid damage to the surface by misuse of the magnetic equipment employed. If such damage occurs it shall be remedied to the satisfaction of the Inspecting Authority.

5.6.3.4 *Penetrant techniques.* Dye or fluorescent penetrant examination of the welds shall be carried out in accordance with BS 6443.

5.6.3.5 ***Surface condition and preparation for non-destructive testing***

5.6.3.5.1 *Radiography.* Surfaces shall be dressed only where weld ripples or weld surface irregularities will interfere with interpretation of the radiographs.

5.6.3.5.2 *Ultrasonics.* The condition of the surfaces that will be in contact with the probe shall be in accordance with BS 3923.

5.6.3.5.3 *Magnetic particle method.* The surface shall be free of any foreign matter which would interfere with interpretation of the test and shall, where necessary, be dressed to permit accurate interpretation of indications.

NOTE If non-fluorescent testing media are employed, a suitable contrast medium (e.g. complying with the requirements of BS 5044) may be applied after cleaning and prior to magnetization.

5.6.3.5.4 *Penetrant method.* The surface shall be free of any foreign matter which would interfere with the application and interpretation of the test. Care shall be taken to avoid masking of flaws by distortion of surface layers by any dressing process which may be necessary.

5.6.3.6 *Reporting of non-destructive testing examinations.* The following information shall be given in reports

5.6.3.6.1 *General*

a) The date and timing, e.g. before or after stress relief, of the examination and report.

b) The name(s) of the personnel responsible for the examination and the interpretation.

c) Identification of the boiler and seam under examination.

d) Brief description of joint design, material, welding process and heat treatment employed (if any).

e) Cleaning and surface preparation or dressing prior to non-destructive testing.

f) Description and location of all relevant indications of defects, together with all permanent records, e.g. radiographs, photographs, facsimiles, scale drawings or sketches, as appropriate. Corresponding reports of visual examinations shall be provided.

5.6.3.6.2 *Additional information for specific methods*

a) *Radiography*

1) Image quality indicator pattern and sensitivity achieved (see BS 3971).

2) Details of the radiographic technique.

NOTE Full details may be recorded in a standard technique data sheet to which cross-reference may be made.

b) *Ultrasonics*

1) Report on parent metal examination including internal soundness, thickness and surface conditions.

2) Details of the ultrasonic technique and equipment employed.

NOTE Full details may be recorded in a standard technique data sheet to which cross-reference may be made.

c) *Magnetic particle method.* Details of the technique(s) employed.

NOTE Full details may be recorded in a standard technique data sheet to which cross-reference may be made.

d) *Penetrant method.* Details of the materials and techniques employed.

NOTE Full details may be recorded in a standard technique data sheet to which cross-reference may be made.

5.7 Acceptance criteria for weld defects revealed by visual examination and non-destructive testing

5.7.1 General. This clause applies to the main constructional welds of boilers. Other welded joints shall be examined as agreed between the parties concerned [see **1.7.3**(k)].

Welds shall be accepted unless defects exceed the levels given in Table 5.7(1), Table 5.7(2) and Table 5.7(3).

5.7.2 Groups of inclusions

5.7.2.1 *Isolated inclusions.* Inclusions shall be treated as isolated only if they are separated as follows.

a) *Linearly aligned* [curvilinear or rectilinear, see Figure 5.7.2(a) and Figure 5.7.2(b)]. Linearly aligned inclusions shall be separated by a minimum distance of twice the length of the largest inclusion [see Figure 5.7.2(c)].

b) *Randomly oriented inclusions* [see Figure 5.7.2(d)]. Inclusions that overlap are acceptable provided that they are contained within an envelope not exceeding 3 mm or $e/15$, whichever is the greater, and are separated by at least $e/4$ from any other envelope or individual inclusion.

5.7.2.2 *Assessment of a group of linearly aligned inclusions.* Inclusions within a group shall first be assessed individually in accordance with Table 5.7.

Adjacent inclusions contained within any envelope of radius $e/8$ shall be projected on to a polar centreline and then treated as being linearly aligned [see Figure 5.7.2(c)].

Adjacent inclusions shall be treated as interactive if the linear separation is less than twice the length of the longest inclusion in the pair under consideration. Only the actual length of adjacent inclusions, not their effective length, shall be taken into account when assessing whether they are interactive [see Figure 5.7.2(c)].

If the inclusions are found to be interactive, the actual length of each inclusion plus its separation from its neighbour shall be summed and the resulting length taken as the effective inclusion length for assessment in accordance with Table 5.7.

5.7.3 Repair of welds. Welds containing unacceptable defects shall be repaired. Repair of welds shall be carried out in accordance with a procedure approved by the Inspecting Authority and subjected to the same acceptance criteria as the original weld.

Table 5.7(1) — Visual acceptance levels

NOTE The following symbol is used.

h is the height of the defect

Profile defects	Permitted maximum
Undercut	Slight undercut permitted, depth should not exceed 0.5 mm
Shrinkage grooves and root concavity	As for undercut except that depth shall not exceed 1.5 mm
Excess penetration	h ⩽ 3 mm. Occasional local slight excess is allowable
Reinforcement shape	The reinforcement is to blend smoothly with the parent metal. Dressing is not required provided the shape does not interfere with the specified non-destructive testing techniques (see also **5.4.12**)
Overlap	Not permitted

Table 5.7(2) — Radiographic acceptance levels

NOTE The following symbols are used.

e is the parent metal thickness. In the case of dissimilar thicknesses, e applies to the thinner component

w is the width of the defect

I is the length of the defect

ø is the diameter of the defect

c is the mean circumference of the weld

Defect type		Permitted maximum	
Planar defect	a) Cracks and lamellar tears	Not permitted	
	b) Lack of root fusion Lack of side fusion Lack of inter-run fusion	Not permitted	
	c) Lack of root penetration	Not permitted except as specified in **5.3.2.4** and **5.3.2.6**	
Cavities	a) Isolated pores (or individual pores in a group)	$ø \le e/4$ and $\le$ 3.0 mm for *e* up to and including 50 mm $\le$ 4.5 mm for *e* over 50 mm up to and including 75 mm $\le$ 6.0 mm for *e* over 75 mm	
	b) Uniformly distributed or localized porosity	2 % of radiographic area[a] for $e \le 50$ mm, and pro rata for greater thicknesses	
	c) Linear porosity	Linear porosity parallel to the axis of the weld may indicate lack of fusion or lack of penetration and is therefore not permitted	
	d) Wormholes, isolated	$I \le 6$ mm, $w \le 1.5$ mm	
	e) Wormholes, aligned	As linear porosity	
	f) Crater pipes	As wormholes, isolated	
	g) Surface cavities	Not permitted	
Slag inclusions	a) Individual and parallel to major weld axis (see **5.7.2**)	Main butt welds in shells, furnaces and end plates and the welds of set-on end plates [see Figure B(3)(c) and Figure B(3)(d)]	$I = e \le 100$ mm $w = e/10 < 4$ mm
	b) Individual and randomly oriented (not parallel to weld axis) see **5.7.2**	As isolated pores	
	c) Non-linear group	As uniformly distributed or localized porosity	
Solid inclusions	a) Tungsten inclusions 1) Isolated 2) Grouped	 As isolated pores As uniformly distributed or localized porosity	
	b) Copper inclusions	Not permitted	

NOTE The simultaneous presence of more than one type of allowable defect within a given length of weld is permitted and each type should be individually assessed.

[a] The area of radiograph to be considered is the length of weld affected by porosity, but not less than 50 mm, multiplied by the maximum width of the weld.

Table 5.7(3) — Ultrasonic acceptance levels for welds of thickness 7 mm or greater

Group	Echo response height	Type of indication (see note 1)	Maximum permitted dimensions
A	Less than 20 % D.A.C.	All types	No limitations
B	Greater than D.A.C.	All types	None permitted
C	20 % to 50 % D.A.C. (D.A.C. – 14 dB to D.A.C. – 6 dB)	Threadlike (Th) $h < 3$ mm	$I \leqslant e$
		Volumetric (Vl) $h \geqslant 3$ mm	w or $I \leqslant e$
		Planar longitudinal (Pl) $h \geqslant 3$ mm	$I \leqslant \frac{e}{2}$
		Planar transverse (Pt) $h \geqslant 3$ mm	$I \leqslant 5$ mm
D	50 % to 100 % D.A.C. (D.A.C. – 6 dB to D.A.C.)	Threadlike (Th) $h < 3$ mm	lesser of $I \leqslant \frac{e}{2}$ or $\leqslant 5$ mm
		Volumetric (Vl) $h \geqslant 3$ mm	w or $I \leqslant 5$ mm
		Planar longitudinal (Pl) $h \geqslant 3$ mm	lesser of $I \leqslant \frac{e}{2}$ or $\leqslant 5$ mm
E	20 % to 100 % D.A.C. (D.A.C. – 14 dB to D.A.C.)	Planar surface (Ps) (see note 2) $h \geqslant 3$ mm	$I \leqslant 5$ mm
		Multiple (M) (see note 3)	I, w, or $h \leqslant 5$ mm
		Isolated point (Is) $h \leqslant 3$ mm	$I \leqslant 5$ mm

Key

e = Parent metal thickness. In the case of dissimilar thickness, e applies to the smaller thickness.

h = Through-wallDimension of flaw.

I = Length of flaw.

w = Width of flaw.

NOTE 1 Definition of types of indication: the following definitions apply to the types of indication detailed in Table 5.7(3).

— *Threadlike (Th):* indications having measurable length but no measurable width or through-wall dimension, and which are not classified as planar (e.g. linear inclusion).

— *Volumetric (Vl):* indications having measurable length and/or width and measurable through-wall dimension, and which are not classified as planar (e.g. linear or globular cavity or inclusion).

— *Planar longitudinal (Pl):* indications having a planar nature, which lie parallel to, or closely parallel to, the weld axis (e.g. longitudinal crack, lack of side-wall fusions, lack of inter-run fusion).

— *Planar transverse (Pt):* indications having planar nature, which lie transverse to the weld axis (e.g. transverse crack).

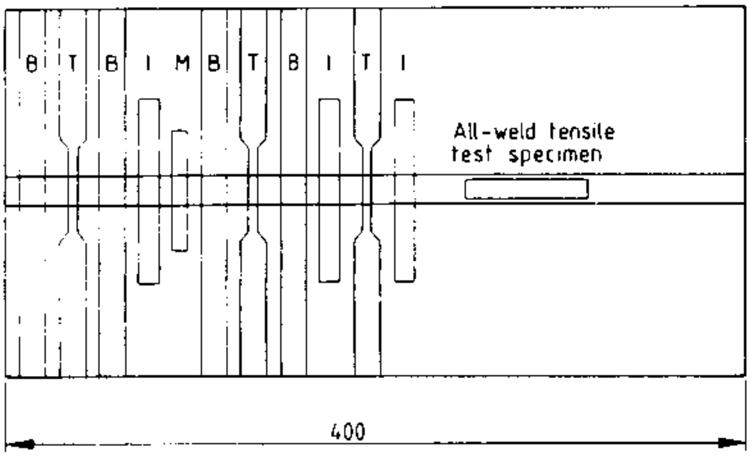
— *Planar surface (Ps):* indications of types Pl or Pt, which lie within 25 % of e, or 6 mm (whichever is the smaller) of the nearest surface, where e is the parent metal thickness or, in the case of dissimilar joined thicknesses, the smaller thickness (e.g. longitudinal and transverse cracks, lack of side-wall fusion, lack of root fusion and lack of root penetration).

— *Multiple (M):* group or cluster of indications in which individual indications cannot be resolved at the reference sensitivity (e.g. group or cluster of cavities or inclusions).

— *Isolated Point (Is):* indications having no measurable dimension and which can be resolved at the reference sensitivity from neighbouring indications. (It is not possible to determine from the ultrasonic information alone whether an isolated point indication is actually a pore, inclusion, short crack or small area of lack of fusion.)

NOTE 2 Indications shall be disregarded only by agreement between the manufacturer and the Inspecting Authority.

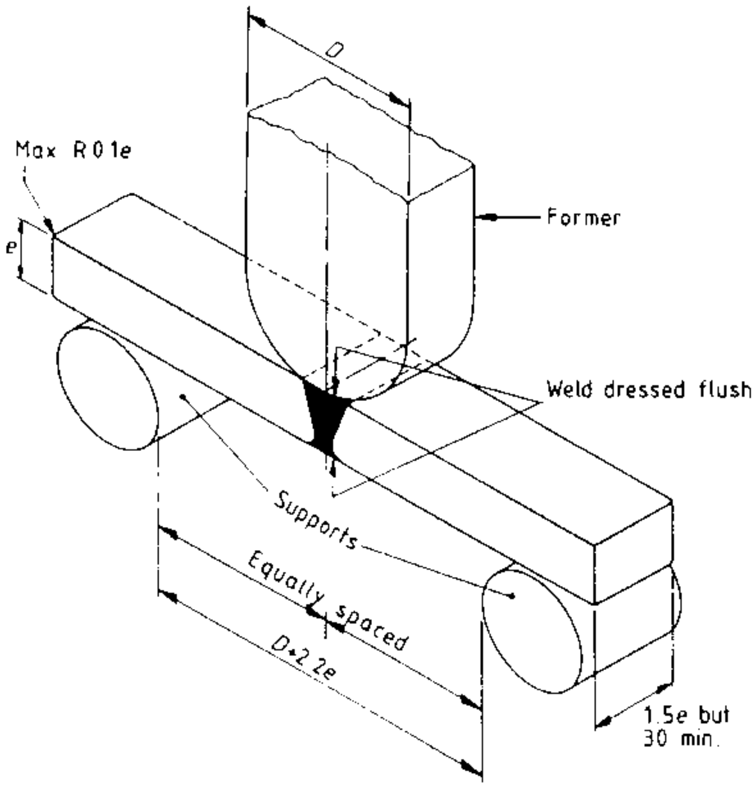
NOTE 3 Where adjacent, linearly aligned indications are separated by a distance of less than twice the length of the longest indication, they shall be considered as continuous. The total, combined length shall then be assessed against the appropriate flaw size criteria in Table 5.7(3).



B is a bend test specimen
T is a reduced section tensile test specimen
I is an impact test specimen
M is a macro-examination specimen

Dimension is in millimetres.

Figure 5.4.6.1.3 — Cutting up of the test plate



All dimensions are in millimetres.

NOTE The figure illustrates a root bend test.

Figure 5.4.7.4 — Transverse bend test specimen

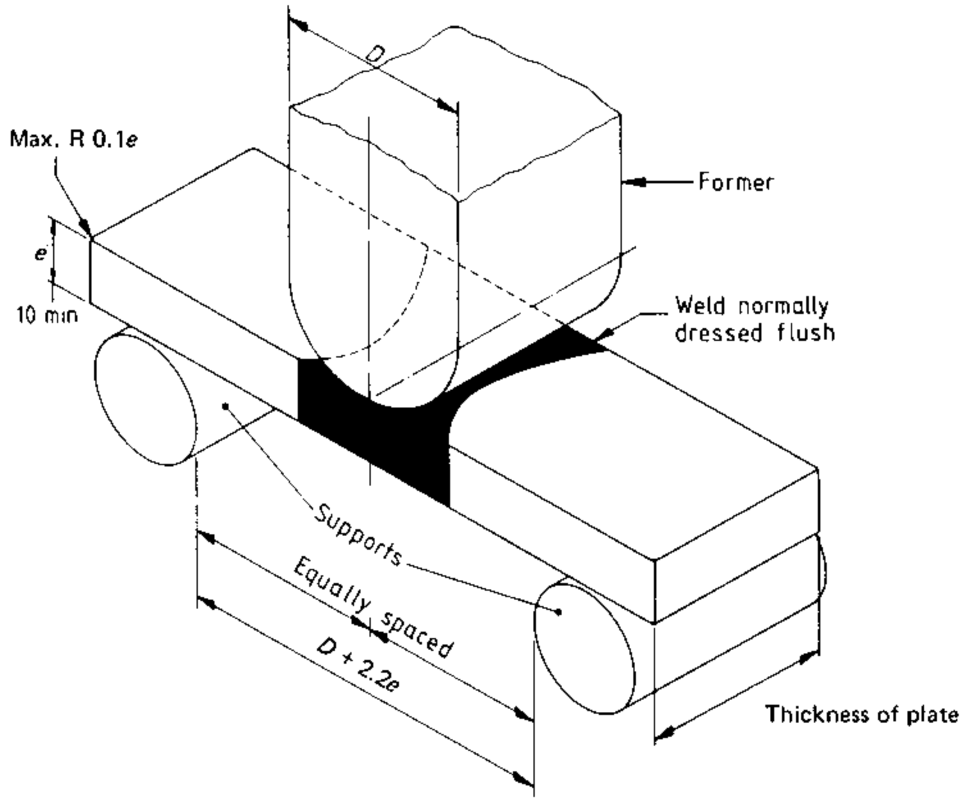


Figure 5.4.7.5 — Side bend test specimen

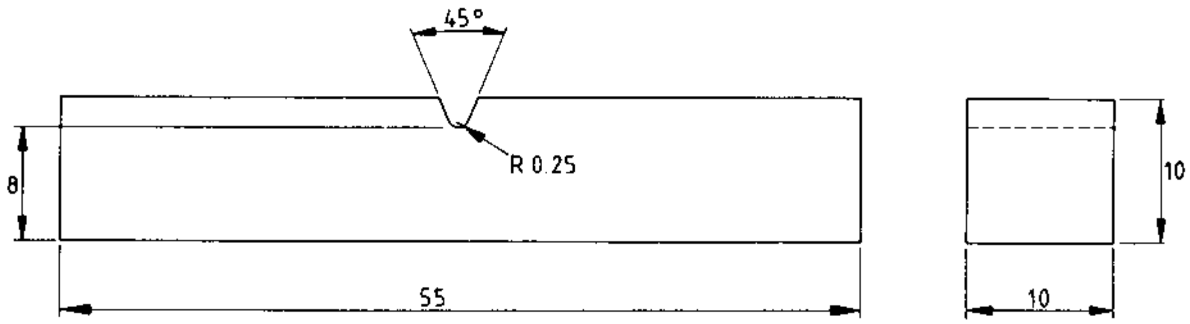


Figure 5.4.7.7 — V-notch test piece

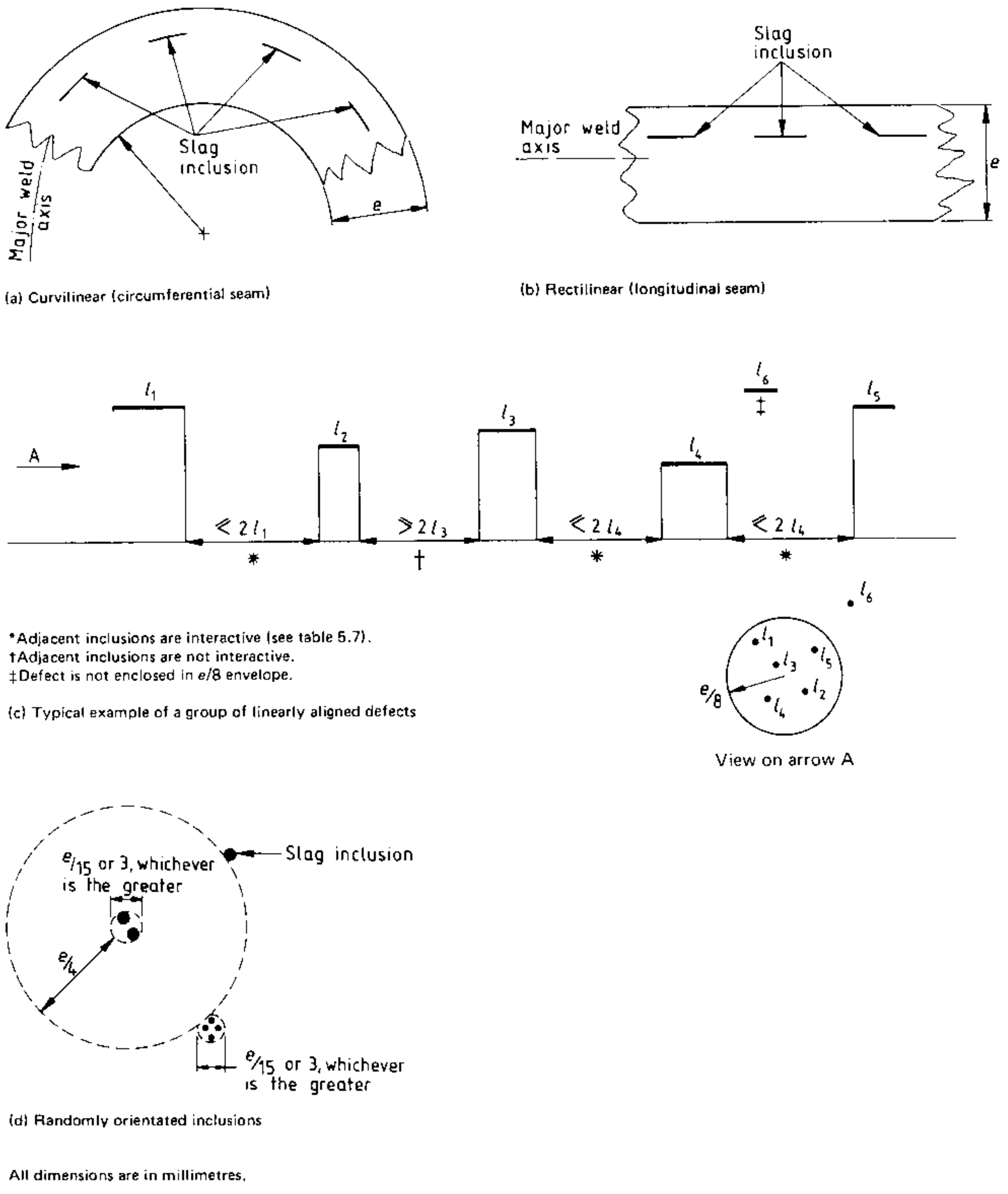


Figure 5.7.2 — Assessment of inclusions

Section 6. Inspection and pressure testing

6.1 Inspectors

Inspectors, as referred to in this section, shall be persons employed and trained as inspectors by inspection organizations that are recognized as Inspecting Authorities (see **1.3.7**) in the country of manufacture and/or installation.

The inspector, for the purpose of inspecting and/or certification of boilers under the requirements of this standard, shall be independent of the manufacturer and the purchaser and shall not be in the employ of either, except that, where the purchaser maintains a separate competent engineering inspection department, then competent inspectors from such a department may carry out the inspection and certification requirements of this standard.

6.2 Inspection during construction

6.2.1 Each boiler shall be inspected during construction by persons nominated by the Inspecting Authority. Sufficient inspections shall be made to ensure that the materials, construction, and testing comply in all respects with this standard.

The Inspecting Authority shall have the right to require evidence that the design complies with this standard.

The Inspecting Authority shall have access to the works of the manufacturer at all times during which work is in progress, and shall be at liberty to inspect the manufacture at any stage and to reject any part not complying with this standard.

The Inspecting Authority shall notify the manufacturer before construction begins of the stages of the construction at which special examinations of materials will be made, and the manufacturer shall give reasonable notice to the Inspecting Authority when such stages will be reached, but this shall not preclude the Inspecting Authority from making examinations at any other stages, or from rejecting material or workmanship whenever they are found to be defective.

6.2.2 The Inspecting Authority shall make examinations at the following stages:

a) when plates have been received at the boilermaker's works, to:

1) check the identification markings on the plates with those recorded on the platemaker's certificates;

2) check the reported results of mechanical and chemical properties given on the platemaker's certificates against the requirements of the standard;

3) witness the marking of test plates for identification before they are cut from the parent plate or plates.

b) when shell plates and end plates have been formed, with the plate edges prepared for welding, and when test plates are attached;

c) during the following stages of welding, if appropriate to the welding technique and as agreed between the manufacturer and the Inspecting Authority:

1) when the first run has been deposited along the principal seams and test plates;

2) when these seams have been completed on one side and prepared for welding on the other side;

3) on completion of welding;

d) to examine radiographs and/or reports of non-destructive testing;

e) when weld test specimens have been prepared from the test plate, previously selected, to witness the required tests;

f) when openings have been prepared, when standpipes and similar connections have been tack-welded in position, and subsequently on completion;

g) on completion of manufacture, during hydraulic testing and again after testing, to inspect internally and externally.

6.3 Pressure tests

6.3.1 When welding of all pressure parts has been completed and after heat treatment, if required by this standard, each boiler shall be hydrostatically tested to a pressure of 1.5 times the design pressure without any indication of weakness or defect.

The test shall be witnessed by the Inspecting Authority.

6.3.2 The test pressure shall be maintained for a period of not less than 30 min.

It is important, in the interests of safety, that the boiler shall be properly vented, so as to prevent the formation of air pockets, before the test pressure is applied.

NOTE 1 It is recommended that the temperature of the water should be not less than 7 °C during the hydrostatic test.

NOTE 2 It is recommended that before the boiler is approached for close examination, the pressure shall be reduced to not less than 1.1 times the design pressure and not more than 0.9 times the hydrostatic test pressure.

NOTE 3 On completion of the hydrostatic test, release of pressure should be gradual.

NOTE 4 The welding of non load bearing assemblies, e.g. smoke boxes, to the pressure parts of the boiler may be carried out after hydrostatic test.

6.3.3 If any repairs are found to be necessary during or subsequent to the hydrostatic pressure test, the boiler shall again be subjected to the pressure test specified above after completion of the repairs and after any heat treatment.

Section 7. Documentation and marking

7.1 Drawings, documents and data sheets

7.1.1 The manufacturer shall supply to the purchaser and to the Inspecting Authority, by drawings, documents or data sheets, full information of the dimensions and design pressure of each boiler together with particulars of the materials of which it is constructed. If erection on site is not undertaken by the manufacturer, he shall supply full information to permit the proper erection of the boiler.

7.1.2 When completed, the boiler shall be accompanied as necessary by the appropriate drawings, documents and data sheets for the information of the Regulating Authority.

Radiographs, ultrasonic test reports, heat treatment charts and relevant in-house inspection records shall be kept by the manufacturer for a period of not less than five years.

7.2 Certificates

The manufacturer shall issue a certificate that each boiler has been designed, constructed and tested in every respect in accordance with this British Standard, and this certificate shall be countersigned by the Inspecting Authority as evidence that it has been so constructed and tested. If erection is inspected by a second Inspecting Authority each Inspecting Authority shall sign the certificate in respect of the work it has supervised.

If the design and fabrication functions are carried out by separate organizations, each organization shall issue a certificate in respect of the work it has performed; alternatively a joint certificate signed by each organization in respect of the work it has performed shall be issued (see **1.4.2** and **1.7.2.2**). Each certificate shall be countersigned by the Inspecting Authority as required above.

7.3 Marking

7.3.1 Each boiler shall be permanently and legibly marked to show its identity and origin. This marking shall be made either above the furnace or, where this is not practicable, on a plate permanently attached to a principal pressure part or on the steel structure of the boiler in a position where it will be visible after the boiler is lagged. Any stamps which are used directly on pressure parts shall have letters and figures with radiused edges.

7.3.2 The marking shall show the following particulars:

a) the name and domicile of the manufacturer;

b) the manufacturer's serial number;

c) the design pressure;

d) the minimum design pressure of the vessel where it is other than atmospheric;

e) the design temperature;

f) maximum continuous rating;

g) the year of manufacture;

h) the date of the hydrostatic test, and the test pressure;

i) the mark of the Inspecting Authority;

j) any other mark required by statute in the country in which the boiler will operate;

k) the number of this British Standard and class of boiler, e.g. BS 2790:1992[2)] Class 1;

[2)] Marking BS 2790:1992 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the standard. The accuracy of the claim is therefore solely the responsibility of the person making the claim.

Section 8. Safety valves, fittings and mountings

8.1 Safety valves

8.1.1 General

8.1.1.1 Materials, design and construction of safety valves shall be in accordance with BS 6759-1.

8.1.1.2 The minimum bore of the valve seat of any safety valve directly connected to a boiler shall be not less than 15 mm.

8.1.1.3 Every boiler, with the exception of open vented hot water boilers, shall have at least one safety valve sized for the rated output of the boiler, and this valve shall be mounted on the boiler shell in accordance with the requirements of **8.1.3**.

Additionally, where a superheater is fitted, it shall have at least one safety valve mounted on the outlet side, and this valve shall have a nominal capacity of 25 % of the boiler rated output.

8.1.1.4 When a boiler is fitted with an integral superheater without an intervening stop valve, the safety valves fitted on the superheater may be considered as forming part of the safety valve relieving capacity of the boiler.

8.1.1.5 Where a superheater is fitted with a valve intervening between it and the boiler, the superheater safety valves shall not be taken into account when assessing the boiler safety valve relieving capacity.

8.1.1.6 Where an economiser is fitted with a valve intervening between it and the boiler, it shall be fitted with a safety valve which shall not be counted as forming part of the boiler safety valve capacity.

8.1.1.7 Where a safety valve is required for an economiser, its capacity shall be calculated on the basis of the economiser thermal capacity. The valve shall be sized for steam.

8.1.1.8 There shall be no intervening valves between the boiler and its protective safety valves or between the safety valves and their point of discharge to atmosphere.

8.1.1.9 In cases where sub-atmospheric pressures may occur which the boiler could not sustain, a vacuum break device shall be provided.

8.1.2 Discharge capacity

8.1.2.1 *Steam and unvented hot water boilers.* The total rated discharge capacity of all the safety valves mounted on a boiler (and integral superheater) calculated in accordance with BS 6759-1 shall be at least equal to the maximum evaporative capacity of the boiler in the case of steam boilers or the maximum rating of the boiler in the case of hot water boilers. Where the feedwater temperature, and hence the actual evaporative capacity of the boiler is not known, the required safety valve capacity shall be based on the specific peak load evaporation "from and at 100 °C".

NOTE The term "from and at 100 °C" is an abbreviation indicating the evaporation from feedwater at 100 °C to steam at 100 °C and as such is the basis of determining the peak load equivalent evaporation of a steam boiler.

8.1.2.2 *Full rated discharge capacity.* The full rated discharge capacity of the safety valves shall be achieved without causing the boiler pressure to increase to more than 110 % of the design pressure (see **3.1.2**).

On steam boilers this shall be demonstrated by the carrying out of an accumulation test at the maximum evaporative capacity with the stop valve closed, in the presence of the Inspecting Authority, before the boiler is put into normal operation.

During this test, no more feedwater shall be supplied than is necessary to maintain a safe working water level. Tests shall not be carried out on boilers fitted with superheaters where overheating may occur, and special consideration shall be given to boilers fired with solid fuels.

8.1.3 Attachment to the boiler

8.1.3.1 Safety valves shall be mounted, without any intervening valve, on pads or branches used for no other purpose. The axis of the valve shall be vertical. The cross-sectional area of the bore of each pad or branch shall be at least equal to the area of the bore of the inlet of the safety valve or, where two or more safety valves are mounted on the same pad or branch, at least equal to the sum of the areas of the inlet bores of all the safety valves.

8.1.3.2 Branches shall be as short as possible with minimum protrusion into the boiler shell.

8.1.3.3 Pressure drop in the inlet branch shall not exceed 3 % of the set pressure or 1/3 of the maximum allowable blowdown permitted by BS 6759-1, whichever is the least, at actual flow, that is certified capacity divided by 0.9.

NOTE Excessive pressure loss at the inlet of a safety valve will cause extremely rapid opening and closing of the valve which is known as "chattering" or "hammering". This may result in reduced capacity and damage to seating faces and other parts of the valve.

Reference should be made to the recommendations given in Appendix B of BS 6759-1:1984.

8.1.3.4 Safety valves shall be accessible for functional testing and maintenance.

8.1.4 Drainage. For each safety valve fitted with discharge piping, an individual unrestricted drain shall be provided.

The drain pipe shall be laid with a continuous fall to a place where the discharge is visible and cannot injure any person

NOTE Reference may be made to BS 806 for the design of discharge pipe.

8.2 Water-level gauges

8.2.1 General

8.2.1.1 Each steam boiler with a rating of more than 100 kW shall be fitted with at least two suitable water level indicators, or at least one of which shall be a suitable water gauge connected directly to the boiler. For boilers of less than 100 kW rating, one suitable water level gauge shall be sufficient.

Where two water-level gauges are required it shall be permissible to mount them on a column or to attach them independently to the boiler shell. If water-level gauges are attached to other items of equipment, e.g. water-level control chambers, at least one gauge shall be attached directly to the boiler shell. Water-level gauges and columns shall comply with BS 759-1.

8.2.1.2 The required water-level gauge in which the water level can be observed shall be mounted so that the water level is visible in the gauge glass at the ultimate lowest alarm level (see **8.3.2**) and also at that of any high level alarm which is fitted.

8.2.1.3 At least one water-level gauge with its isolating valves or cocks shall be connected directly to the boiler, except as provided for in **8.2.1.1**, and other than a drain, no device shall be fitted to the gauge that could cause incorrect indication of the water level in the gauge.

8.2.1.4 In the case of horizontal return tube boilers, such as waste heat, economic or similar, where the water-level gauge connections are taken from the sides of the boilers, the lower or water end at least shall be arranged with a tee or cross connection so as to permit cleaning and proving of the pipes.

8.3 Water-level alarms

8.3.1 Requirements for the provision of water level alarms are given in section 9.

8.3.2 The ultimate lowest alarm level referred to in **9.2.3** shall be at a height above the level of the highest heated surface within the boiler shell which is the greater or either:

a) 100 mm; or

b) a height which will give sufficient water volume above the level of the highest heated surface to allow a sinking time, i.e. the time for the water to fall from the lowest alarm level to the level of the highest heated surface, of not less than 5 min or, in the case of solid fuel fired boilers, not less than 7 min at a steam generation rate equal to the maximum capacity of the boiler.

The required water volume shall be determined from

$$W = TDv$$

where

- W is the water volume (in m^3);
- T is the sinking time (in min);
- D is the maximum evaporative capacity (in kg/min);
- v is the specific volume of water at the saturation steam temperature (in m^3/kg).

8.4 Connecting pipes for water-level fittings

Where a water level gauge, safety control or alarm device is connected to the boiler by pipes, the bore of such pipes shall be not less than 25 mm.

NOTE The ends of pipes local to the fittings may be reduced to not less than 20 mm bore for water level gauges and to 25 mm bore for separate safety control and alarm devices.

In order that the true level of the water in the boiler, at the point of connection, is indicated accurately in the water-level gauges and the water-level control chambers, the water connection of these fittings shall be mounted as close as is practicable to the boiler shell or drum.

Connecting pipes shall be as short as practicable.

The water connections shall all be on or as near as practicable to the same horizontal plane.

8.5 Pressure gauges

At least one pressure gauge of the bourdon-tube type, complying with BS 759-1, shall be fitted to each boiler.

8.6 Boiler feedwater valves

8.6.1 Each boiler shall be fitted with:

a) a feed water stop valve and a check valve; or

b) a globe stop and check valve.

8.6.2 Further to the requirements of **8.6.1**, where two or more boilers are supplied from a common feedwater system, each boiler shall be provided with an additional stop valve capable of being locked in the closed position.

Feed water valves shall comply with BS 759-1.

8.7 Boiler blowdown and drain mountings

8.7.1 General

8.7.1.1 Each boiler shall be fitted with suitable blowdown and drain valves or cocks. Cocks shall not be used for pressures over 13 bar. All such valves and cocks shall comply with BS 759-1.

8.7.1.2 Boiler blowdown and drain valves shall be attached to the boiler by pipes that are as short as practicable.

8.7.2 Blowdown valves or cocks. Blowdown valves or cocks shall be placed as near as practicable to the lowest point of the boiler.

8.7.3 Continuous and automatic blowdown mountings. When specified in the contract, valves, cocks and mountings required to control the water conditions in a boiler shall be fitted at appropriate positions.

8.7.4 Drains. Valves or cocks shall be fitted to drain all parts of boilers that are not drained by blowdowns.

8.7.5 Safety arrangements

8.7.5.1 All blowdown mountings and drain valves connected directly to the boiler and discharging into the boiler blowdown system shall either be capable of being locked in the closed position or be protected by a second valve at their discharge which is capable of being locked in the closed position

NOTE The expression "connected directly to the boiler" covers any valve that cannot itself be isolated from the boiler.

8.7.5.2 Where manually operated blowdown valves or cocks from more than one boiler deliver into a common discharge, a common handle or operating/interlocking device shall be provided which is capable of being removed only when such valves or cocks are fully closed. No other arrangement is permissible.

8.7.5.3 When at least two boilers are equipped with a continuous and/or automatic boiler blowdown system leading to a common main, this common main shall be separate from and independent of any main to which manually operated valves are connected. The discharges from the two mains shall be led to separate disposal points such that inadvertent pressurization of the manual blowdown main cannot occur. All such systems shall be either fitted with a stop valve, capable of being locked in the closed position, and a check valve, in addition to any regulating valves or devices required to control the blowdown flow or, alternatively, a globe stop and check valve, capable of being locked in the closed position, may be substituted for the stop valve and the check valve.

NOTE Attention is directed to Section 34 of the Factories Act, 1961 which states "No person shall enter or be in any steam boiler which is one of a range of two or more steam boilers unless:

a) all inlets through which steam or hot water might otherwise enter the boiler from any other part of the range are disconnected from that part; or

b) all valves or taps controlling the entry of steam or hot water are closed and securely locked, and, where the boiler has a blow-off pipe in common with one or more other boilers or delivering into a common blow-off vessel or sump, the blow-off valve or tap on each such boiler is so constructed that it can only be opened by a key which cannot be removed until the valve or tap is closed and is the only key in use for that set of blow-off valves or taps."

8.8 Boiler main stop valves

8.8.1 General. Boiler main stop valves shall comply with BS 759-1.

8.8.2 Cast iron valves. The use of flake graphite (grey) cast iron to BS 1452, grade 220 and above, and nodular graphite (SG) cast iron to BS 2789, with a minimum elongation > 12 %, shall be permitted for valves up to and including DN200 where the operating pressure and temperature does not exceed 13 bar and 220 °C respectively.

However, the use of flake graphite cast iron is not permitted for main stop valves on steam boilers.

8.8.3 Main stop valves for steam boilers. The stop valve connecting the boiler to the steam pipe shall be attached directly to the boiler or shall be as near as practicable to it. In the case of a boiler with a superheater, the stop valve shall be located as near to the outlet from the superheater header as is convenient and practicable.

Where two or more boilers are connected to a common header, in addition to the boiler stop valve, a second valve shall be incorporated in the steam connection and this valve shall be capable of being locked in the closed position. Unless a separate non-return valve is fitted in the steam connection, one of the two stop valves shall incorporate a non-return facility.

NOTE 1 An isolating valve is necessary to enable an individual boiler to be isolated from a common header or manifold to facilitate maintenance and examination.

NOTE 2 It is also essential that drainage facilities are incorporated in steam supply pipework for removal of condensate.

8.8.4 Main stop valves for hot water boilers. Each boiler shall be fitted with a parallel slide valve or other form of gate valve at the flow and return connections as near as practicable to the boiler. Where two or more boilers are connected to a common header or manifold, the boiler flow and return connections shall each be fitted with an additional parallel slide valve or other form of gate valve capable of being locked in the closed position to isolate the boiler. All valves on flow and return connections shall be capable of being locked in the open position at all times while the boiler is in service.

8.9 Vent pipes

For a fully flooded hot water boiler in an open vented system, the vent pipe shall be sized according to the maximum rated output of the boiler it is intended to protect. The minimum pipe size to be used for rated out-puts up to 600 kW shall be in accordance with Table 8.9.

Table 8.9 — Minimum open vent pipe size

Rated output	Minimum bore	Designated size[a]
kW	mm	
below 60	25	1
60 to 150	32	1 ¼
151 to 300	38	1 ½
301 to 600	50	2

[a] Steel pipe sizes complying with medium or heavy quality of BS 1387.

For rated outputs above 600 kW, the minimum cross-sectional area of the vent pipe A (in mm^2) shall be that given by the equation:

$$A = 3.5 \times Q_R$$

where

Q_R is the rated heat output (in kW).

Section 9. Automatic controls

9.1 General

All steam and hot water boilers shall be fitted with automatic water level and firing controls.

The minimum requirements for automatic controls shall be as follows, supplemented by the requirements of either **9.2** or **9.3** as appropriate.

a) In the event of failure of the automatic controls, the boiler shall be capable of being brought under manual control safely. Use under manual control shall be in accordance with a clearly defined written emergency procedure that shall include the immediate provision of a trained boiler attendant.

b) All electrical equipment and circuits for water level and firing controls shall be designed to fail safe, i.e. faults in circuits shall cause the fuel and air supply to the boiler to be shut off automatically. All electrical conductors and equipment in connection with water level and firing controls shall be of adequate size and shall be properly insulated and protected to prevent damage. Where necessary, adequate protection against the ingress of moisture or the effects of abnormal temperature shall be provided.

c) Suitable means shall be provided to test the controls with the boiler in operation. Where float or electrode-type controls are housed in chambers external to the boiler, a blow-down valve which blows through steam and water in sequence shall be fitted to the water-side of the chamber. Where an isolating valve is fitted in the steam balance pipe, either it shall be locked in the open position and the key kept with a responsible person or it shall be of a type that cannot accidentally be left closed. Where a locked valve is used, a duplicate key shall be kept in a glass-fronted cabinet in the boiler house for use in emergency.

d) Where controls are of the internal type, i.e. with the floats or the electrodes mounted inside the boiler, suitable means shall be provided to test the operation of these controls.

e) The blow-down lines from the chambers shall be piped separately to a suitable blow-clown tank or sump. They shall not be piped into the main boiler blow-down line.

NOTE Attention is drawn to the recommendations, in particular those concerned with the testing of controls, contained in guidance note PM 5 entitled "Automatically controlled steam and hot water boilers", produced by the Health and Safety Executive.

9.2 Automatic controls for steam boilers

9.2.1 Automatic water level controls. Automatic water level controls shall be so arranged that they positively control the boiler feed pumps or regulate the water supply to the boilers and effectively maintain the level of water between predetermined limits.

Automatic water level controls shall be operated by one of the following methods:

a) float or displacer;

b) electrical probe;

c) any other method approved by the Inspecting Authority.

9.2.2 Automatic firing controls. Automatic firing controls shall be so arranged that, at all times, they control the supply of fuel and air to the firing equipment. These controls shall shut off the supply of fuel to oil or gas burners or shall shut off the air supply and, if necessary, the fuel supply to solid fuel firing equipment in the event of one or more of the following circumstances arising.

a) Flame failure or pilot flame failure in oil or gas fired boilers. This control shall be of the lock-out type requiring manual resetting.

b) Failure to ignite the burner within a predetermined time. This control shall be of the lock-out type requiring manual resetting.

c) When a predetermined high pressure at or below the safety valve set pressure is reached.

d) When the water level falls to a predetermined level below the normal operating level. This control shall also cause an audible alarm to sound.

e) Failure of forced or induced draft fan or an automatic flue damper.

9.2.3 Independent overriding controls. In addition to the water level and firing controls specified in **9.2.1** and **9.2.2**, an entirely independent and separately operated overriding control shall be fitted. This shall shut off the fuel supply to oil or gas burners or the air and, if necessary, the fuel supply to solid fuel firing equipment when the water level falls to a predetermined ultimate low level in the boiler, this level being lower than the level referred to in **9.2.2** d).

NOTE In the case of solid fuel firing, the heat should be dissipated from the fuel bed as quickly as possible. Ways of achieving this will depend upon the type of installation concerned.

Water shall still be visible in the water level gauge glass when the independent overriding control operates. This control shall also cause an audible alarm to sound and shall be of the lock-out type requiring manual resetting.

Where mounted externally to the boiler, the overriding control shall be provided with its own chamber and independent connections to the boiler and shall comply with the requirements of **9.1.2** where applicable.

9.3 Automatic controls for hot water boilers

9.3.1 Types of system. For the purpose of ensuring compliance with the requirements of this section, fully flooded boiler systems shall be divided into four basic categories:

category 1: static head systems open to atmosphere;

category 2: closed pressurized systems with separate gas cushioned pressurizing vessels and provision for make-up water;

category 3: sealed pressurized systems with separate diaphragm or bladder type pressurizing vessels and provision for make-up water;

category 4: continuously pumped pressurized systems with provision for make-up water.

Boilers pressurized by steam are classified as steam boilers and shall comply, where applicable, with the requirements for steam boilers.

9.3.2 Automatic controls. All categories of fully flooded hot water boilers shall be provided with automatic controls. Automatic controls shall shut off the supply of fuel to oil or gas burners or shall shut off the air supply and, if necessary, the fuel supply to solid fuel firing equipment in the event of one of more of the following circumstances arising.

a) Flame failure or pilot flame failure in oil or gas fired boilers. This control shall be of the lock-out type requiring manual resetting.

b) Failure to ignite the fuel within a predetermined time in oil or gas fired boilers. This control shall be of the lock-out type requiring manual resetting.

c) Failure of forced or induced draft fan or an automatic flue damper.

d) When the water at or near the boiler flow outlet rises to a predetermined temperature providing a margin of at least 17 °C below the temperature of saturated steam corresponding with the pressure at the highest point of the circulating system above the boiler.

e) When the water level in the pressurizing equipment in a category 2 system falls to a predetermined level below the normal operating level. This control shall also cause an audible alarm to operate.

f) When the pressure in a category 2, 3 or 4 system falls to a predetermined pressure below the specified operating pressure. This predetermined pressure shall be at a level that will ensure that the water does not reach boiling point in any part of the system while working temperature is maintained.

g) When the pressure in a category 3 system increases to within 0.35 bar of the safety valve set pressure. The safety valve set pressure shall be such that it will not allow the design pressure of any part of the boiler to be exceeded.

h) Loss of water within the boiler. This control shall be of the lock-out type requiring manual resetting.

9.3.3 Independent overriding controls. In addition to the automatic controls required by **9.3.2**, all categories of fully flooded hot water boilers shall be provided with independent overriding controls that cut off the fuel supply to oil or gas burners or cut off the air supply and, where required, the fuel supply to solid fuel firing equipment in the event of one or more of the following circumstances arising.

a) When the temperature of the water at or near the boiler flow outlet rises to a predetermined temperature providing a margin below the temperature of saturated steam corresponding with the pressure at the highest point of the circulating system above the boiler. For oil or gas fired boilers this margin shall be at least 6 °C and for solid fuel fired boilers it shall be at least 10 °C. This control shall be of the lock-out type requiring manual resetting.

b) When the water level in the pressurizing equipment of a category 2 system falls to a predetermined level below the level referred to in **9.3.2** e). This control shall lock out the firing equipment and shall be of a type that requires manual resetting.

NOTE In the case of solid fuel firing, the heat should be dissipated from the fuel bed as quickly as possible. Ways of achieving this will depend upon the type of installation concerned.

9.3.4 Boilers using mixing valves. Where mixing valves are used to blend return water with flow water, solid fuel fired boilers shall serve at least one circuit that is independent of the mixing valve and that is capable of dissipating residual heat in the fuel bed when the mixing valve closes against the boiler, e.g. during mild weather, or a heat dissipation thermostat that will override the mixing valve control in the event of excessive temperature rise shall be fitted in the boiler flow line.

Appendix A Information to be supplied by the purchaser to the manufacturer

A.1 General

The information given in **A.2** to **A.5** shall be the minimum supplied to the manufacturer by the purchaser at the time of the enquiry.

A.2 Saturated steam boilers

a) Maximum steam capacity (in t/h).

b) Working pressure (gauge) (in bar).

c) Feed water inlet temperature (in °C).

A.3 Superheated steam boilers

a) Maximum steam output (in t/h).

b) Working pressure (gauge) at the superheater outlet (in bar).

c) Superheated steam temperature at maximum steam capacity (in °C).

d) Feed water inlet temperature (in °C).

A.4 Hot water boilers

a) Maximum heat output (in kW).

b) Working pressure (gauge) (in bar).

c) Water return temperature (in °C).

d) Water flow temperature (in °C).

e) Method of pressurization (e.g. by steam, gas, static head or continuous pumping).

f) Description of the control system of the hot water circuit.

A.5 General information

A.5.1 *Liquid fuels.* Specification and analysis.

A.5.2 *Gaseous fuels.* Type and origin. Specification and analysis. Gross and net calorific value. Available gas pressure at installation.

A.5.3 *Solid fuels, including waste.* Type and origin (e.g. country, district, mine, manufacturer, industrial undertaking). Specification and analysis (e.g. state of material as supplied, gross and net calorific value, size of granule, ash-fusion point).

A.5.4 *Mixed fuels.* The proportion of the various fuels and the method of combustion (this requires agreement between the purchaser and the manufacturer).

A.5.5 *Characteristic values.* The limits of certain characteristic values on which the guarantees shall be based. (This requires agreement between the purchaser and the manufacturer.)

A.5.6 *Electrical power supply.* The specification (e.g. voltage, frequency, number of phases, number of wires and any limitations for the direct starting of motors.

A.5.7 *Site conditions.* Responsibility for erection, height above sea level and climatic conditions.

A.5.8 *Chimney emissions.* The permitted levels of chimney emissions of combustion products for the fuel to be used, in accordance with the regulations applying in the district of installation.

NOTE Attention is drawn to the Clean Air Act 1993.

Appendix B Typical examples of acceptable weld details

B.1 General

The drawings given in this appendix are intended to convey recommendations relating to connections welded manually by the metal-arc process in carbon steel boilers with a shell thickness of not less than 6 mm. The following types of connection are dealt with.

	Figures
a) Plate preparation for butt-welded longitudinal and circumferential seams	Figure B(1)
b) Cross seams in end plates	Figure B(2)
c) End plate- or tube plate-to-shell connections	Figure B(3)
d) Attachment of end plate or tube plate to reversal chamber or firebox wrapper plates	Figure B(4)
e) End plate-to-furnace connections	Figure B(5) and Figure B(6)
f) Reversal chamber tube plate-to-furnace connections	Figure B(5)
g) Ash drop-out tube	Figure B(7)
h) Cross tube connections	Figure B(8)
i) Foundation rings	Figure B(9)
j) Firehole opening	Figure B(10)
k) Standard weld preparation details for branches	Figure B(11)
l) Branches without added compensation rings	
1) Set-on branches	Figure B(12) to Figure B(17)
2) Set-in branches	Figure B(18) to Figure B(23)
3) Forged connections	Figure B(24) and Figure B(25)
m) Branches with added compensation rings	
1) Set-on branches	Figure B(26)
2) Set-in branches	Figure B(27)
n) Studded connections and couplings	
1) Butt-welded studded connections	Figure B(28)
2) Fillet-welded studded connections	Figure B(29)
o) Manhole frame	Figure B(30)

B.2 Purpose

The purpose of this appendix is to exemplify sound and commonly accepted practice and not to promote the standardization of connections that may be regarded as mandatory or to restrict development in any way. A number of connections have been excluded which, whilst perfectly sound, are restricted in their use to certain applications, firms, or localities. Furthermore, the desirability is appreciated of introducing amendments and additions in the future to reflect improvements in welding procedures and techniques as they develop.

B.3 Selection of detail

The connections recommended are not considered to be equally suitable for all service conditions, nor is the order in which they are shown indicative of their relative mechanical characteristics. In selecting the appropriate detail to use from the several alternatives shown for each type of connection, consideration should be given to the manufacture and service conditions that pertain.

B.4 Weld details and dimensions

B.4.1 *General*. The limitations quoted in **B.4.2** to **B.4.4** are based on commonly accepted sound practice, but may be subject to modifications dictated by special welding techniques or design conditions.

B.4.2 *Weld dimensions*. The dimensions of the welds, i.e. throat thickness, have been proportioned to develop the full strength of the parts joined.

B.4.3 *Modifications*. Cases may well arise where sound modifications may be made with advantage as follows:

a) to the weld preparation details to suit special welding techniques; or

b) to the weld dimensions to suit design and service conditions.

B.4.4 *Butt joints [including tee butt joints of the type shown Figure B(3)]*. In cases where full penetration butt joints are indicated, it is intended that they should be back chipped or gouged and back welded or, alternatively, that the welding procedure should be such as to ensure sound root conditions.

B.4.5 *Weld preparation details for branches*. The weld preparation details (for example bevel angles, root radii, and root faces) recommended are indicated by letters and numbers in circles which refer to the details shown in Figure B(11). They are designed to provide correct conditions for welding and to facilitate the deposition of sound weld metal in the root of the joint. This is particularly important in the case of single-bevel and single-J welds, and, if these are given as alternatives, it is recommended in general that preferences be given to the latter if the depth or throat thickness of the weld exceeds about 16 mm.

B.5 Connections of the types specified in Figure B(3), Figure B(12) to Figure B(17) and Figure B(19) to Figure B(28)

B.5.1 The dimensions and shape of the detail chosen can influence the feasibility and/or efficiency of ultrasonic examination. This may also be a function of the equipment and time available. If ultrasonic examination is specified, these factors should be given due consideration.

B.5.2 If welds are made from one side only, the penetration bead should have a smooth contour and be flat or slightly convex.

B.5.3 The use of ring-type compensation is not suitable for cases where there are severe temperature gradients.

B.5.4 If ring-type compensation is used, the material used for the ring should be of the same nominal strength as that of the shell.

B.5.5 If partial penetration joints are used, it is possible that root defects may be present. Since such defects cannot always be detected or interpreted by means of non-destructive testing, the use of partial penetration joints is not suitable for cases where there are severe temperature gradients, especially when these are of a fluctuating nature.

B.5.6 If ultrasonic inspection is required by this standard, it may be necessary to examine the welded connection between the branch and shell prior to fitting the compensation ring.

B.6 Branches of the types shown in Figure B(12) to Figure B(17) and Figure B(19) to Figure B(28)

B.6.1 *Weld dimensions*. The dimensions of the welds shown have been proportioned to develop the full strength of the parts joined (see also **B.4.2** and **B.4.3**, as well as **B.7.2.1**).

B.6.2 *Weld preparation details*. While both single-bevel and single-J welds have been shown as acceptable in the smaller sizes, in general the latter are to be preferred because of the sounder root conditions obtained, and it is recommended that single-bevel welds be limited in size to about 16 mm in depth (see also **B.4.3** and **B.4.5**).

B.7 Branches without compensation rings in Figure B(12) to Figure B(17) and Figure B(19) to Figure B(25)

B.7.1 *Set-on branches*. Consideration should be given to the necessity for examining the shell plate for laminations around the branch hole if set-on branches are used.

B.7.2 ***Set-in branches***

B.7.2.1 *Weld dimensions.* The type of branch-to-shell connections and the dimensions of welds employed may be influenced by several factors in the operational conditions for which the boiler is designed. For general guidance in this appendix, weld dimensions have been shown for the various connections recommended, based on the concept that the welded joints should develop the full strength in tension of the branch radial to the shell as indicated in Figure B(18)(a) and Figure B(18)(b). In general it should therefore be unnecessary to apply larger welds than those shown.

The approximate assumption has been made that the total throat thickness of the welds should equal twice the branch thickness. It has also been assumed that the welds should be reasonably symmetrical about the full thickness of the connection.

It is further recommended that, when the branch thickness exceeds half the thickness of the shell, full penetration joints should be used with fillet welds equal in total throat thickness to 20 % of the shell thickness as shown in Figure B(18)(c) and Figure B(18)(d). This additional throat thickness is recommended to compensate for the relative practical difficulty of applying perfectly sound welds in nozzle connections and of applying non-destructive tests for their examination. These additional fillet welds are also intended to provide a reasonable geometric profile. For practical reasons a minimum dimension of 6 mm has been applied to the fillet weld size.

There may be service conditions for which smaller welds are adequate. In such cases the weld sizes may be reduced subject to agreement with the Inspecting Authority.

B.7.2.2 *Gap between branch and shell.* The gap between the branch and the shell should not exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

B.7.2.3 *Removal of internal sharp edge in branch bore.* The internal edges in the bores of set-in branches are shown radiused because a stress concentration occurs at this point. This precaution is recommended if the branch connection is fully stressed or subjected to fatigue, but may not be necessary if these conditions do not occur.

B.7.2.4 *Preparation of hole in shell.* In the case of set-in branches of the types shown in Figure B(19) to Figure B(22) inclusive, the hole in the shell may be cut and profiled in two ways as follows.

a) The depth of the grooves B and D may be constant around the hole as shown in Figure B(18)(e). This, the normal case, is the basis upon which the drawings have been prepared.

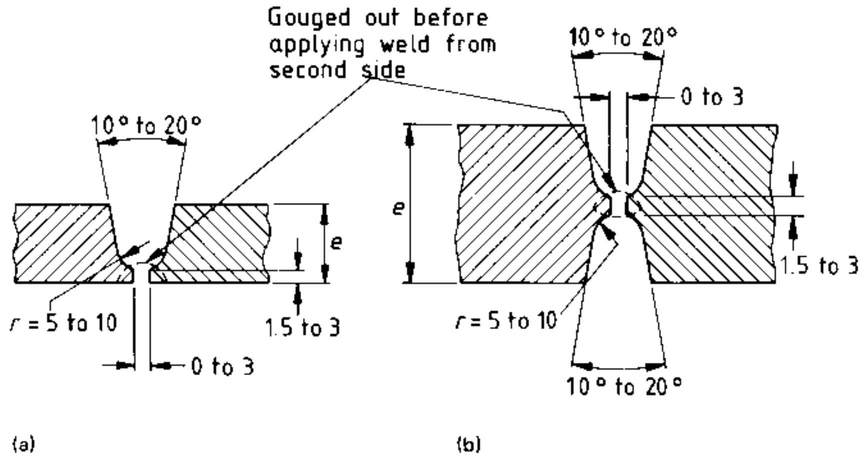
b) The roots of the weld grooves may be in one plane, as for example, when they are machine bored, in which case the depths of the grooves will vary around the hole as shown in Figure B(18)(f).

B.8 Branches with added compensation rings in Figure B(26) and Figure B(27)

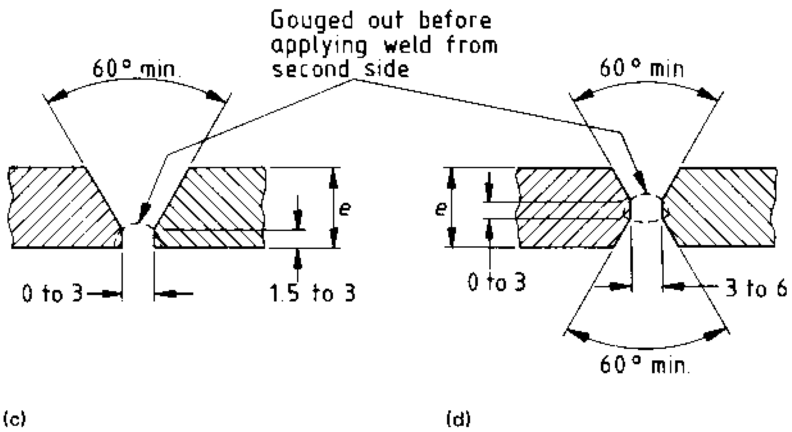
B.8.1 *General.* Compensation rings should be a close fit to the shell and tell-tale holes should be provided in them.

B.8.2 *Set-in branches.* The gap between the branch and the shell should not exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

B.9 Flanges. See BS 806 for weld details of flanges.

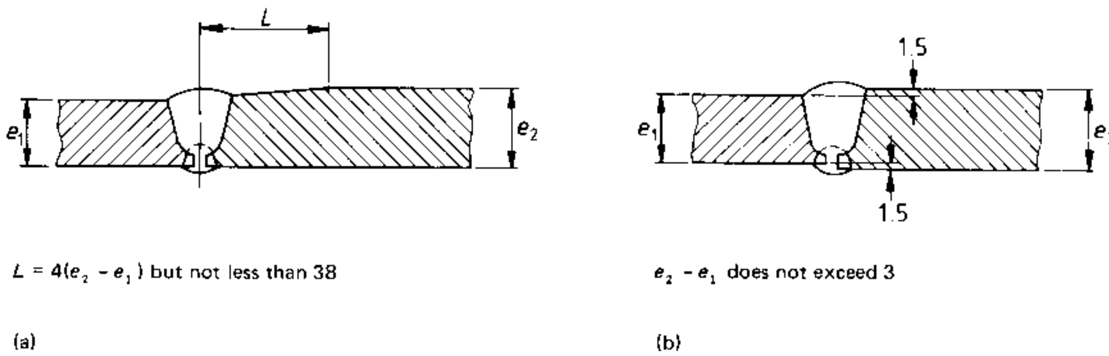


NOTE The use of the minimum gap and the minimum angle should be associated with the maximum radius r of 10 mm. Conversely, the maximum gap and the maximum angle should be associated with the minimum radius r of 5 mm.



All dimensions are in millimetres.

Figure B(1) — Plate preparation for butt-welded longitudinal and circumferential seams

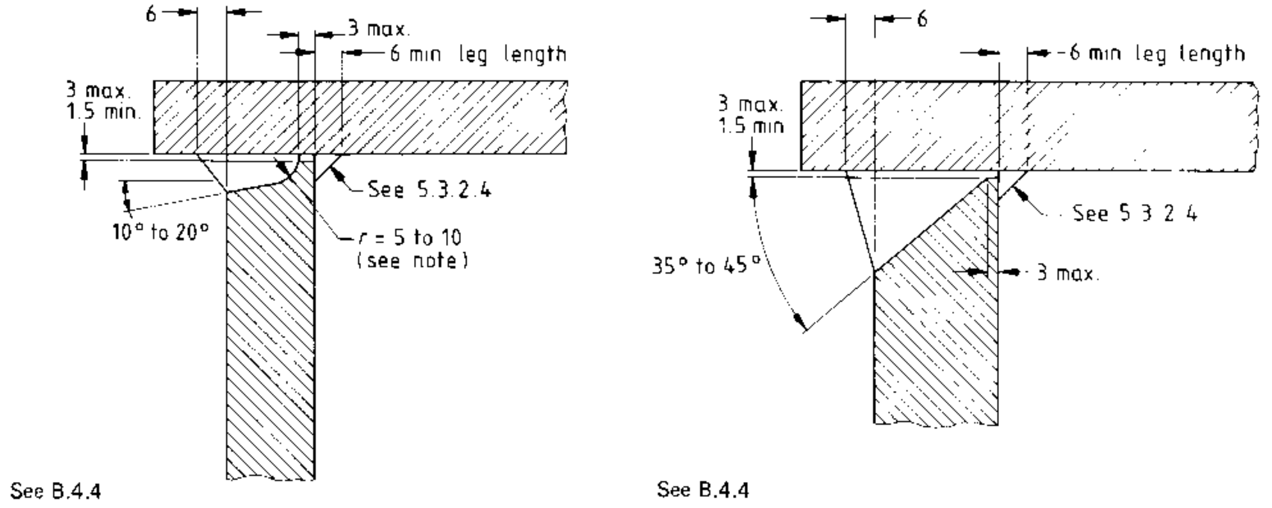


See B.4.4

All dimensions are in millimetres.

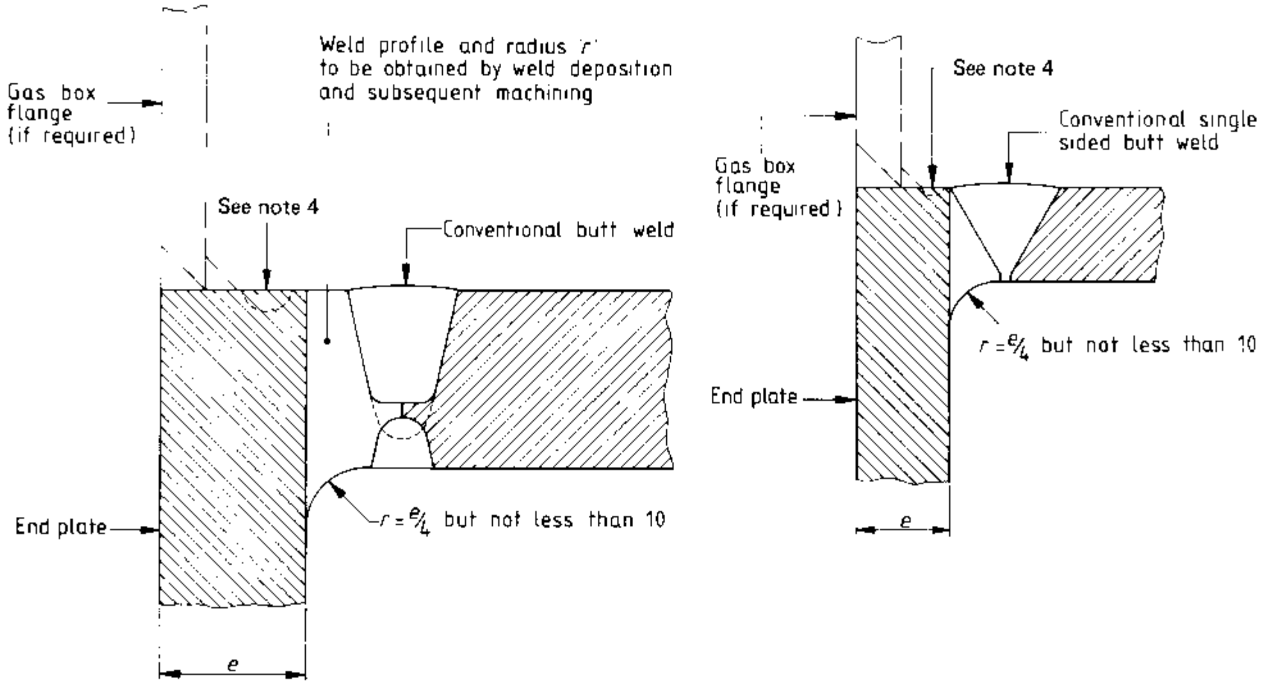
NOTE V-preparation may be used as an alternative.

Figure B(2) — Cross seams in end plates



NOTE 1 The use of minimum angle should be associated with a maximum radius *r* of 10 mm. Conversely, the maximum angle should be associated with a minimum radius *r* of 5 mm.

(a) (b)



(c) Preferred construction for set-on end plates (see notes 2, 3 and 4)

(d) Construction for set-on end plates where internal access is limited (see notes 2, 3 and 4)

All dimensions are in millimetres.

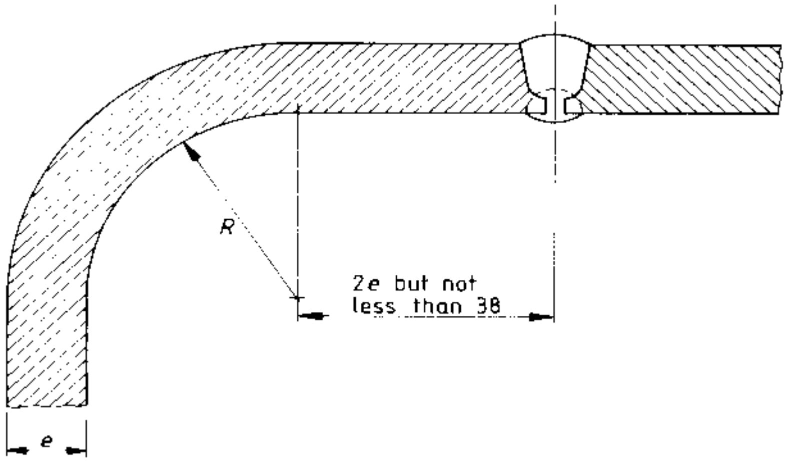
NOTE 2 Figure B(1)(3)(c) and Figure B(1)(3)(d) are for attachment of end plates to shell in waste heat boilers if there is danger of lamellar tearing of the shell plate. These methods of attachment should be used in class I boilers only.

NOTE 3 Conventional butt joints are used and may not necessarily be of the form shown.

NOTE 4 If a gas box flange is attached by welding as shown, a machined groove to reduce stress concentration is preferred.

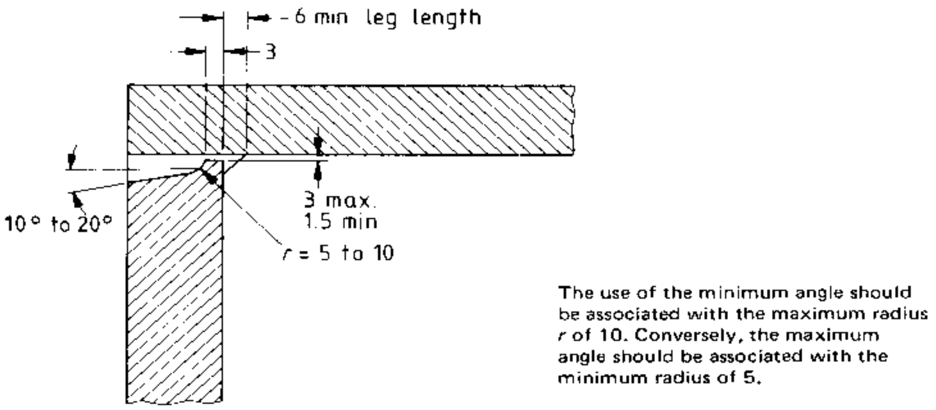
NOTE 5 For non-destructive testing requirements, see **5.6.2**.

Figure B(3) — Attachment of unflanged flat end plates or tube plates to shell



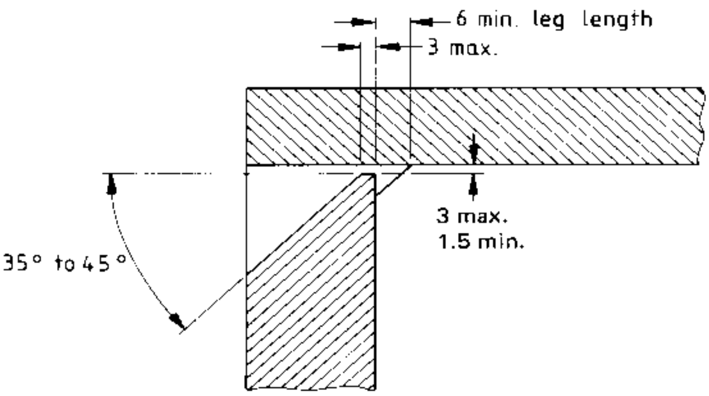
See B.4.4

(a)



See B.4.4

(b)

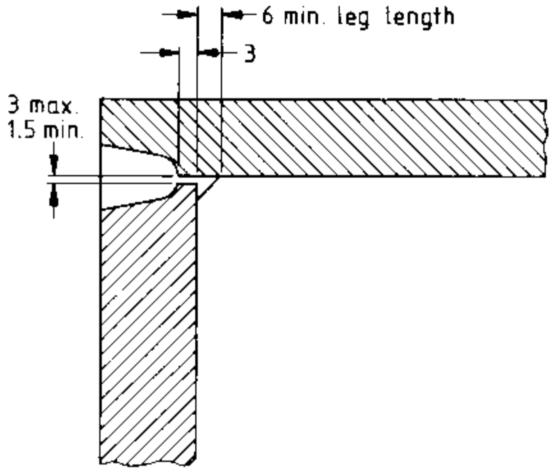


See B.4.4

(c)

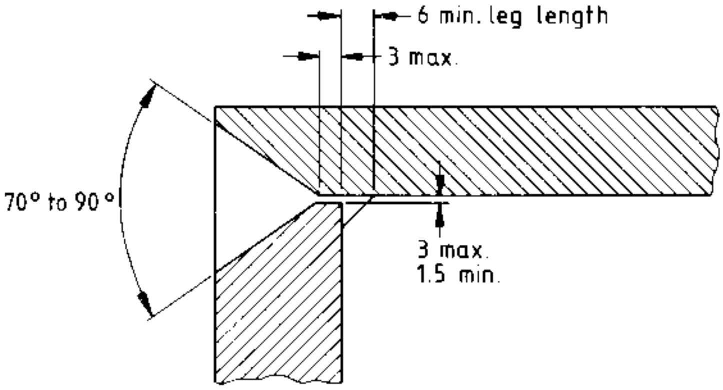
All dimensions are in millimetres.

Figure B(4) — Attachment of end plates or tube plates to reversal chamber or firebox wrapper plates



See B.4.4

(d)

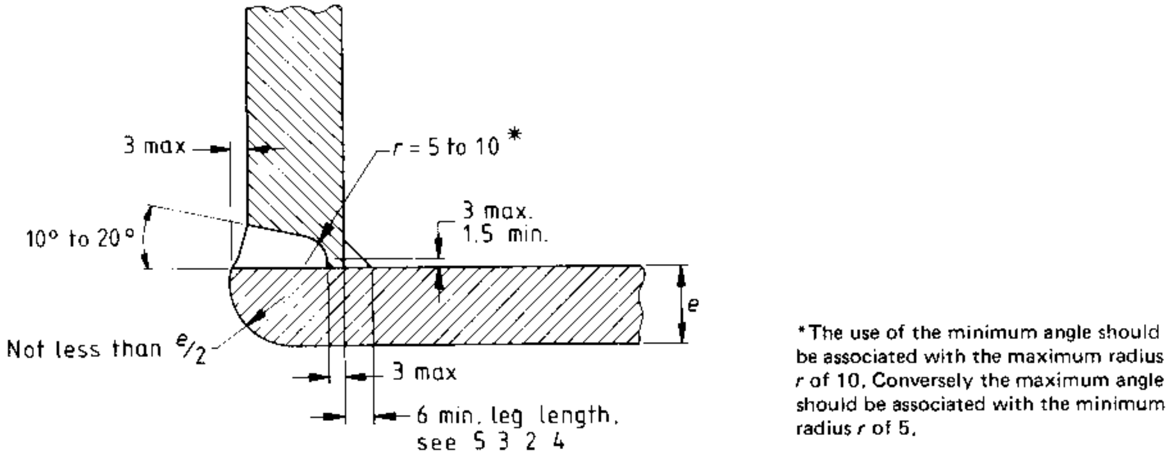


See B.4.4

(e)

All dimensions are in millimetres.

Figure B(4) — Attachment of end plates or tube plates to reversal chamber or firebox wrapper plates *(concluded)*

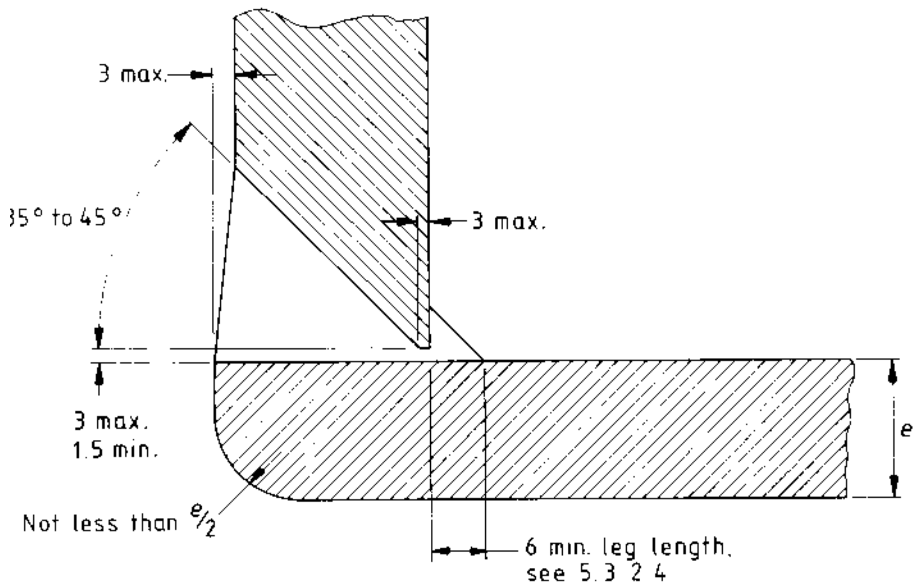


See **B.4.4.**

NOTE 1 The plate edge radius of not less than *e*/2 is only required when the furnace end is exposed to a flame or a comparably high temperature, e.g. at the entry to the reversal chamber.

NOTE 2 The front end of the furnace can protrude beyond the weld provided that the protrusion and the weld area are adequately insulated to prevent overheating.

(a)



See **B.4.4.**

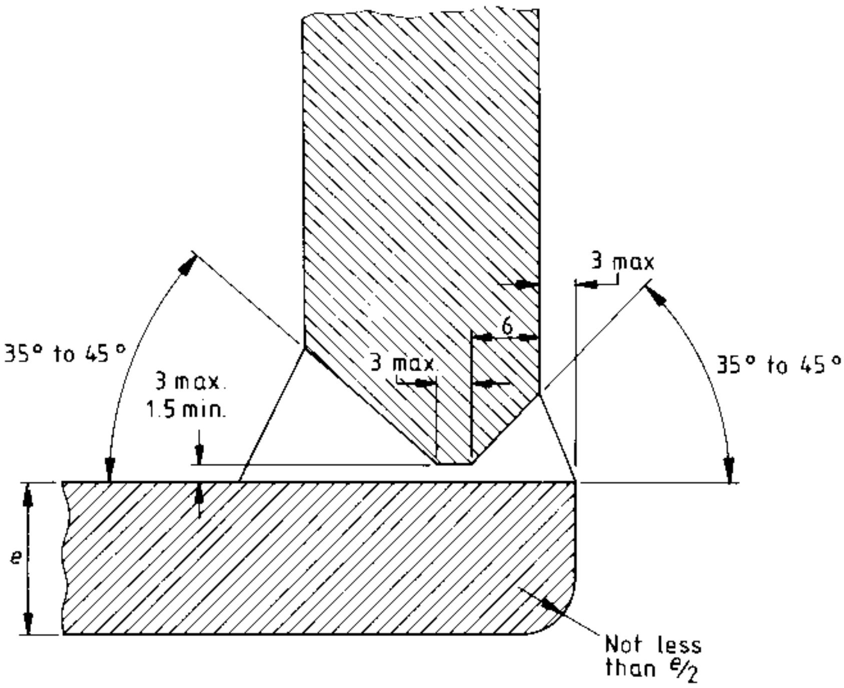
NOTE 1 The plate edge radius of not less than *e*/2 is only required when the furnace end is exposed to a flame or a comparably high temperature, e.g. at the entry to the reversal chamber.

NOTE 2 The front end of the furnace can protrude beyond the weld provided that the protrusion and the weld area are adequately insulated to prevent overheating.

(b)

All dimensions are in millimetres.

Figure B(5) — Attachment of furnaces to end plates or reversal chamber tubeplates



See **B.4.4**.

NOTE 1 The plate edge radius of not less than $e/2$ is only required when the furnace end is exposed to a flame or a comparably high temperature, e.g. at the entry to the reversal chamber.

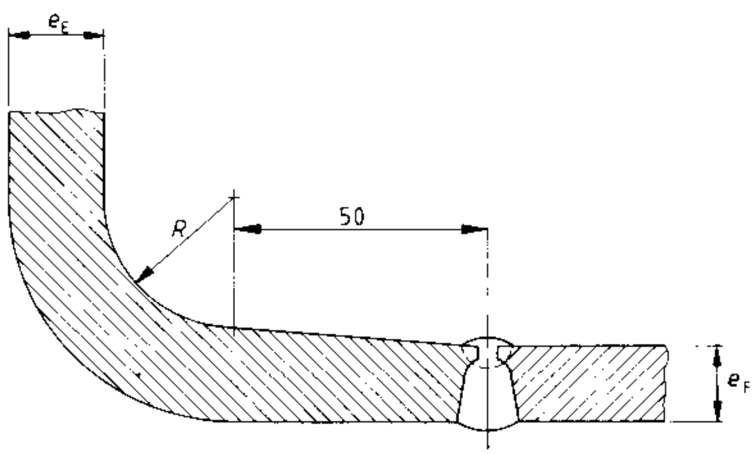
NOTE 2 The front end of the furnace can protrude beyond the weld provided that the protrusion and the weld area are adequately insulated to prevent overheating.

NOTE 3 The position of the welds can be reversed if desired in order to deposit the larger weld from the outside.

Dimensions are in millimetres.

(c)

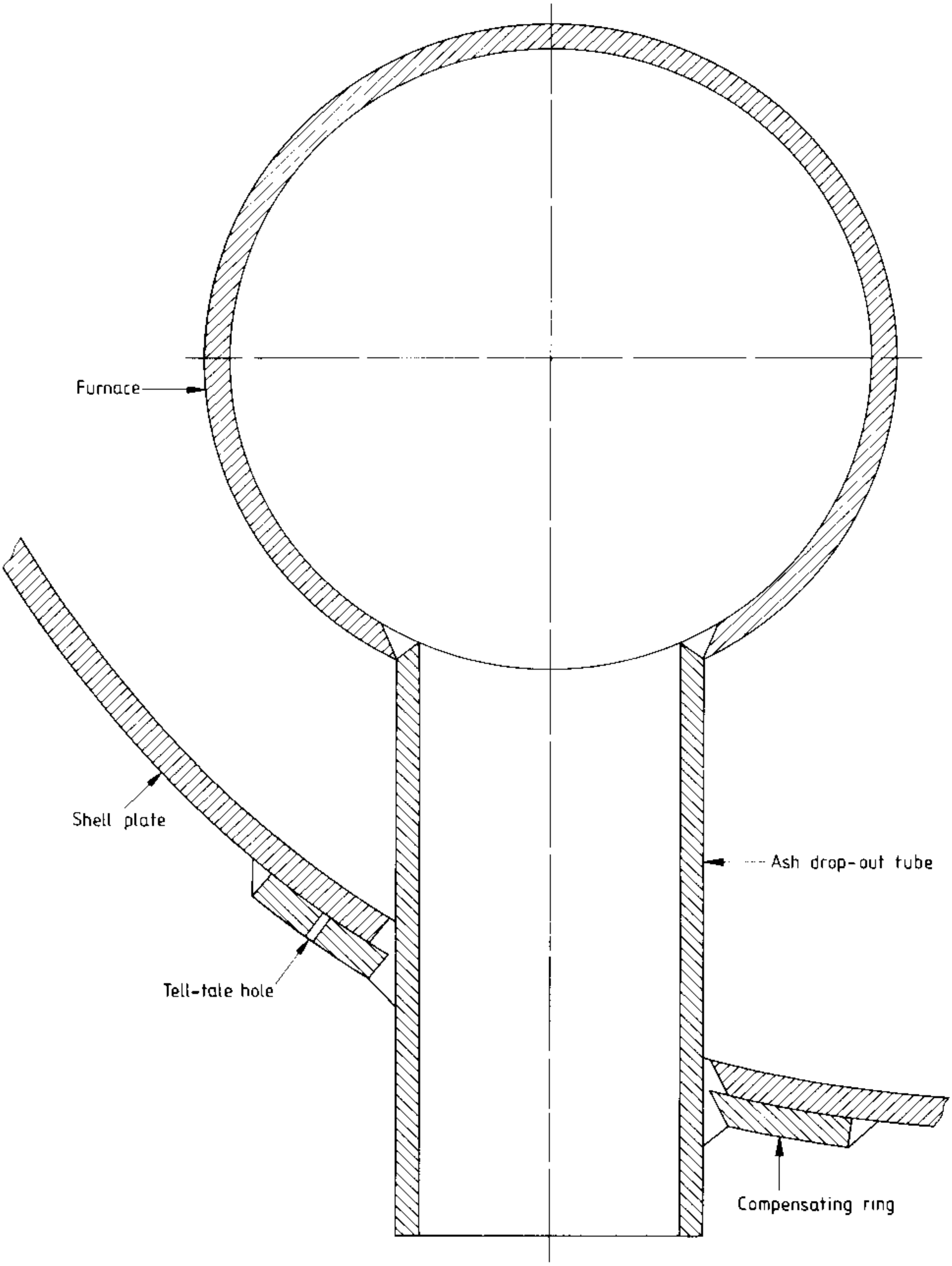
Figure B(5) — Attachment of furnaces to end plates or reversal chamber tubeplates



See **B.4.4**.

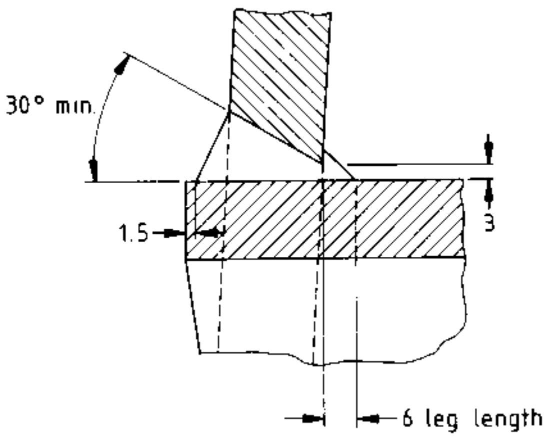
Dimension is in millimetres.

Figure B(6) — Attachment of furnaces to flanged end plates



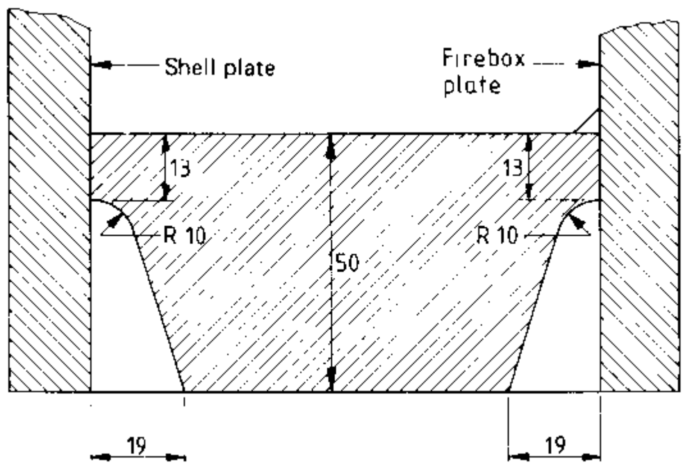
See **5.3.2.6**

Figure B(7) — Typical method of attachment of ash drop-out tube



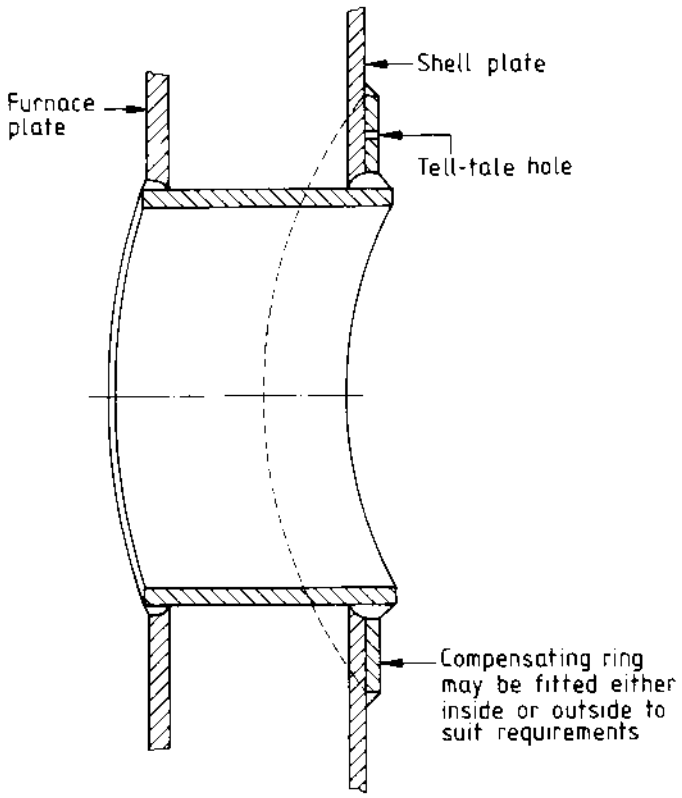
See B.4.4
All dimensions are in millimetres.

Figure B(8) — Fusion welds of cross tubes

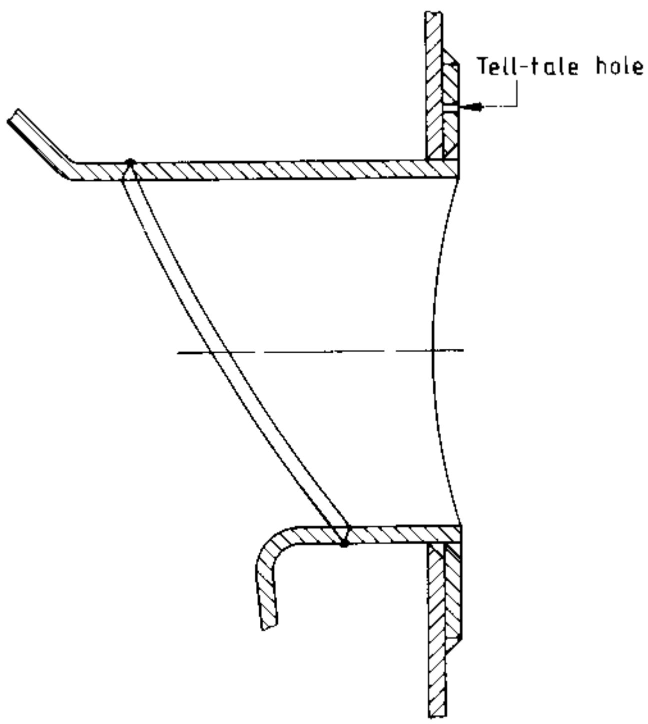


All dimensions are in millimetres.

Figure B(9) — Foundation ring

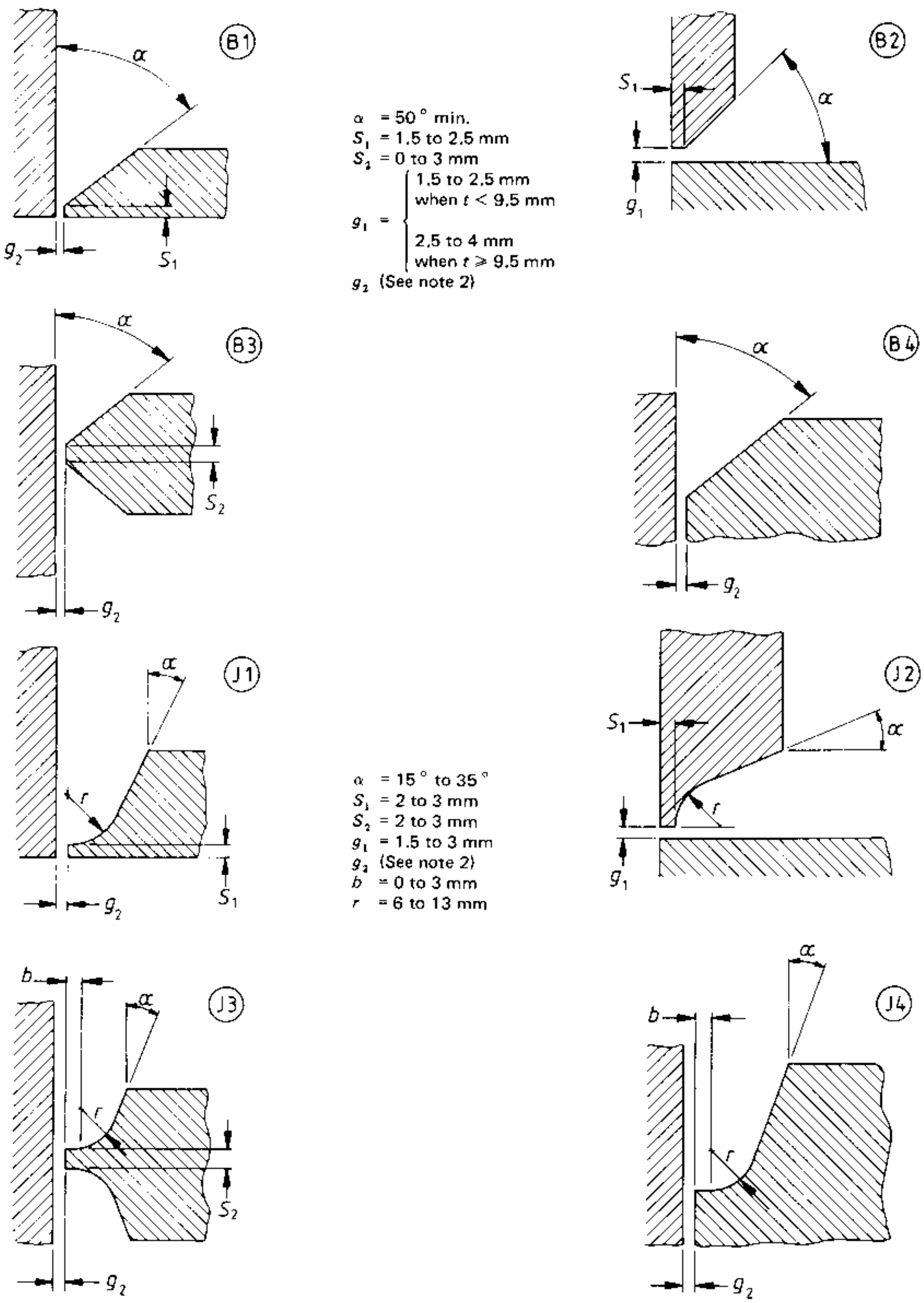


NOTE All welds are full penetration welds (see **B.4.4**).
(a)



NOTE All welds are full penetration welds (see **B.4.4**).
(b)

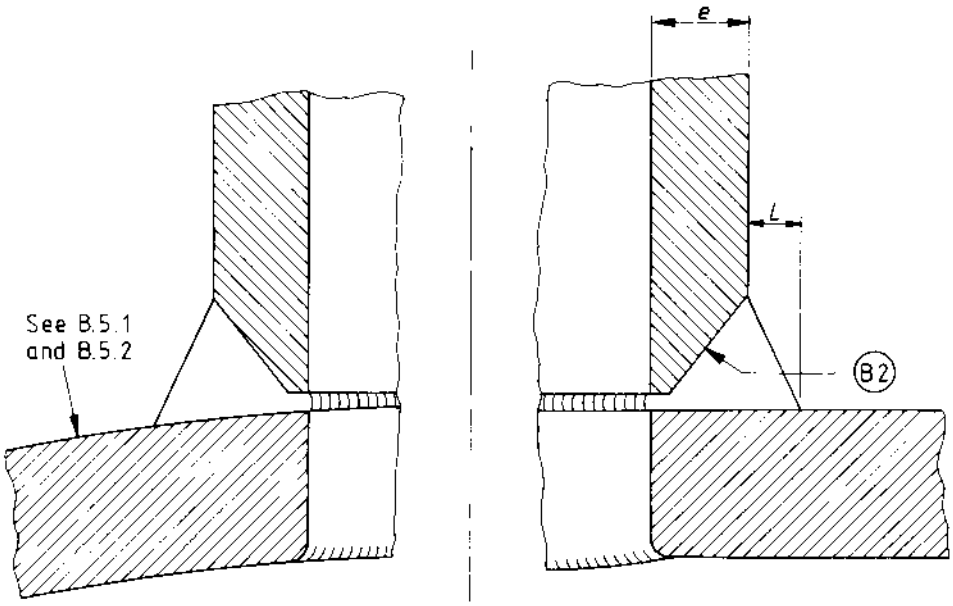
Figure B(10) — Typical method of attachment of firehole opening



NOTE 1 These recommendations have been included for general guidance. Discretion should be used in applying the maximum and minimum dimensions quoted which are subject to variation according to the welding procedure employed (for example, size and type of electrodes), the position in which the welding is carried out and the practicability of carrying out satisfactory non-destructive testing, where necessary.

NOTE 2 It is recommended that in no case should the gap between the branch and shell exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

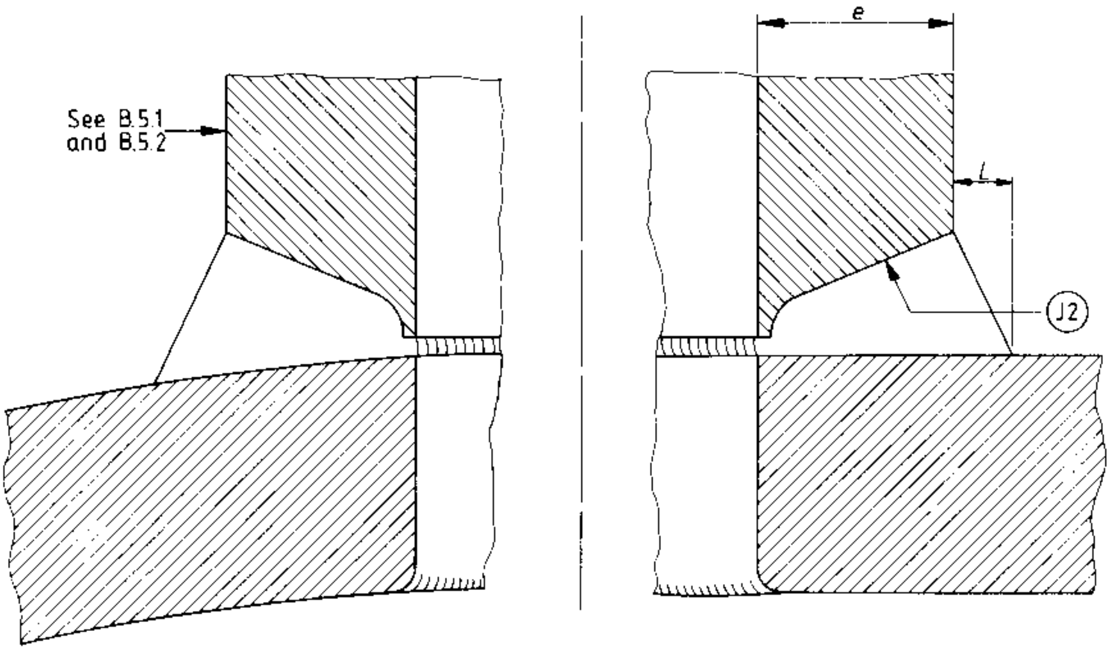
Figure B(11) — Standard weld preparation details



L = *e*/3 min. but not less than 6 mm

NOTE Preference should be given to the detail shown in Figure B(12)(b) if *e* exceeds about 16 mm.

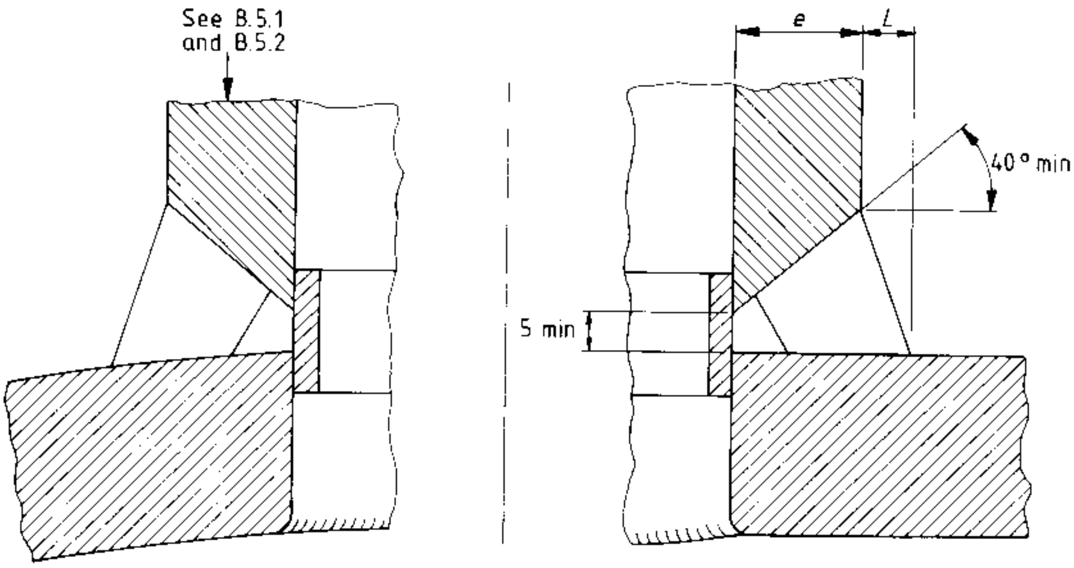
(a)



L = *e*/3 min. but not less than 6 mm

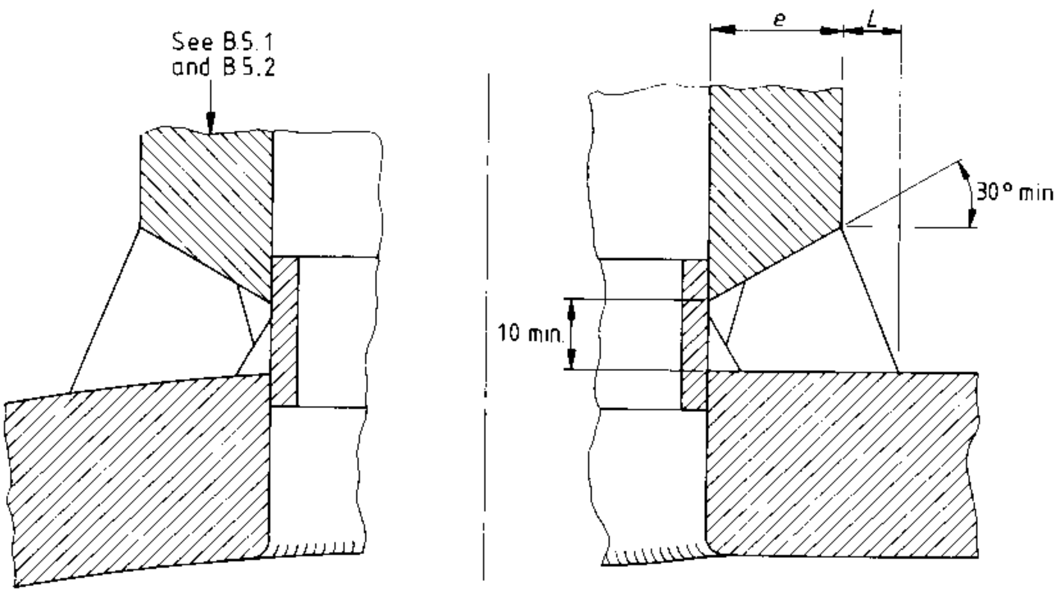
(b)

Figure B(12) — Set-on branches



L = e/3 min, but not less than 6

(a) Single root run technique



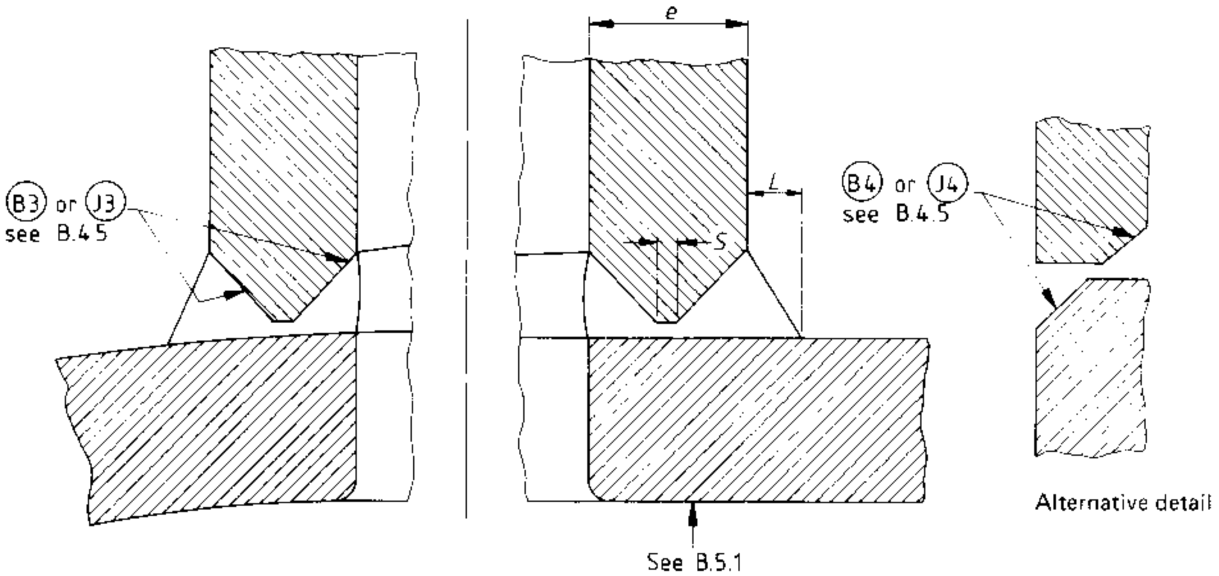
L = e/3 min, but not less than 6

(b) Double root run technique

All dimensions are in millimetres.

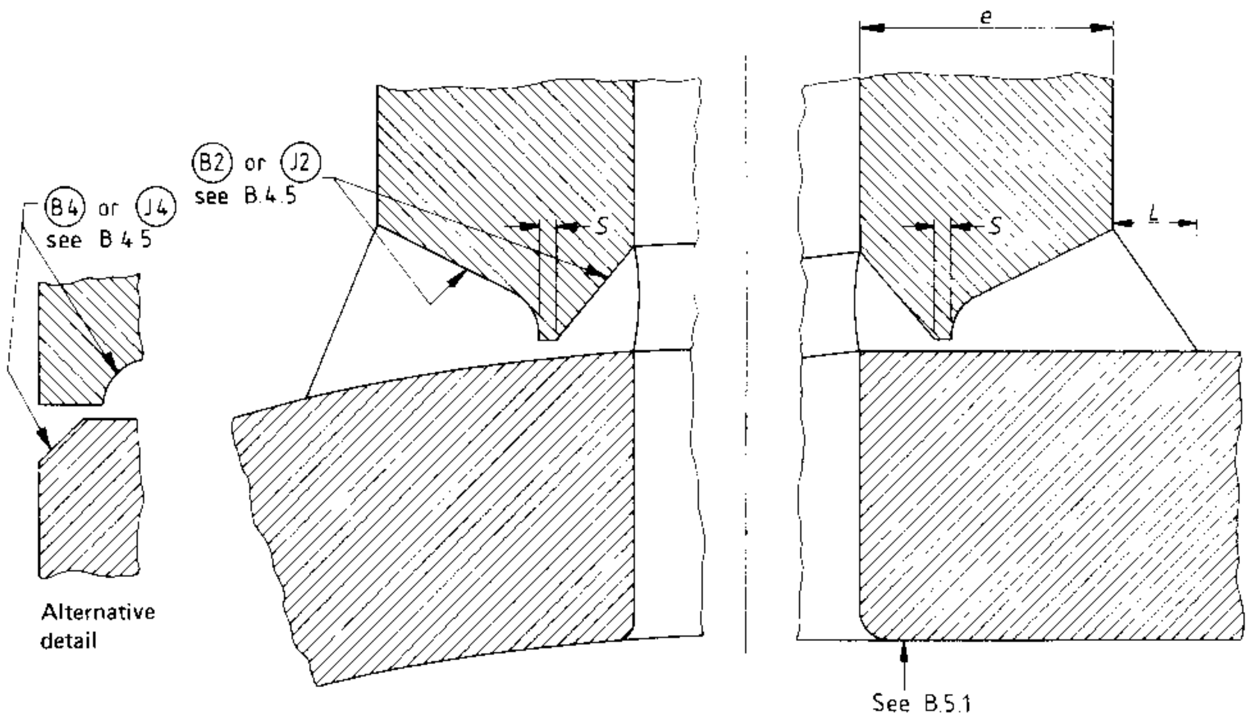
NOTE The backing ring material should be of the same nominal composition as that of the vessel shell. Care should be taken to ensure close fitting of the backing rings which should be removed after welding. After the removal of backing rings the surface should be ground smooth and examined for cracks by dye penetrant, magnetic, or other equivalent methods.

Figure B(13) — Set-on branches



S = 1.5 mm to 2.5 mm
L = *e*/3 min. but not less than 6 mm

(a)

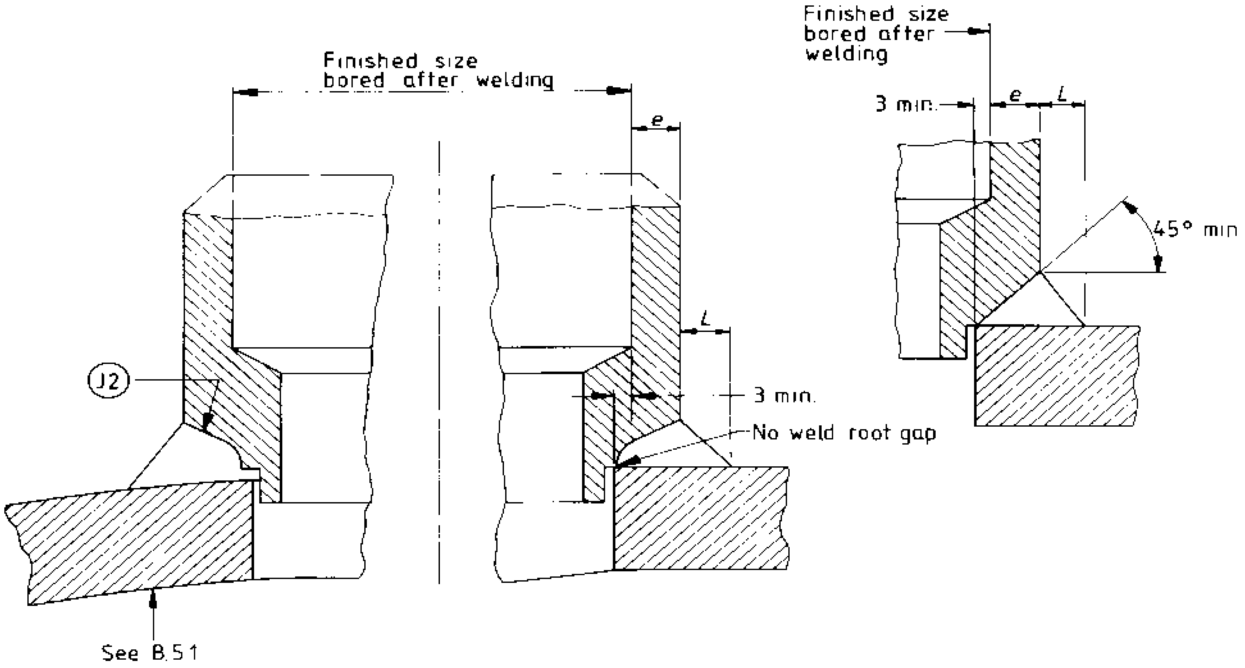


S = 1.5 mm to 2.5 mm
L = *e*/3 min. but not less than 6 mm

(b)

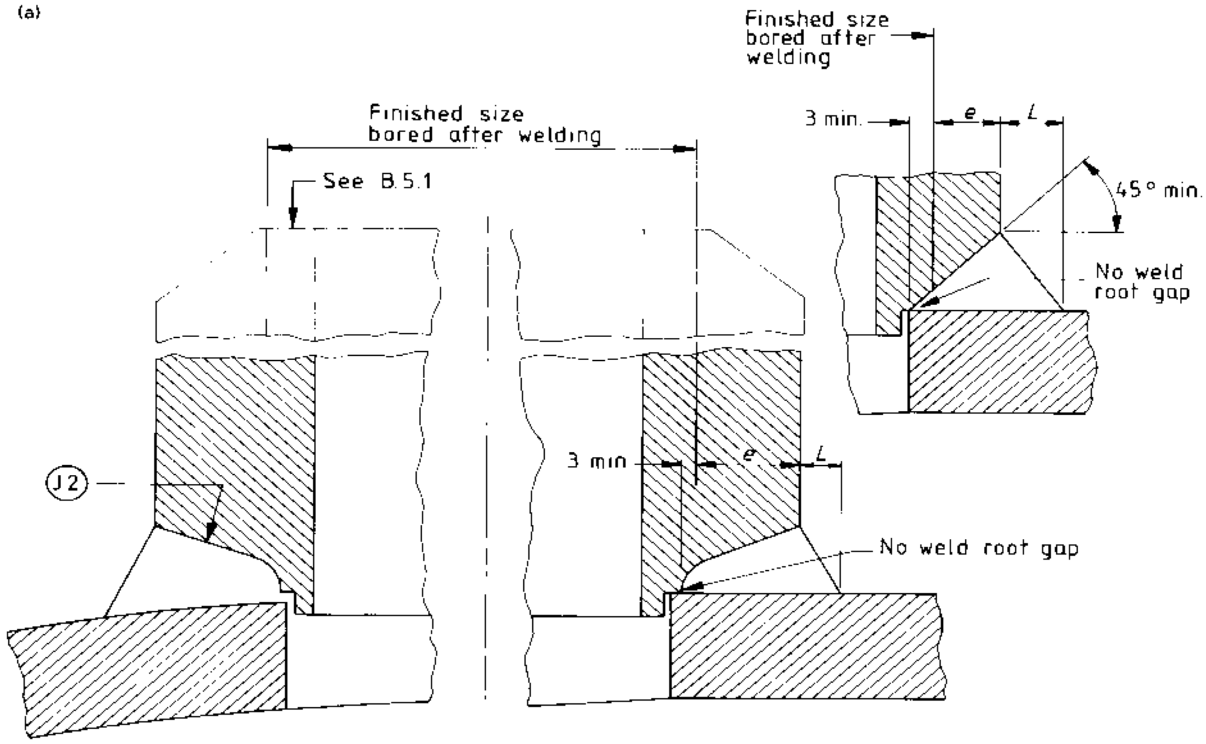
NOTE These details are recommended only where the bore of the branch is readily accessible for welding. The joint should be back-gouged from the side most accessible and suitable for this purpose, generally the outside.

Figure B(14) — Set-on branches



$L = e/3$ min. but not less than 6

(a)



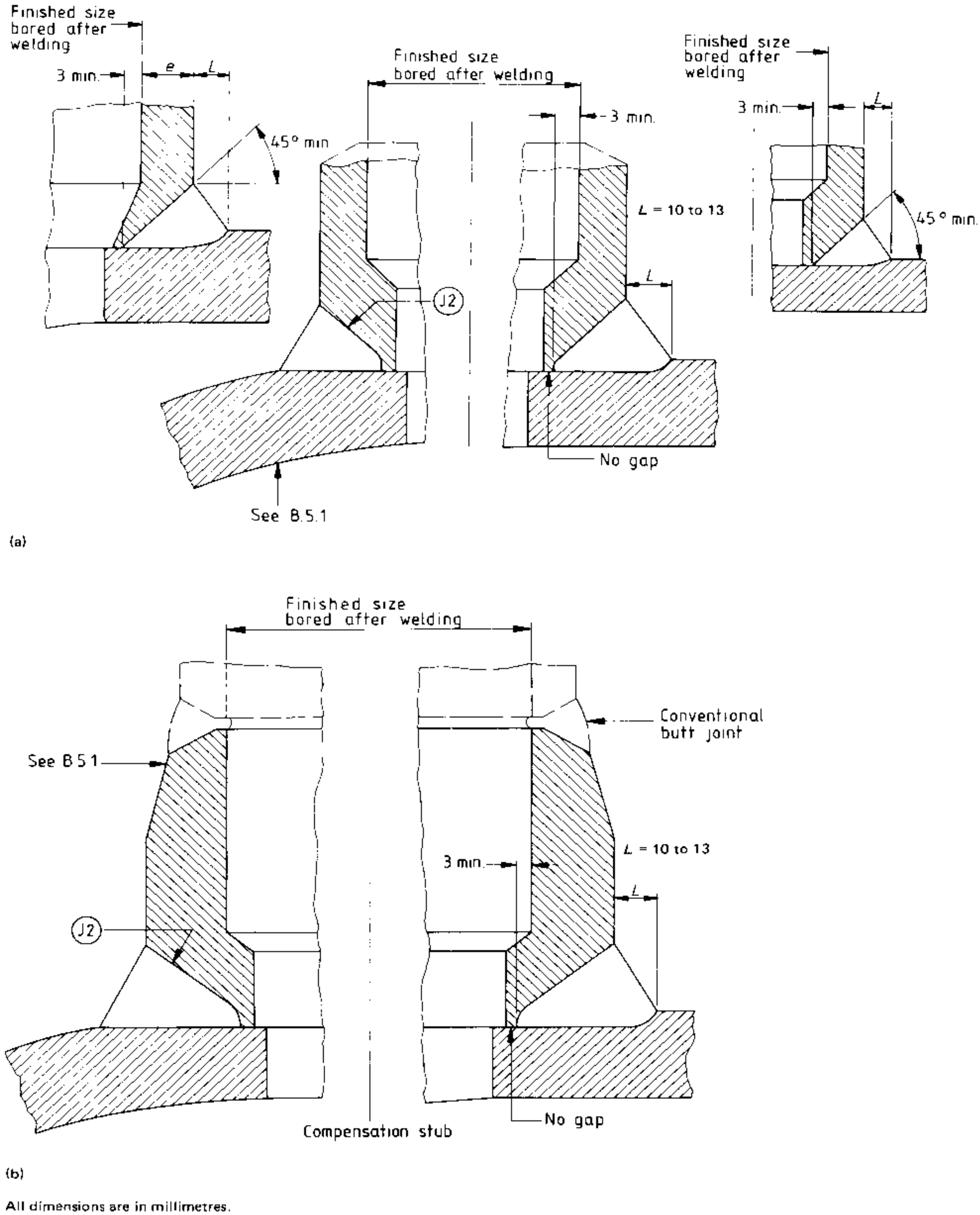
$L = e/3$ min. but not less than 6

(b)

All dimensions are in millimetres.

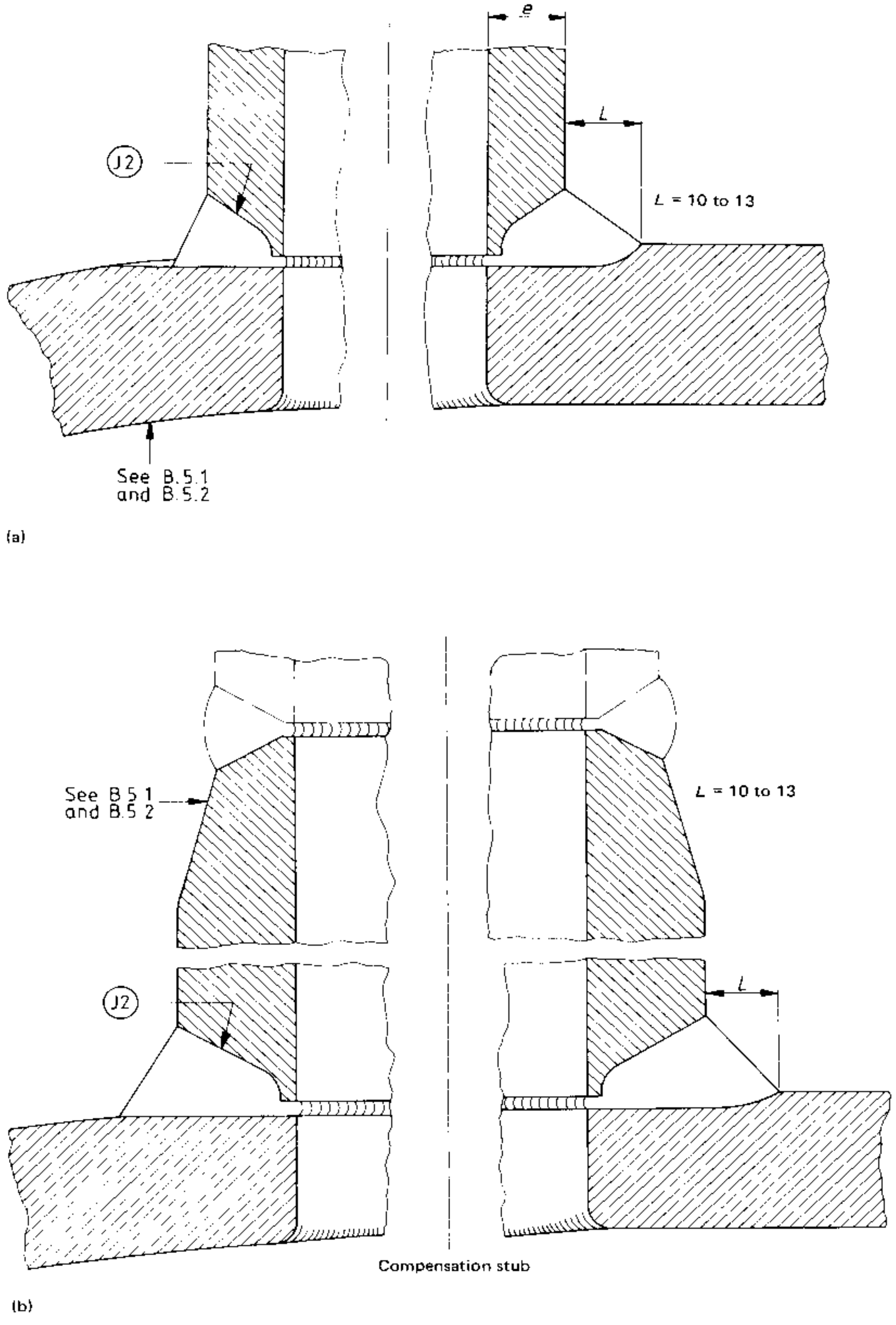
NOTE These joints are generally used for small branch-to-shell diameter ratios.

Figure B(15) — Set-on branches



NOTE These joints are generally used for small branch-to-shell diameter ratios.

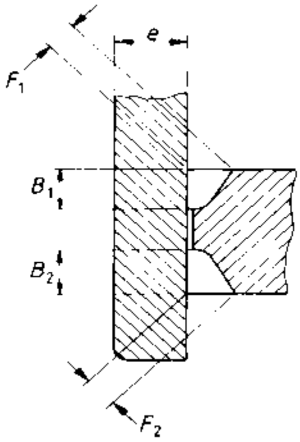
Figure B(16) — Set-on branches



All dimensions are in millimetres.

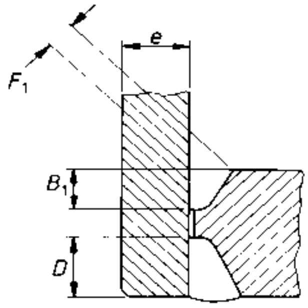
NOTE These joints are generally used for small branch-to-shell diameter ratios.

Figure B(17) — Set-on branches



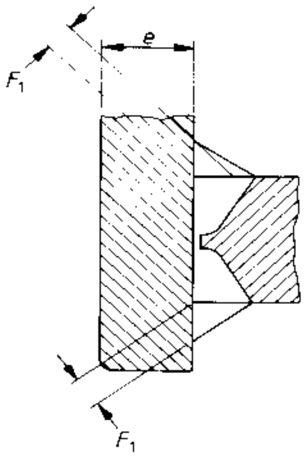
Weld sizes
$(B_1 + F_1) + (B_2 + F_2) = 2e$ approx.

(a) (See also figure B(19)(a))



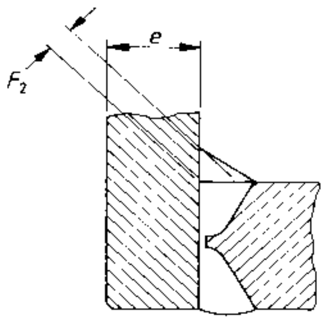
Weld sizes
$(B_1 + F_1) + D = 2e$ approx.

(b) (See also figure B(19)(b))



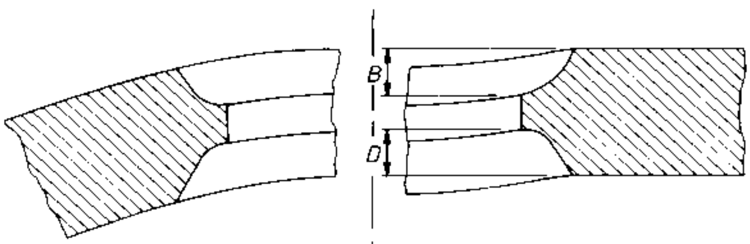
$F_1 = e/10$ or 6 mm whichever is larger

(c) (See also figure B(21)(a))

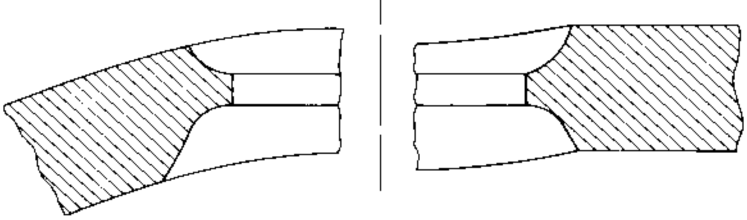


$F_2 = e/3$ or 6 mm whichever is larger

(d) (See also figure B(21)(b))

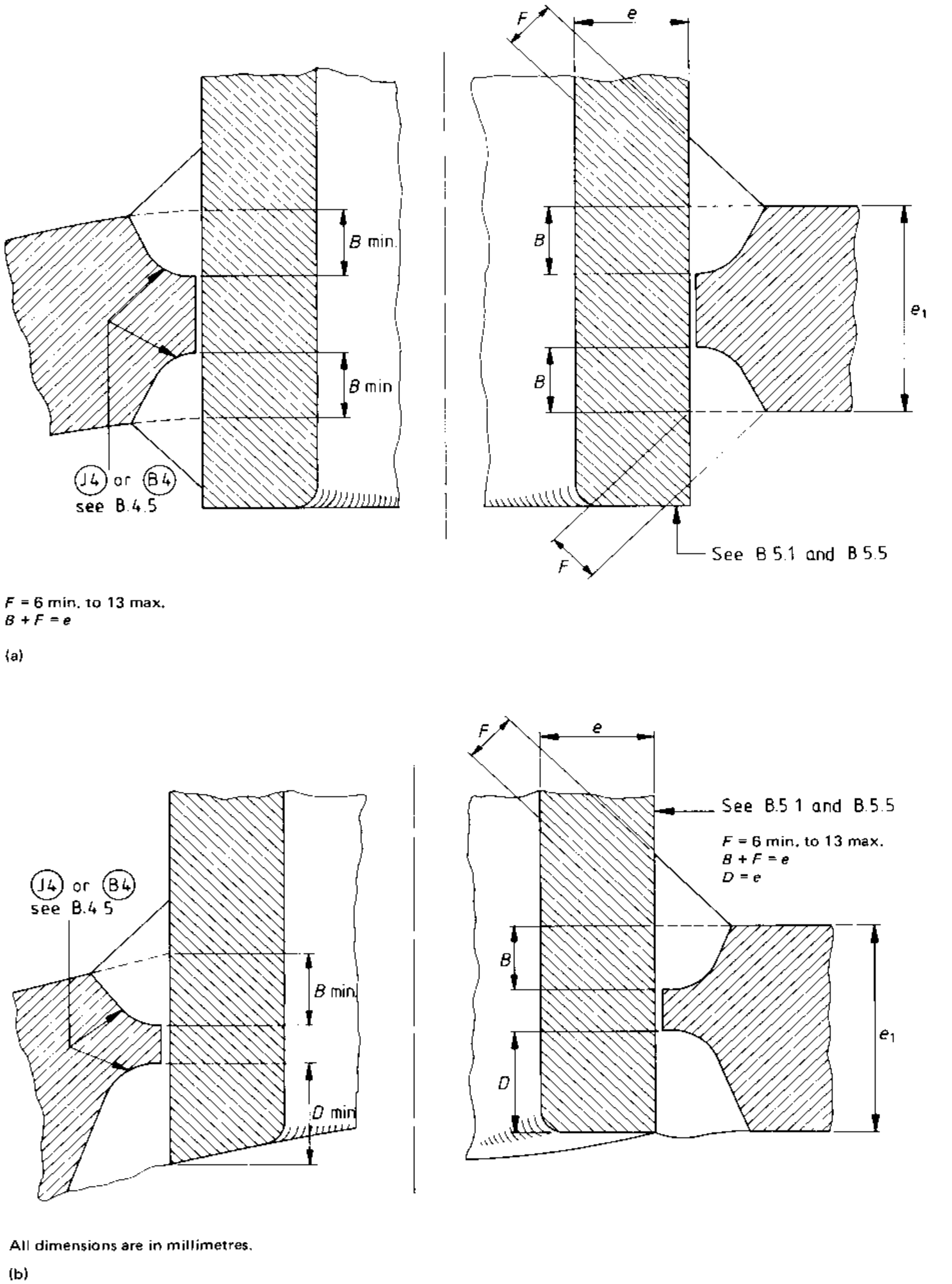


(e)



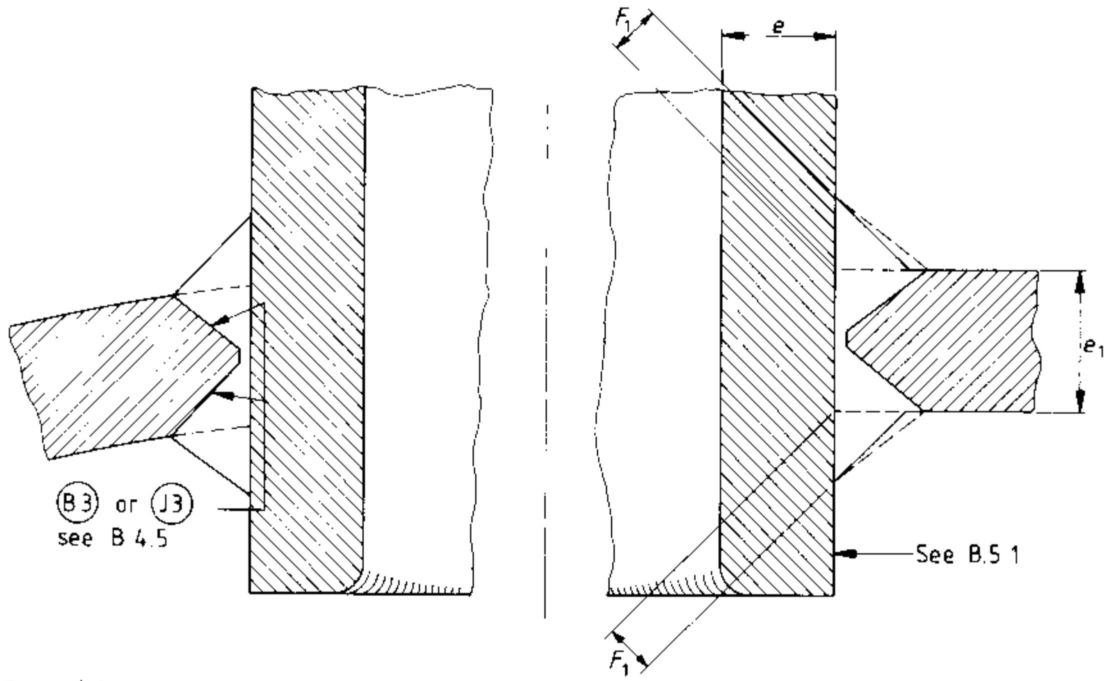
(f)

Figure B(18) — Weld details for set-in branches



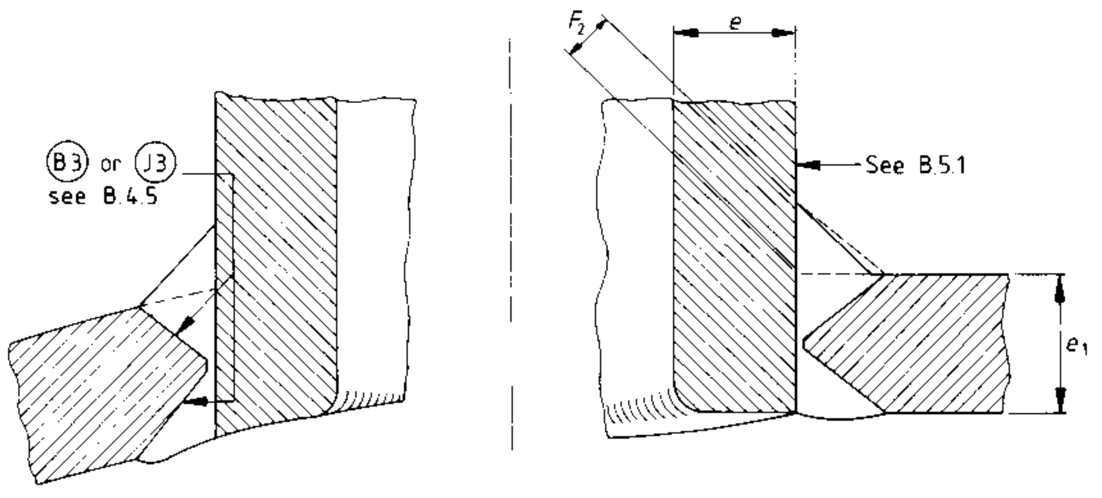
NOTE These are generally used when e is approximately equal to $e_1/2$.

Figure B(19) — Set-in branches (partial penetration weld)



$F_1 = e_1/10$ min. or 6 mm, whichever is larger

(a)

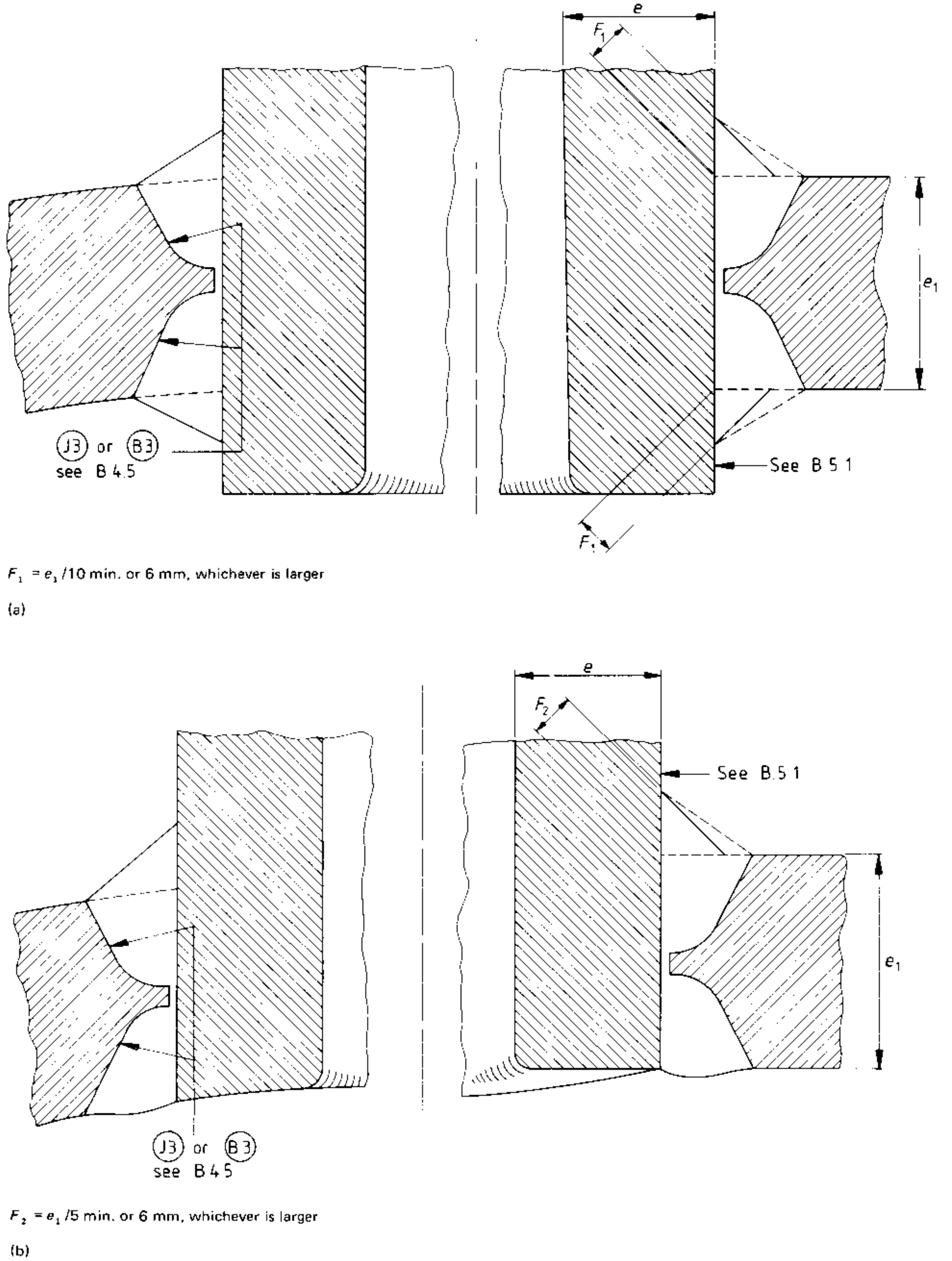


$F_2 = e_1/5$ min. or 6 mm, whichever is larger

(b)

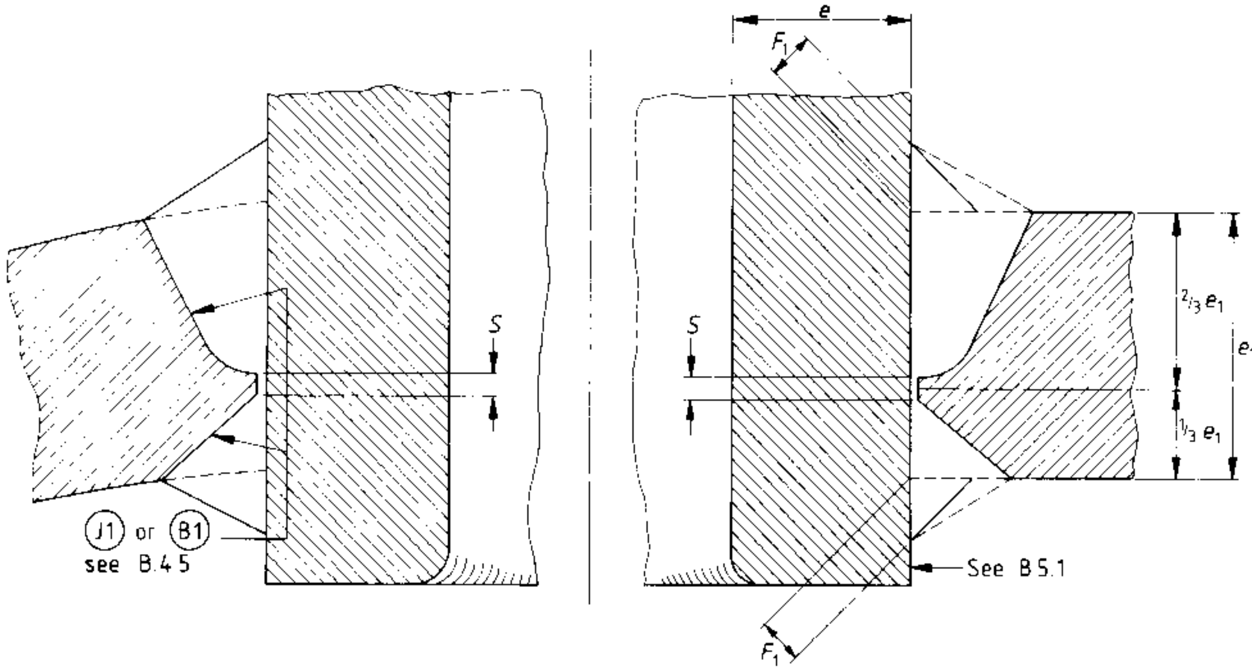
NOTE These are generally used when e is greater than $e_1/2$.

Figure B(20) — Set-in branches (full penetration weld)



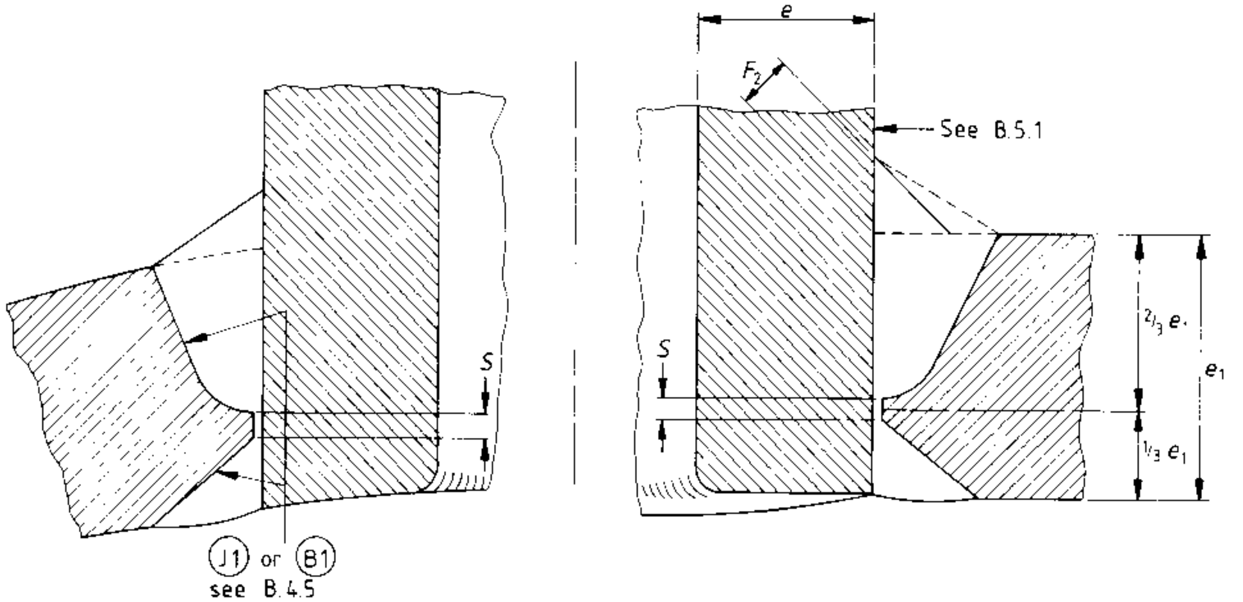
NOTE These are generally used when e is greater than $e_1/2$.

Figure B(21) — Set-in branches (full penetration weld)



S = 1.5 mm to 2.5 mm
$F_1 \approx e_1$/10 min. or 6 mm, whichever is larger

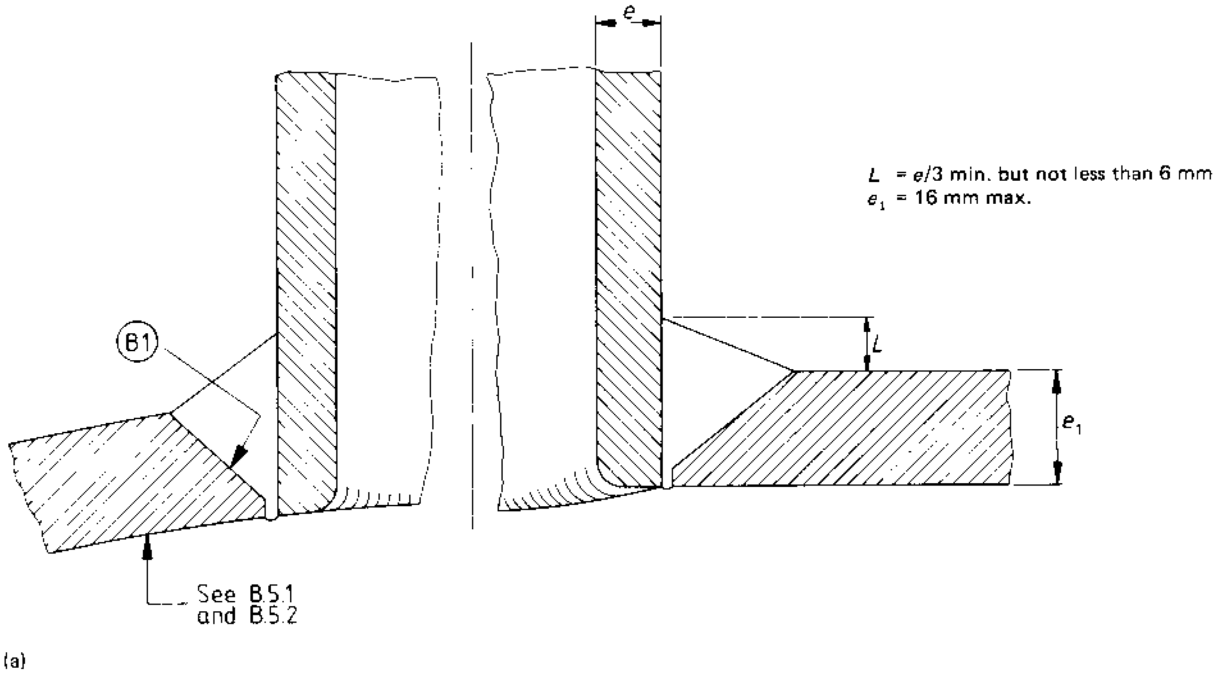
(a)

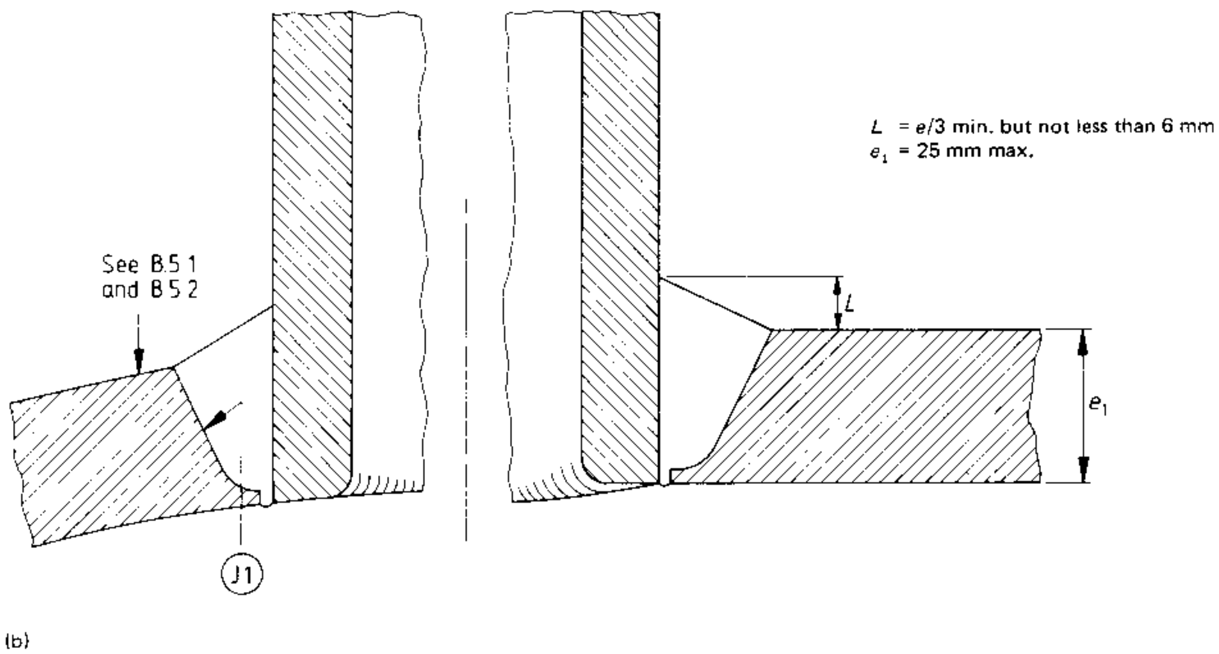


S = 1.5 mm to 2.5 mm
$F_2 = e_1$/5 min. or 6 mm, whichever is larger

(b)

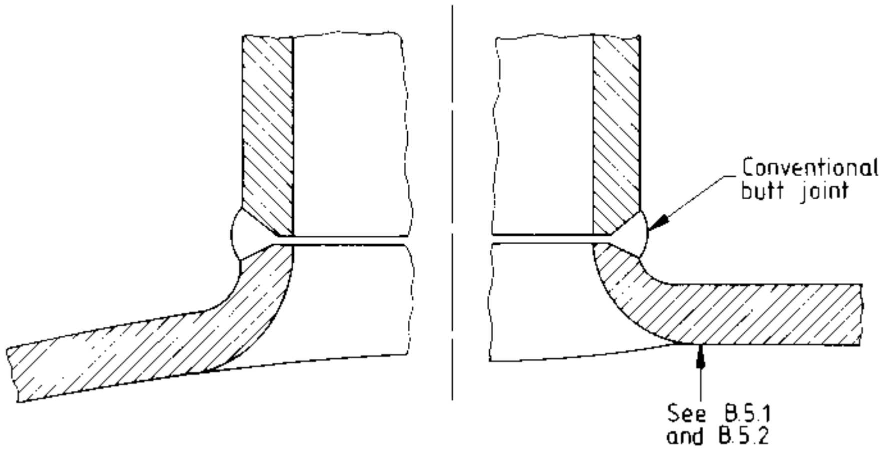
Figure B(22) — Set-in branches (full penetration asymmetrical welds)





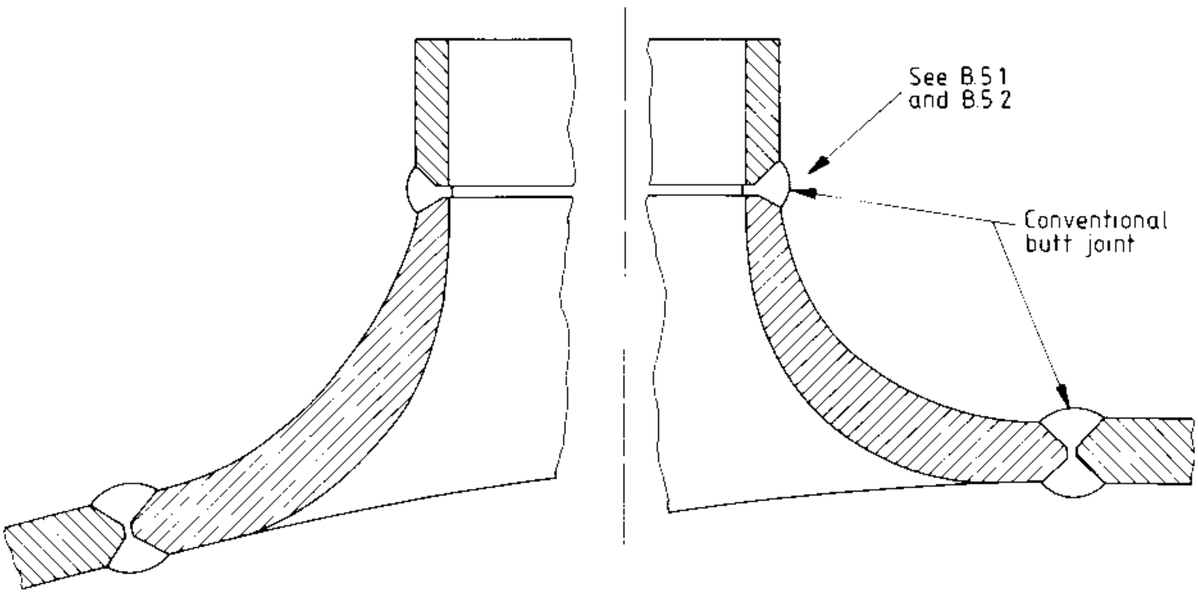
NOTE As a general recommendation, all set-in branches should be welded on the inside of the shell as shown in Figure B(19) to Figure B(22) if they are accessible for the purpose; otherwise preference should be given to set-on branch connections shown in Figure B(12) to Figure B(17). However, the connections shown above in Figure B(23)(a) and Figure B(23)(b) are considered to be acceptable if assurance can be provided that the welding procedure employed will ensure sound and consistent root conditions with uniform penetration.

Figure B(23) — Set-in branches (full penetration welds, welded from one side only)



NOTE Forging should be carried out within the correct range of temperature for the materials used.

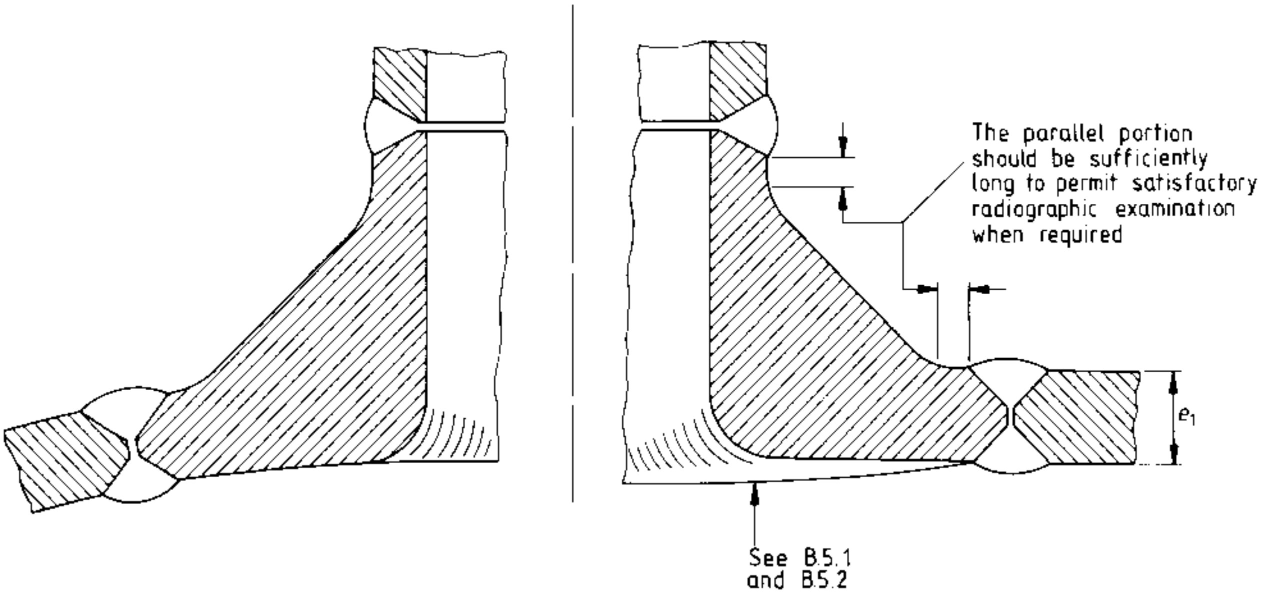
(a)



NOTE Conventional butt joints are used to weld the forged branch connection to the shell and branch and may not necessarily be of the form shown. See **B.4.4** and **B.4.5**.

(b)

Figure B(24) — Forged branch connections



NOTE Conventional butt joints are used to connect the forging to the shell and may not necessarily be of the form shown. See also **B.4.4** and **B.4.5**. These forgings connecting branches to shells are used with various forms of profile.

Figure B(25) — Forged branch connections

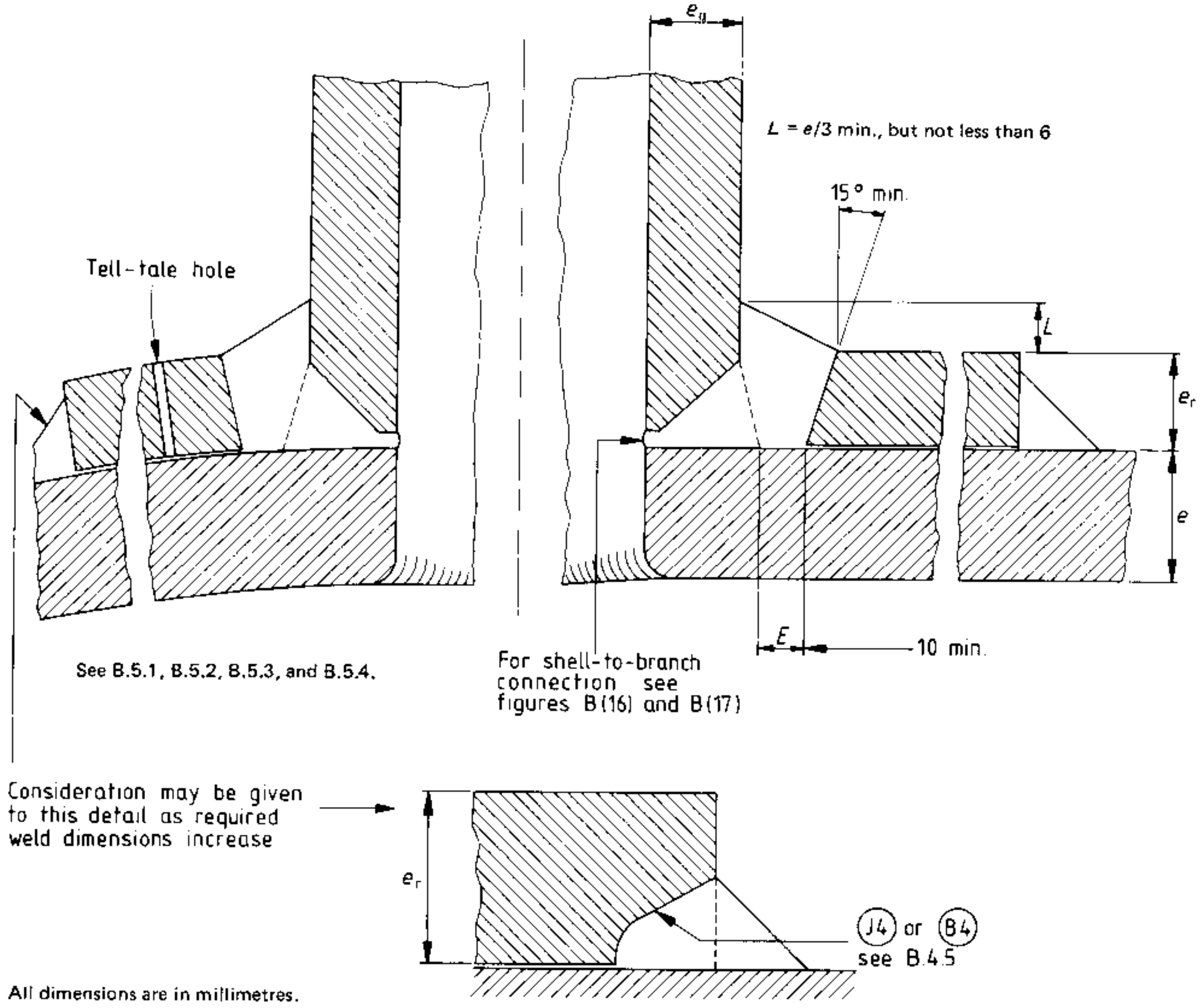
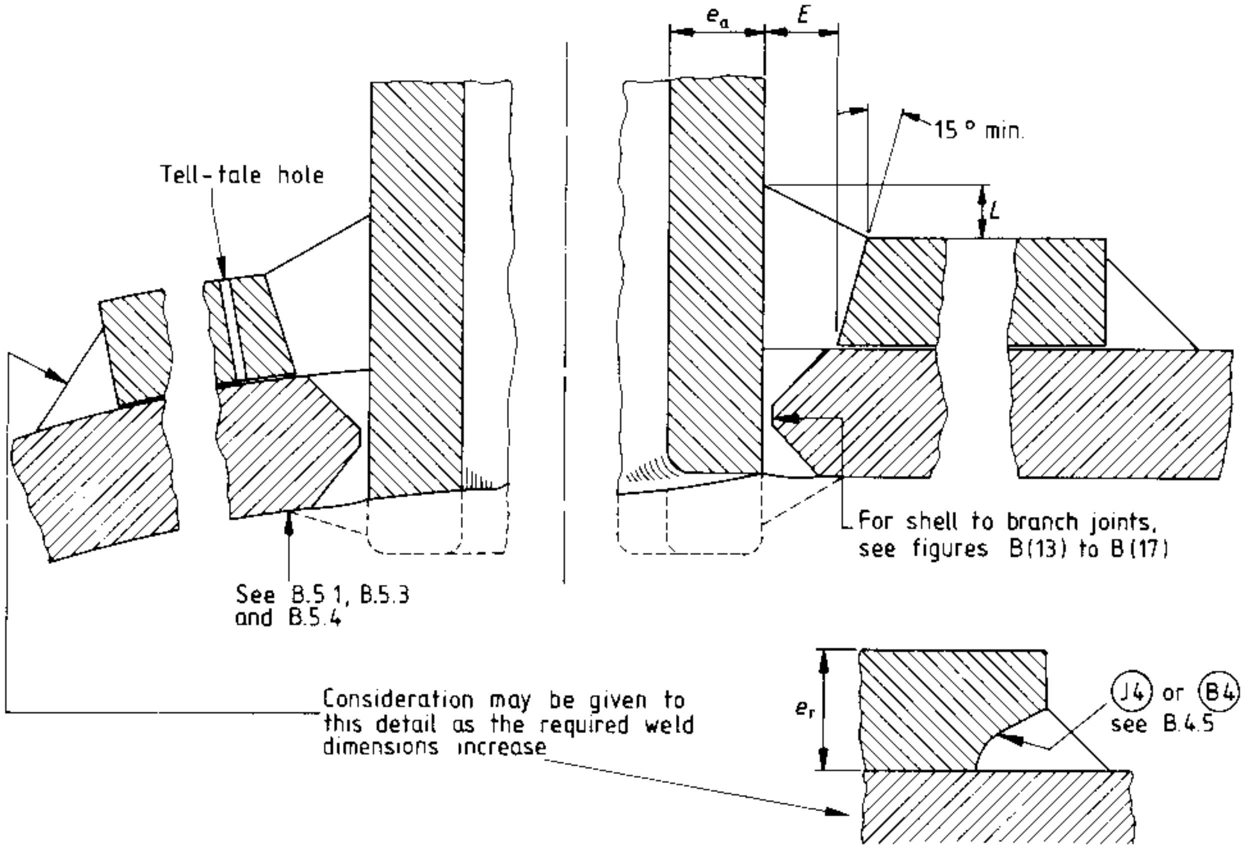


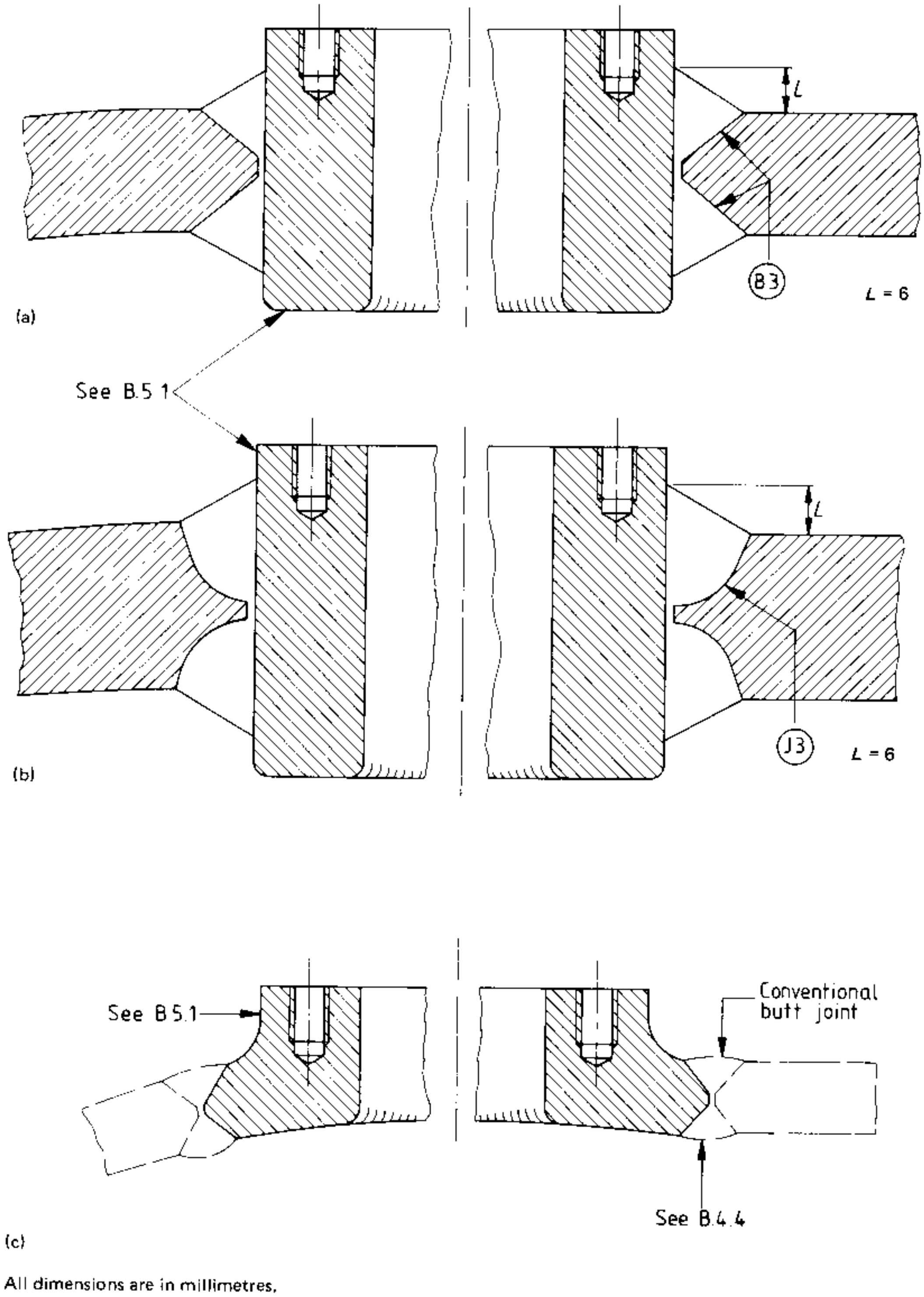
Figure B(26) — Set-on branches with added compensation rings



E = 10 min.
L = *e*/3 min., but not less than 6

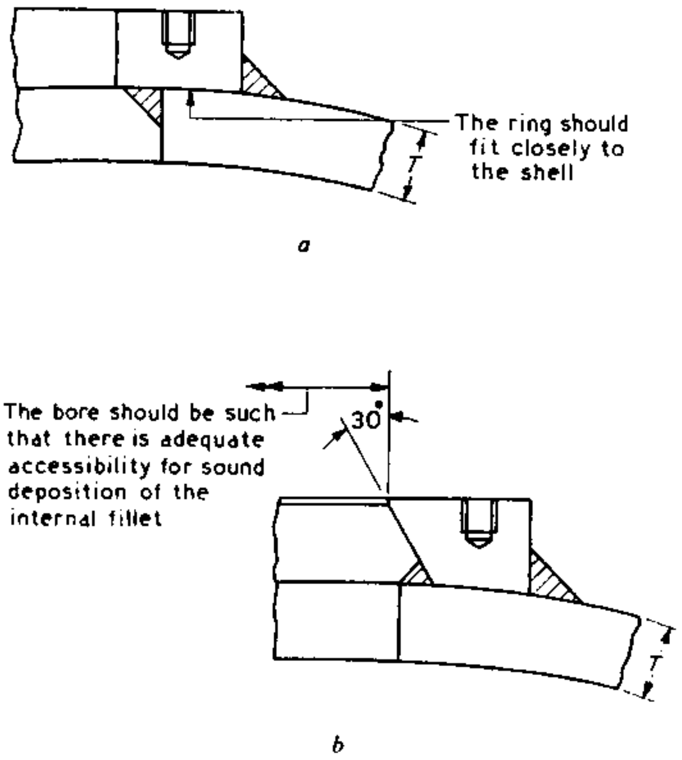
All dimensions are in millimetres.

Figure B(27) — Set-in branches with added compensation rings



NOTE If partial penetration joints are specified, the details given in Figure B(19) are recommended (see also **B.5.5**).

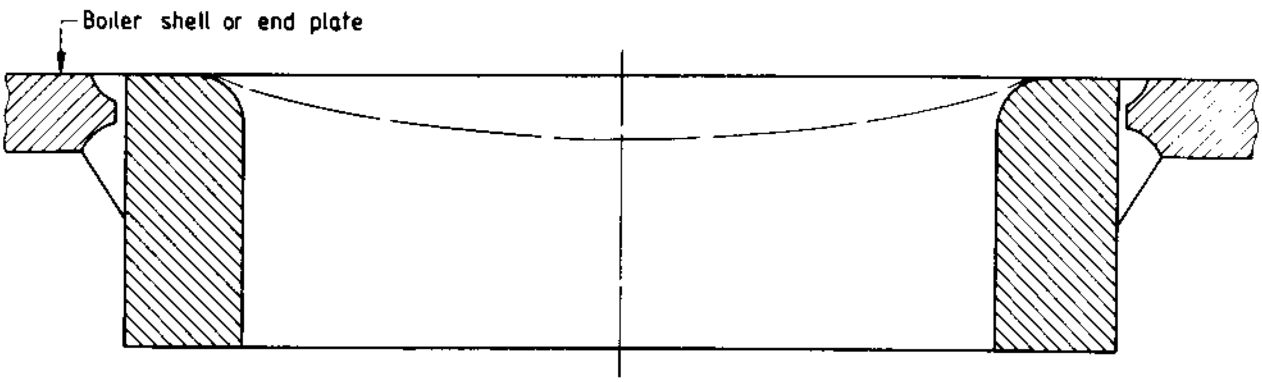
Figure B(28) — Butt-welded studded connections



NOTE 1 Fillet welded details are not recommended if the boiler is subjected to pulsating loads; in this case preference should be given to the details shown in Figure B(28).

NOTE 2 The sizes of the fillet welds should be based on the loads transmitted paying due regard to all fabrications and service requirements but in any case should not be less than 6 min. (See also Figure B(11) for standard weld preparation details.)

Figure B(29) — Fillet-welded studded connections



See **B.4.4**

Figure B(30) — Oval manhole frame

Appendix C Calculation of tube plate temperatures

C.1 General

This appendix provides a method for the calculation of the hot face metal temperature and the average (design) temperature of tube plates within the tube nest.

The calculation takes into account the effects under steady conditions of heat transfer

a) from the hot gas to the tube plate face and tube inside surfaces by convection, including the tube entrance effect, and radiation, including radiation interchange in the reversal chamber;

b) by thermal conduction through the tube plate and tube walls from the tube plate face and tube inside surfaces to the water side surfaces, assuming adequate thermal contact between tube and plate;

c) by nucleate boiling from the water side surfaces.

The method and design curves have been developed from published heat transfer data and contain some simplifying approximations which tend to be self-compensating; calculated and measured temperatures have shown good agreement where complete data are available.

C.2 Notation

a is the heat input area to the tube plate element from the tube plate face [see Figure C(8)];
A is the heat input area to the tube plate element from the tube inside surfaces [see Figure C(7)];
A_C is the total effective water cooled surface area in reversal chamber;
A_R is the total refractory surface area in the reversal chamber;
C is the correction factor for tube-to-tube plate contact thermal resistance;
d is the inside diameter of the convection tube (in mm);
D is the reversal chamber inside diameter (for cylindrical chambers) (in mm);
e is the tube plate thickness (in mm);
F is the overall exchange factor for radiation interchange in the reversal chamber [see Figure C(2)];
G is the tube specific gas flow rate [in kg/(m^2·s)];
h_{CE} is the tube entrance convection coefficient [in W/(m^2 · K)] [see Figure C(6)];
h_{CO} is the corrected basis convection coefficient [in W/(m^2 · K)] [see Figure C(5)];
h'_{CO} is the hypothetical basis convection coefficient [in W/(m^2 · K)] [see Figure C(4)];
h_m is the tube plate thermal conductance (in W/(m^2 · K);
h_R is the radiation coefficient for the tube plate face [in W/(m^2 · K)];
h'_R is the radiation coefficient for black exchange [in W/(m^2 · K)] [see Figure C(1)];
h_t is the weighted average heat transfer coefficient [in W/(m^2 · K)];
L is the reversal chamber inside length (for cylindrical chambers) (in mm);
L_B is the reversal chamber radiation beam length (in mm);
N = 4 000;
p is the average pitch between the tube centres (in mm);
t is the tube plate average (design) temperature (in °C);
t_C is the initial estimate of t_M (in °C);
t_G is the true gas temperature at the tube entrance (in °C);
t_M is the tube plate hot face metal temperature (in °C);
t_S is the boiler water temperature (in °C);
β is the tube plate average temperature factor [see Figure C(12)];
η is the heat transfer factor for the tube plate element [see Figure C(10)];
λ is the tube plate thermal conductivity [in W·mm/(m^2 · K)]
= 40,000 for steel grades 460 and 490;
= 45,000 for steel grades 400 and 430;
ϕ is the tube plate hot face temperature factor [see Figure C(11)].

C.3 Calculation method

C.3.1 *Radiation coefficients.* Determine the radiation coefficient h'_R for black exchange, i.e. emissivity = 1, F = 1, from Figure C(1). The gas temperature t_G at tube entry shall be the true value as would be measured by a multishield high velocity suction pyrometer (an ordinary thermocouple will always read low; error may be up to 300 °C). t_C is the initially assumed value of the tube plate hot face metal temperature. Typical values shown on Figure C(1) will usually avoid the necessity for reiteration.

The emissivity of the gas is dependent on the gas analysis, temperature, partial pressures and the beam length in the reversal chamber. The curves in Figure C(2) are based on the excess air normally used in directly fired boilers. For products of coal combustion, it is recommended that the natural gas curve be used to allow for particle radiation. For other gas mixtures the gas emissivity should be determined from a text on radiant heat transfer, e.g. [3].

The radiation beam length for a cylindrical reversal chamber is given by the following formula.

$$L_B = \frac{0.83L}{L/D + 0.5}$$

For chambers which are not cylindrical, the radiation beam length is given by the following formula.

$$L_B = 3.3\frac{V_C}{A_{CS}}$$

where

V_C is the chamber volume

A_{CS} is the chamber surface area

In calculating the chamber surface area no reduction shall be made for tube holes or furnace opening.

For chambers containing refractory linings A_R/A_C is the ratio of the total effective (reflecting) refractory surface area to the effective cooled (absorbing) surface area in the chamber.

A_C includes the total area enclosed within the tube plate perimeter, i.e. no reduction for tube holes or furnace opening.

A_R/A_C for cylindrical chambers may be obtained from Figure C(3).

For fully water cooled chambers $A_R/A_C = 0$.

Determine the overall exchange factor F from Figure C(2), then the radiation coefficient for the tube plate face is given by the following formula.

$$h_R = Fh'_R$$

Radiation to the tube inside surfaces is taken into account by use of the coefficient $0.5h_R$ in the equation for the weighted average heat transfer coefficient h_t.

C.3.2 *Convection coefficients.* The hypothetical basis convection coefficient h'_{CO} is dependent on the specific gas flow rate G in the convection tubes and on the tube inside diameter d. For the products of combustion of oil fuels, natural gas and coal determine h'_{CO} from Figure C(4). Determine the correction factor h_{CO}/h'_{CO} for the tube entry gas temperature from Figure C(5), using the oil fuel curve for coal products. Then the basis convection coefficient for fully developed tube flow at temperature t_G is given by the following formula.

$$h_{CO} = h'_{CO}\left(\frac{h_{CO}}{h'_{CO}}\right)$$

For other gases where the values of specific heat, thermal conductivity or viscosity are different from those for the products of combustion of oil or natural gas, the value of h_{CO} may be calculated from the equation for fully developed flow inside tubes as follows.

$N_u = 0.023\ R_e^{0.8}\ P_r^{0.33}$ (see, for example, [3])

where

N_u is the Nusselt number } based on the tube
R_e is the Reynolds number } inside diameter, d;
P_r is the Prandtl number.

Determine the correction factor h_{CE}/h_{CO} for the tube entrance region from Figure C(6), then the average convection coefficient, h_{CE}, for the tube inside surface over the effective length for heat input to the tube plate, is given by the following formula.

$$h_{CE} = h_{CO}\left(\frac{h_{CE}}{h_{CO}}\right)$$

Convective heat transfer to the tube plate face is taken into account by the use of the coefficient h_{CO} in the equation for the weighted average heat transfer coefficient h_t.

C.3.3 *Weighted average gas-side heat transfer coefficient.* For the tube plate element, bounded by tube inside surfaces and planes containing tube centrelines, the heat input areas A (tube inside surfaces) and a (tube plate face) are determined from Figure C(7) and Figure C(8).

The weighted average heat transfer coefficient is then calculated as follows.

$$h_t = \frac{\frac{CA}{d^2}(h_{CE} + 0.5h_R) + \frac{a}{d^2}(h_{CO} + h_R)}{\left(\frac{A}{d^2} + \frac{a}{d^2}\right)}$$

where

$C = 0.90$ for tubes expanded only;
$C = 0.95$ for tubes expanded and welded;
$C = 1.0$ for tubes full penetration welded.

C.3.4 *Tube plate thermal conductance.* The tube plate thermal conductance is given by the following formula.

$$h_m = \frac{\lambda}{e}\ \text{W/(m}^2\cdot\text{K)}$$

C.3.5 *Water-side heat transfer.* Heat transfer conditions at the water side surfaces are taken into account in the equations for the tube plate metal temperatures by use of the constant N.

C.3.6 *Tube plate temperatures.* The following equations for the tube plate hot face and average metal temperatures are based on equations developed by Gardner [10].

$$t_M = t_S + 15 + \left(1 - \frac{\phi}{1 + \frac{\eta h_t}{N}}\right)(t_G - t_S)$$

$$t = t_S + 15 + \left(1 - \frac{\beta}{1 + \frac{\eta h_t}{N}}\right)(t_G - t_S)$$

The factors η, ϕ and β are dependent on A/a [from Figure C(9)] and on h_t/h_m and are obtained from Figure C(10), Figure C(11) and Figure C(12).

The gas temperature t_G at the tube entrance shall be the true value as would be measured by a multi-shield high velocity suction pyrometer (an ordinary thermocouple will always read low; the error may be as much as 300 °C).

C.4 Bibliography

1. LUCAS, D.M. and LOCKETT, A.A. Mathematical Modelling of Heat Flux and Temperature Distribution in Shell Boilers. *Proc. 4th Syrup. on Flames and Industry,* 1972, BFRC — Inst. Fuel.

2. KERN, D.Q. *Process Heat Transfer,* McGraw-Hill, 1950.

3. McADAMS, W.H. *Heat Transmission,* McGraw-Hill, 1954.

4. GORE, W.H., GUNN, D.C. and HORSLER, A.G. *Natural Gas Firing of Shell Boilers,* Inst. Fuel, March 1972.

5. V.D.I. WÄRMEATLAS.

6. JACOB, M. *Heat Transfer,* John Wiley, 1949.

7. ECKERT, E.R.G. and DRAKE, R.M. *Heat and Mass Transfer,* McGraw-Hill, 1959.

8. FRAAS, A.P. and OZISIK, M.N. *Heat Exchanger Design, John Wiley,* 1965.

9. PERRY, K.P. Heat Transfer by Convection from a Hot Gas Jet to a Plane Surface. *Proc. I. Mech. E.,* 1954, **168**

10. GARDNER, K.A. Heat Exchanger Tube Sheet Temperatures. *Refiner and Natural Gasoline Manufacturer,* March 1942, **21**, no. 3

C.5 Example of a calculation carried out using the method given in Appendix C

C.5.1 *Design data assumed*

Fuel: natural gas

Boiler: multitubular waste heat with refractory lined hot gas chamber

Specified inlet gas temperature: 900 °C

Boiler design pressure: 1.1 N/mm^2

Saturation temperature: t_s = 188 °C

Boiler tubes:	inside diameter	d = 56.3 mm
	pitch, triangular	p = 88 mm
	gas flow rate	G = 11 kg/(m^2 · s)
Tubeplate:	thickness	e = 22 mm
	material	430 grade

Tube end attachment: expanded and welded

Inlet gas chamber: cylindrical, refractory lined on wrapper and back plates

inside diameter	D = 1 800 mm
inside length	L = 1 000 mm

C.5.2 *Calculation of radiation coefficient.* The calculation of radiation coefficient h_R is carried out as described in **C.3.1**.

From Figure C(1), using an assumed value of t_C = 350 °C indicated by the typical dryback curve, h'_R = 185 W/(m^2 · k)

$$L_B \text{ Radiation beam length} = \frac{0.83 \times 1000}{\frac{1000}{1800} + 0.5} = 786 \text{ mm}$$

From Figure C(3) A_R/A_C = 3.15 where L/D = 0.555

From Figure C(2) F = 0.58

$\therefore h_R = 0.58 \times 185 = 107.3$ W/(m^2 · K)

C.5.3 *Calculation of convection coefficients.* The calculation of convection coefficients h_{CO} and h_{CE} is carried out as described in **C.3.2**.

From Figure C(4) $h'_{CO} = 61$ W/(m² · K)

From Figure C(5) $\frac{h_{CO}}{h'_{CO}} = 0.952$

$\therefore h_{CO} = 0.952 \times 61 = 58.1$ W/(m² · K)

From Figure C(6) $\frac{h_{CE}}{h_{CO}} = 2.9$ where $\frac{e}{d} = \frac{22}{56.3} = 0.391$

$\therefore h_{CE} = 2.9 \times 58.1 = 168.5$ W/(m² · K)

C.5.4 *Calculation of weighted average gas-side heat transfer coefficient.* The calculation of weighted average gas-side heat transfer coefficient h_t is carried out as described in **C.3.3**.

From Figure C(7) $\frac{A}{d^2} = 0.6$ where $\frac{e}{d} = 0.391$, triangular pitch

From Figure C(8) $\frac{a}{d^2} = 0.67$ where $\frac{p}{d} = \frac{88}{56.3} = 1.563$

For tubes expanded and welded $C = 0.95$.

$$\therefore h_t = \frac{0.95 \times 0.6\ (168.5 + 0.5 \times 107.3) + 0.67\ (58.1 + 107.3)}{0.6 + 0.67}$$

$$= 187 \text{ W/(m}^2 \cdot \text{K)}$$

C.5.5 *Calculation of tube plate thermal conductance.* The calculation of tube plate thermal conductance h_m is carried out as described in **C.3.4**.

For 430 grade steel $\lambda = 45\ 000$ (see **C.2**).

$$\therefore h_m = \frac{45\ 000}{22} = 2045 \text{ W/(m}^2 \cdot \text{K)}$$

C.5.6 *Calculation of tube plate temperatures.* The calculation of tube plate temperatures t and t_m is carried out as described in **C.3.6**.

$$\frac{h_t}{h_m} = \frac{187}{2045} = 0.09144$$

From Figure C(9) $\frac{A}{a} = 0.9$

From Figure C(10), Figure C(11) and Figure C(12)

$\eta = 1.72$, $\phi = 0.885$, $\beta = 0.935$

∴ Tube plate hot face metal temperature is given by

$$t_M = 188 + 15 + \left[1 - \frac{0.885}{1 + \frac{1.72 \times 187}{4000}}\right] (900 - 188)$$

$$= 332\ ^\circ\text{C}$$

This is below the limit given in **3.1.3.2** and is therefore satisfactory.

Tube plate average (design) metal temperature is given by

$$t = 188 + 15 + \left[1 - \frac{0.935}{1 + \frac{1.72 \times 187}{4000}}\right] (900 - 188)$$

$$= 299\ ^\circ\text{C}$$

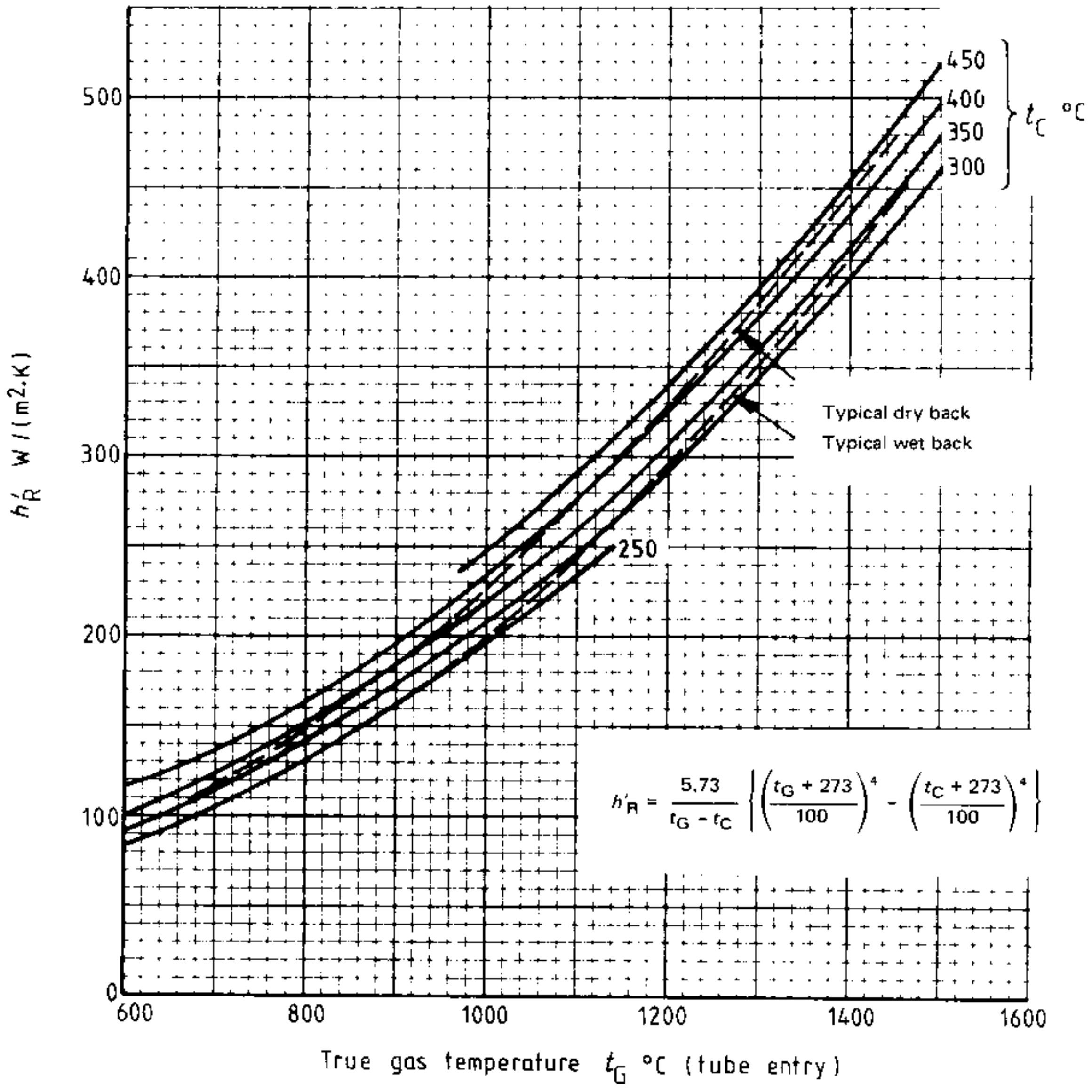


Figure C(1) — Radiation coefficient h'_R for black exchange ($F = 1$)

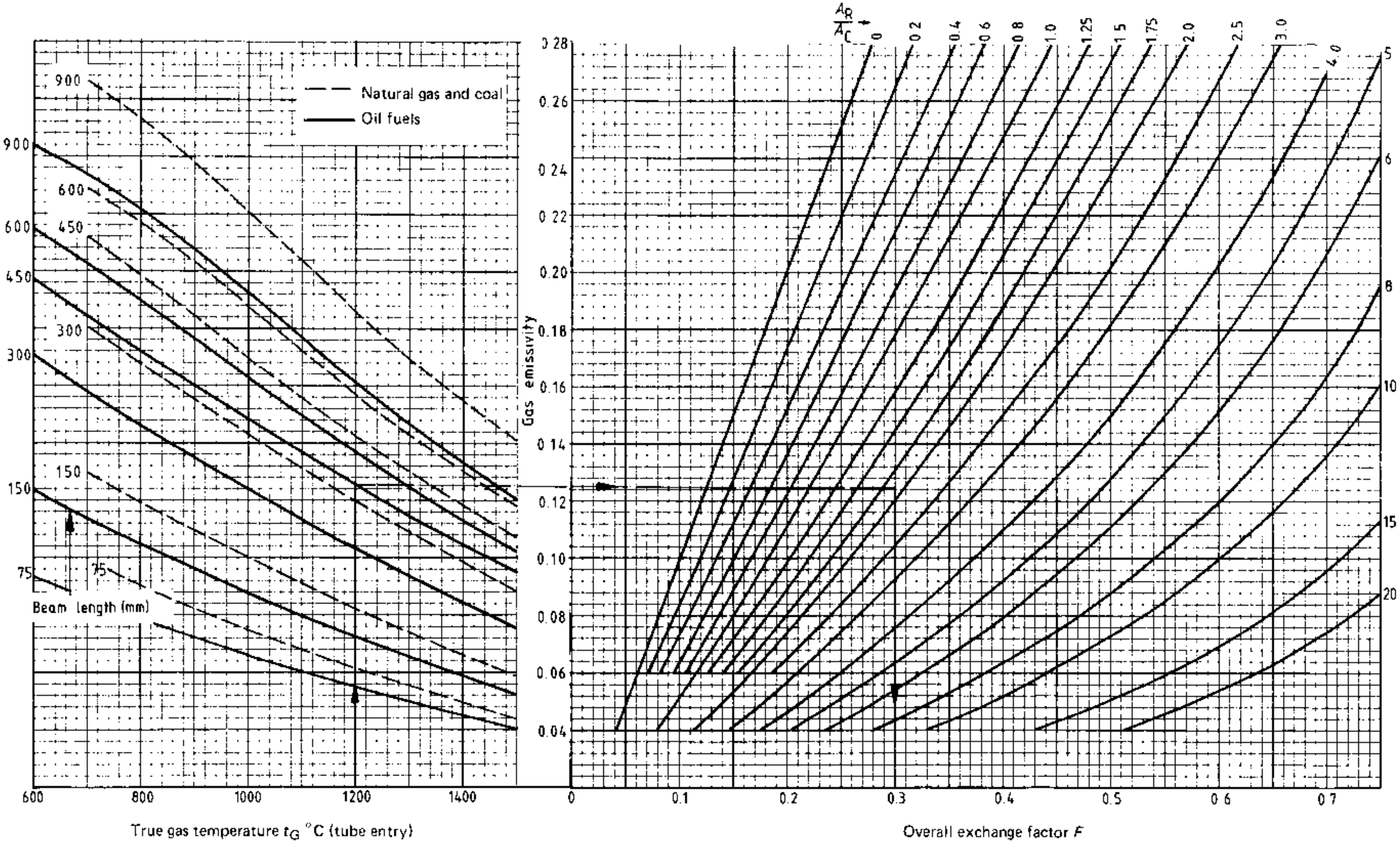


Figure C(2) — Determination of overall exchange factor F

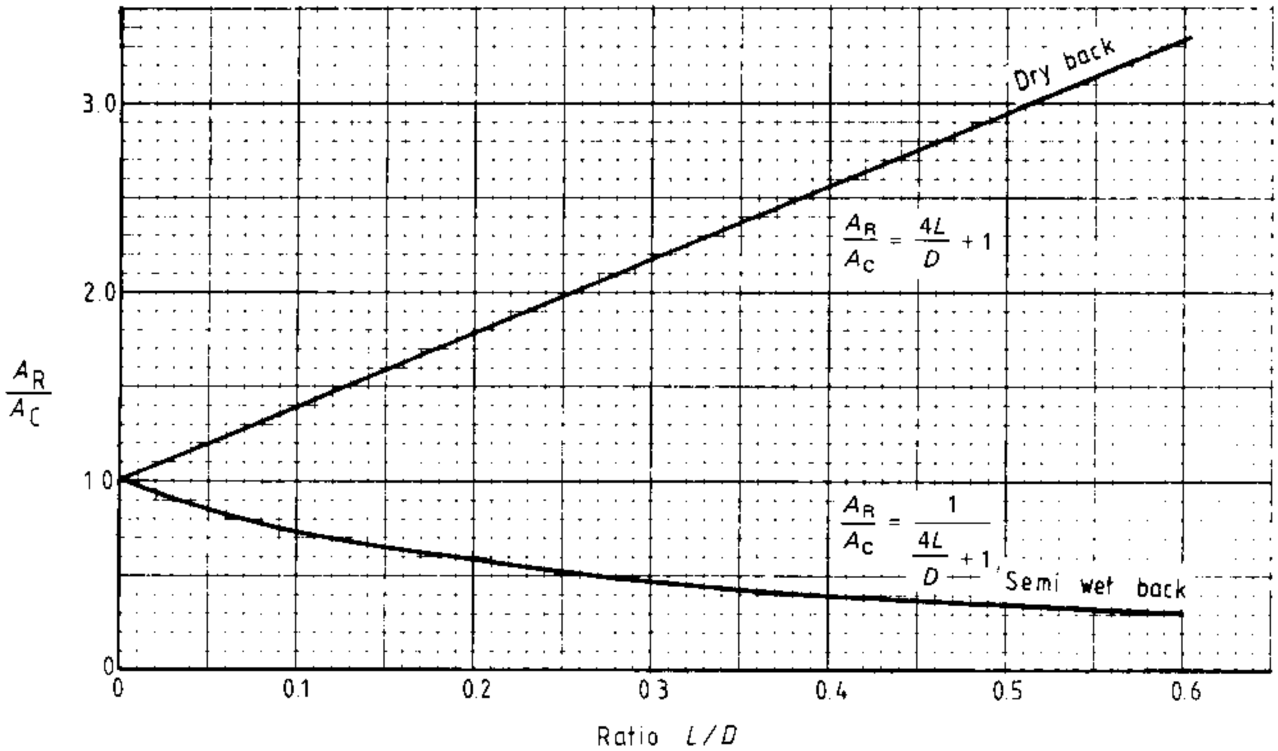
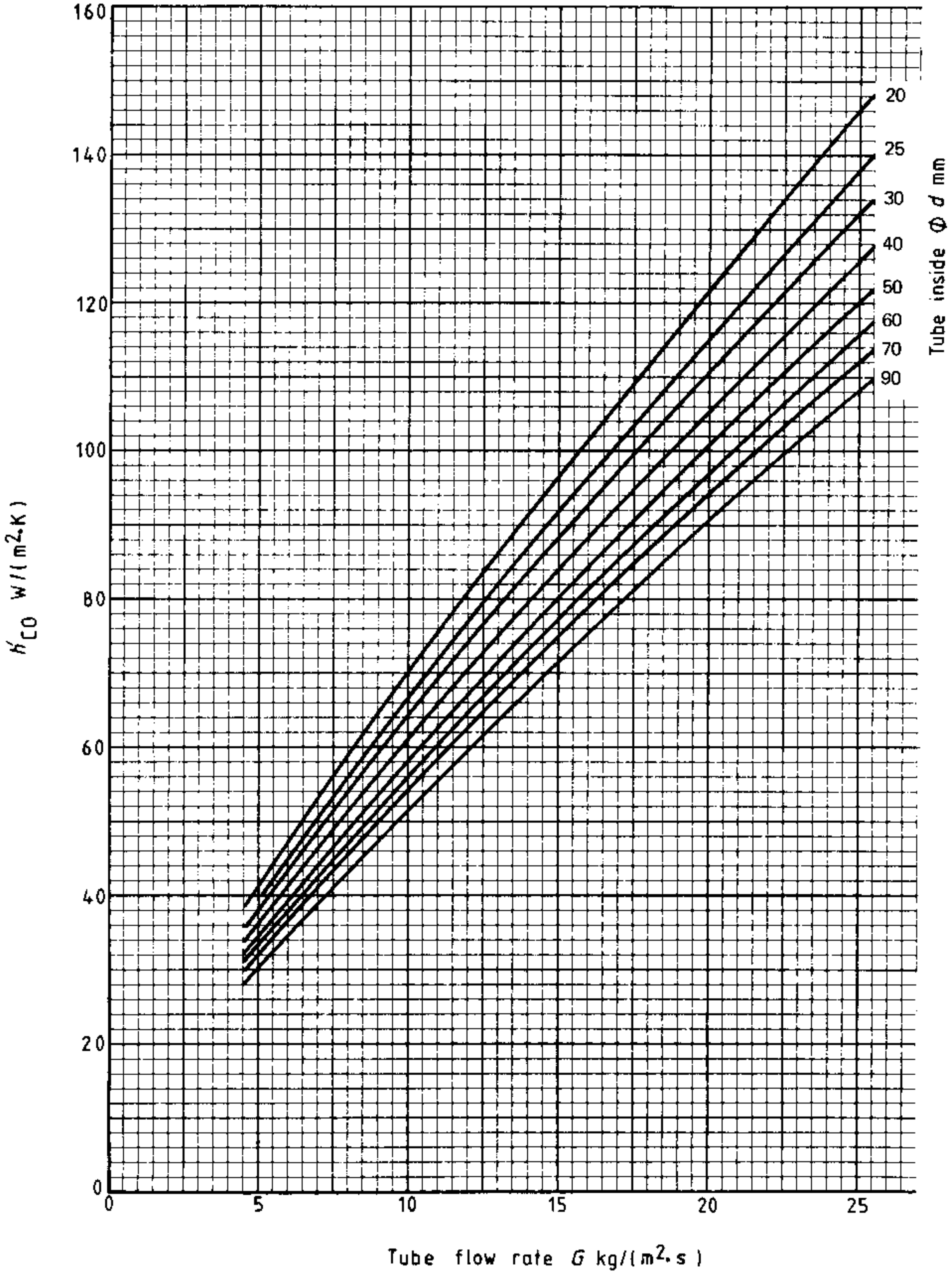


Figure C(3) — Ratio A_R/A_C for cylindrical chamber, diameter D, length L



NOTE $h'_{CO} = 20.2 \dfrac{G^{0.8}}{d^{0.2}}$

Figure C(4) — Basis convection coefficient h'_{CO}

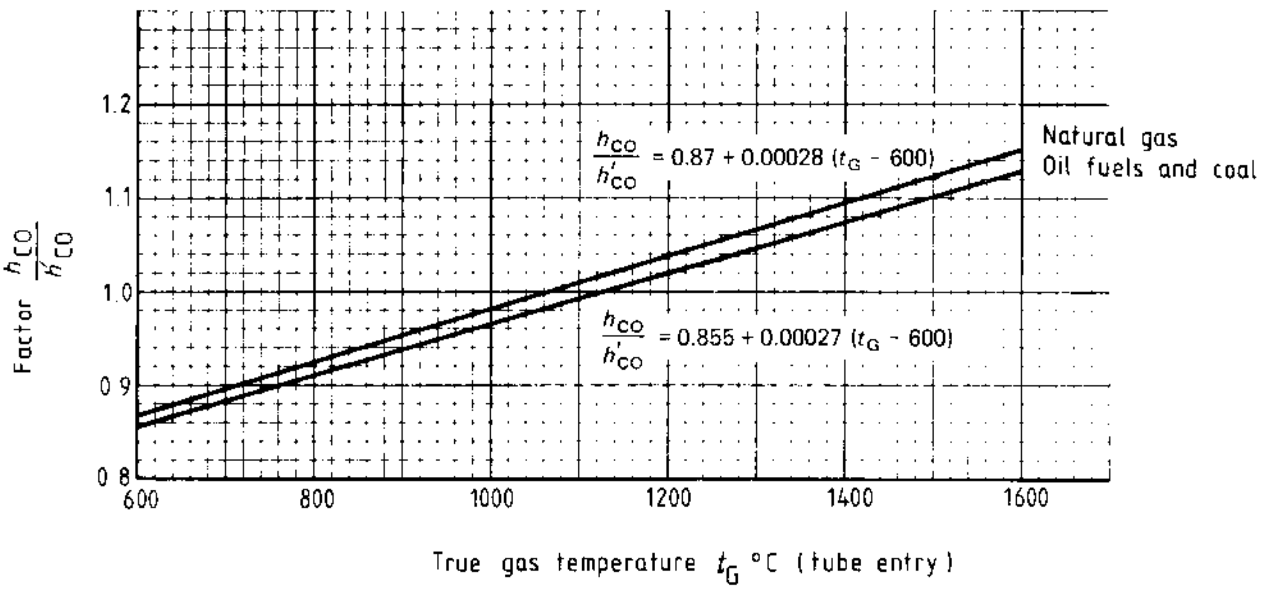


Figure C(5) — Determination of correction factor h_{CO}/h'_{CO}

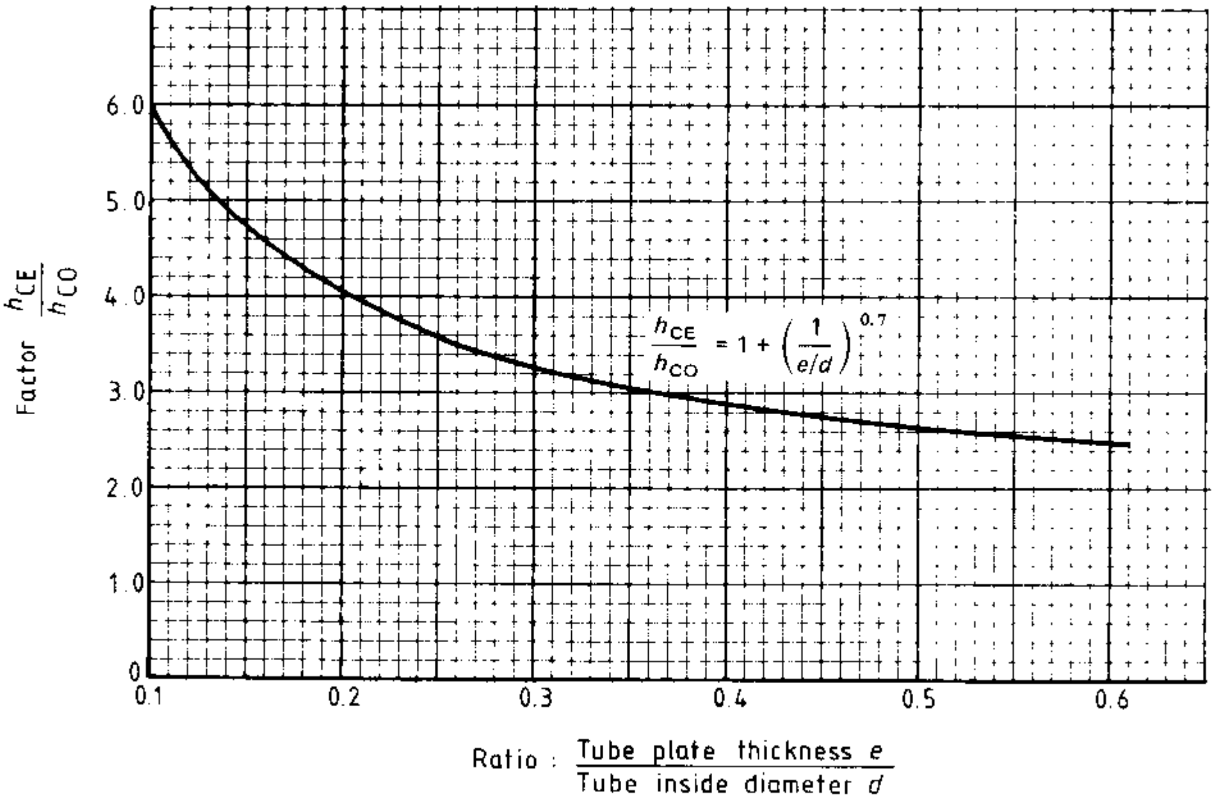


Figure C(6) — Determination of correction factor h_{CE}/h_{CO}

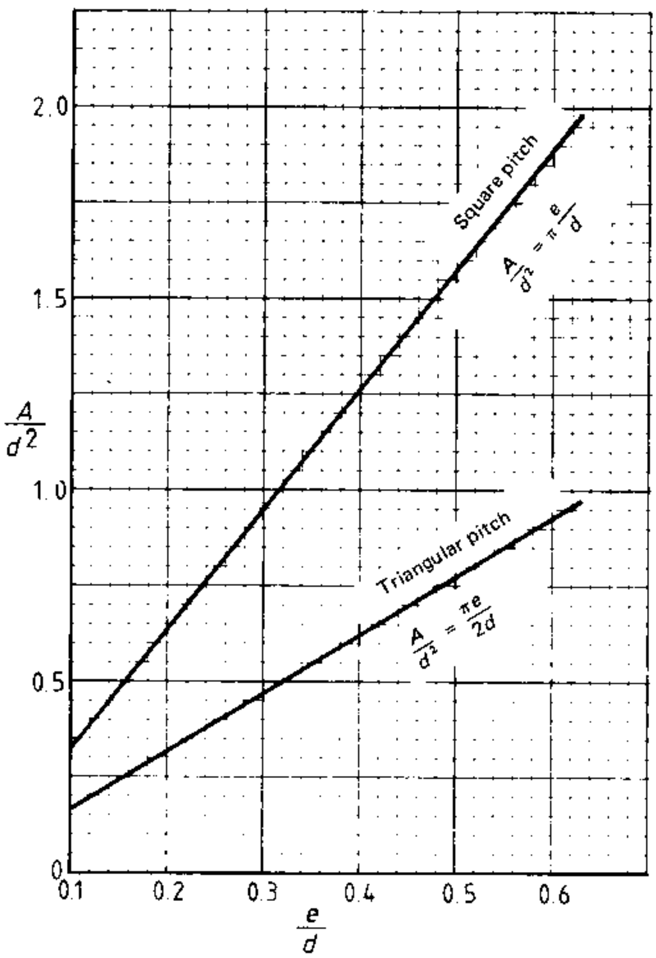


Figure C(7) — Non-dimensional tube area

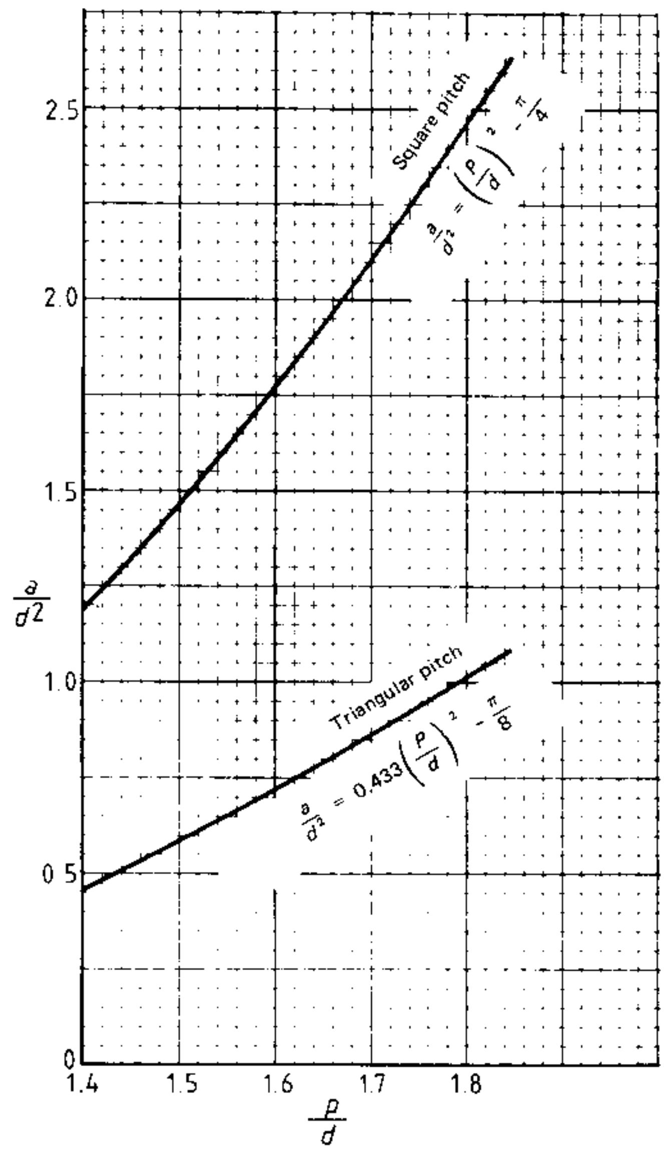


Figure C(8) — Non-dimensional plate area

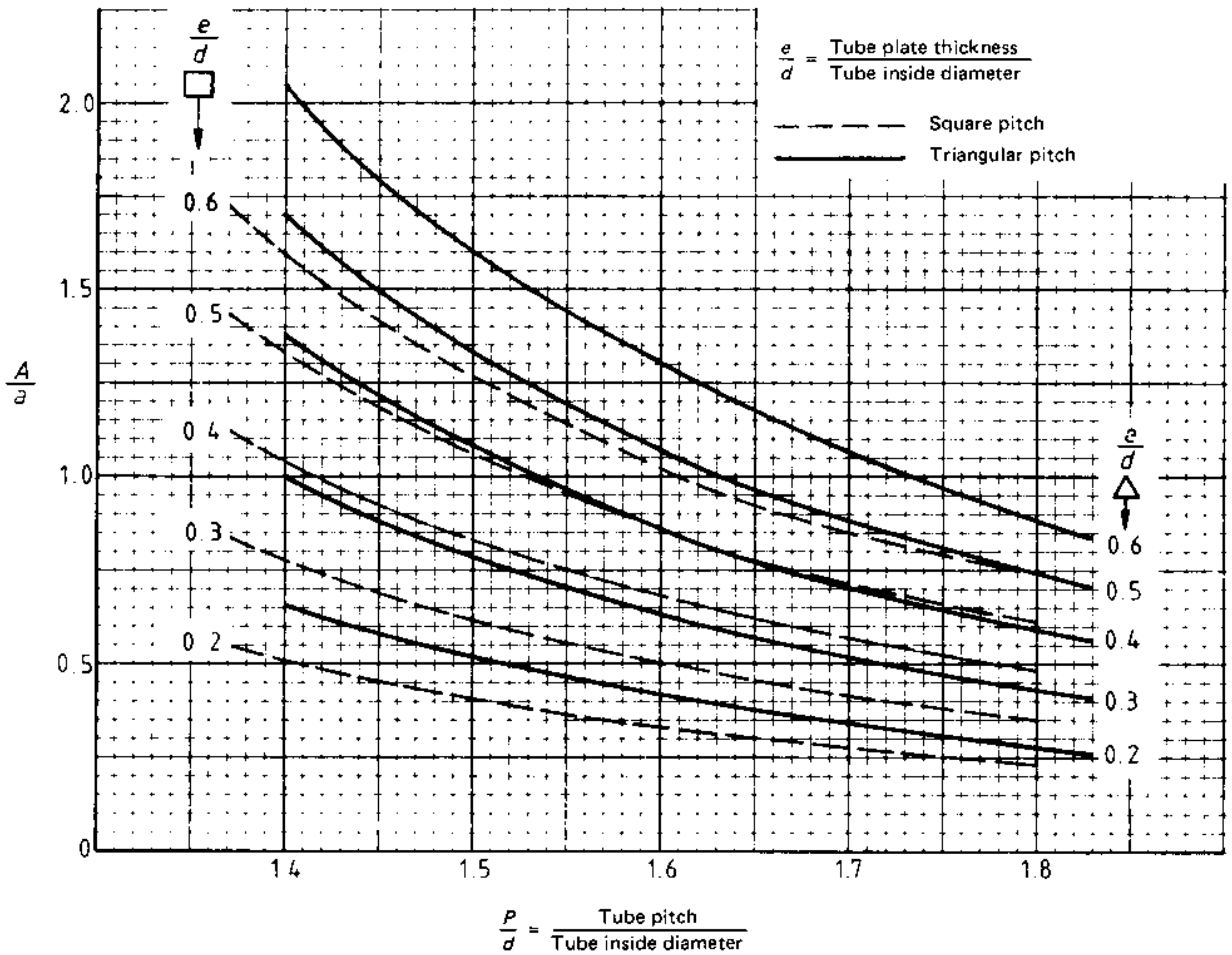


Figure C(9) — Tube/plate area ratio

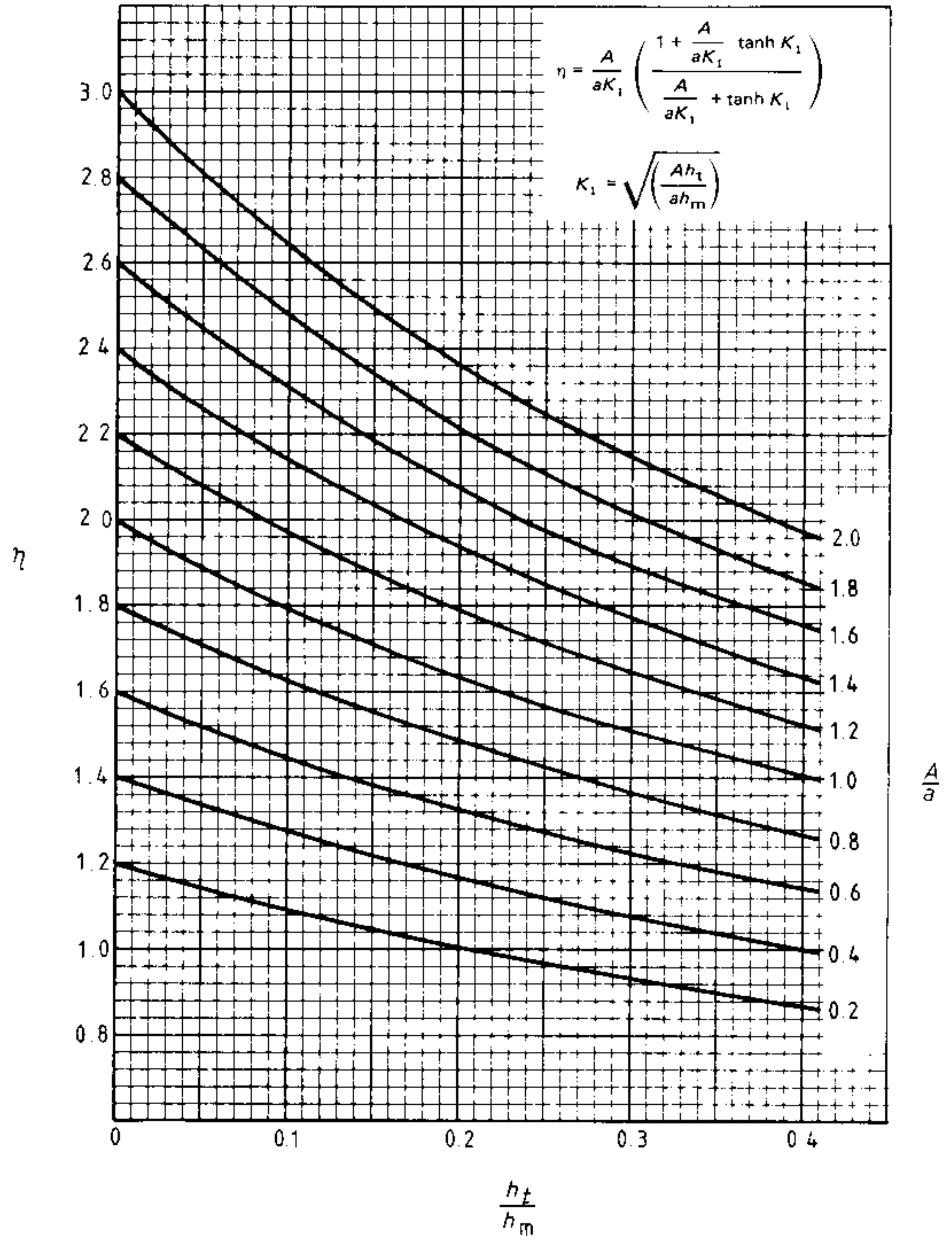


Figure C(10) — Factor η

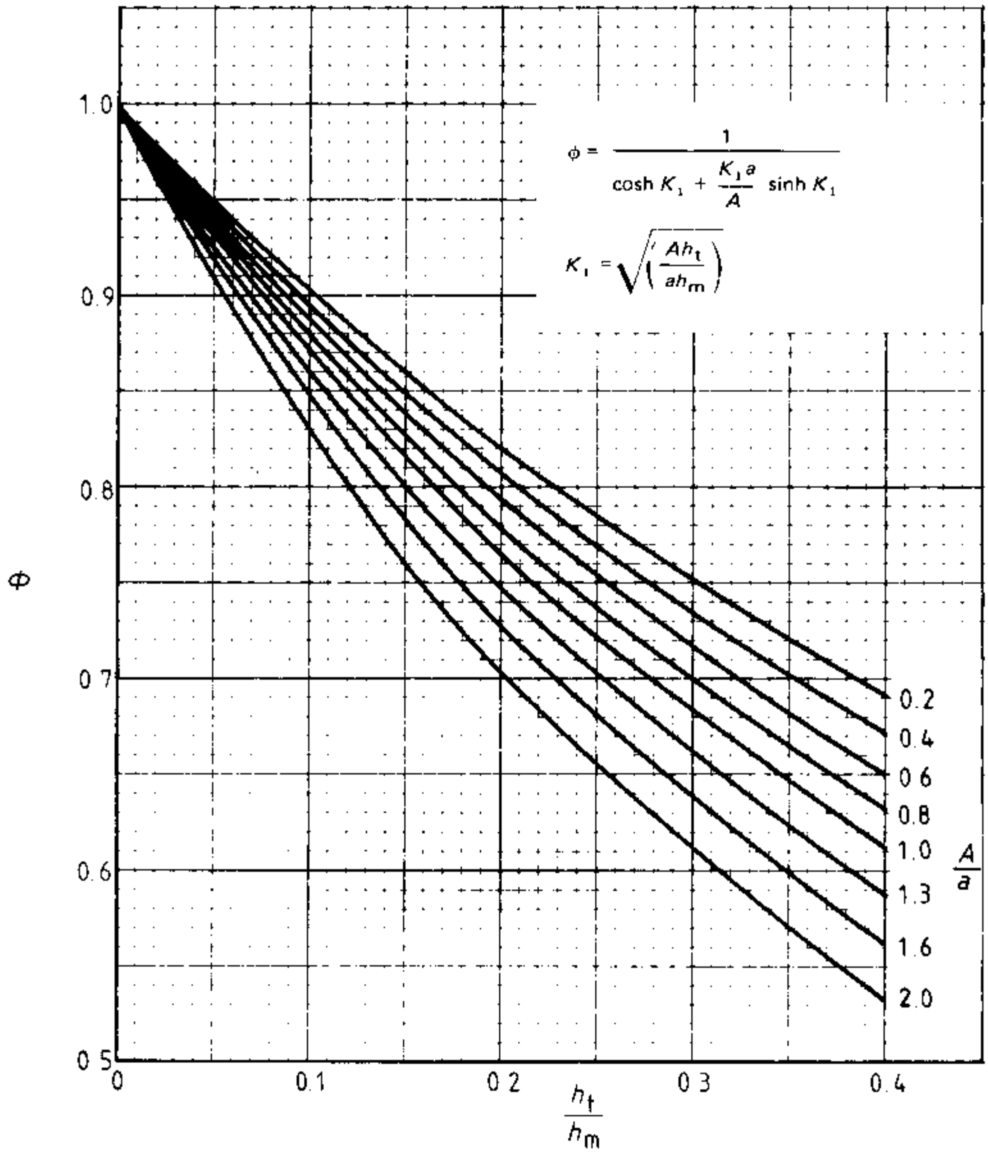


Figure C(11) — Factor ϕ

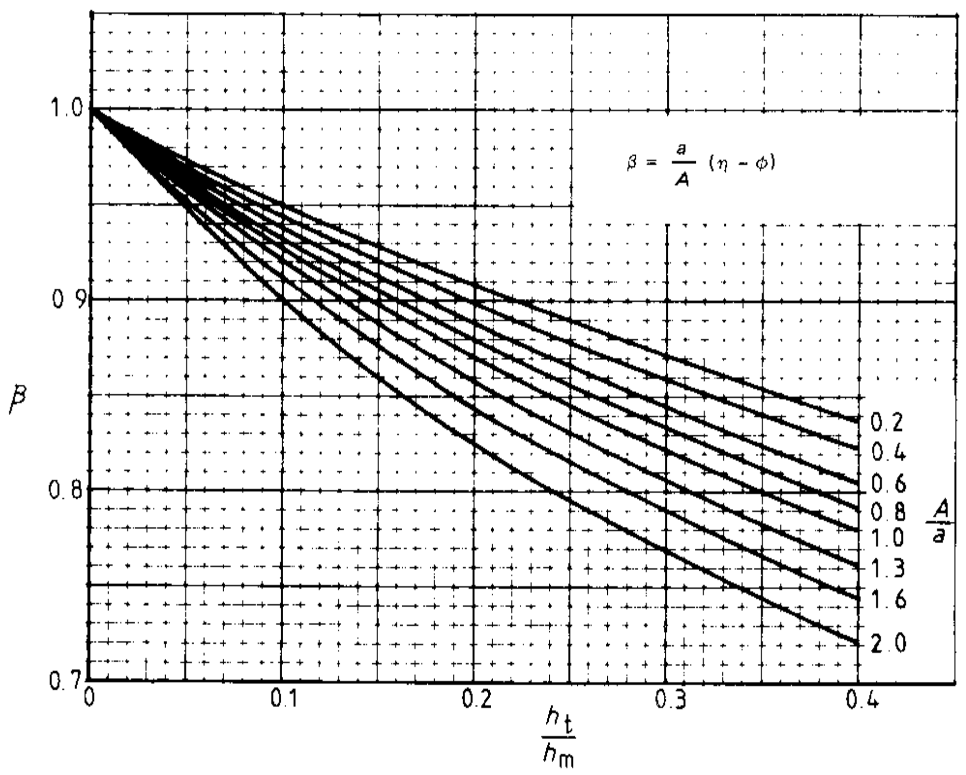


Figure C(12) — Factor β

Appendix D Boiler operation

D.1 Burner matching, control and maintenance

D.1.1 The formulation of the requirements and recommendations of this standard was carried out bearing in mind the need for satisfactory matching of a burner or burners to the boiler. The limitations on furnace heat input related to furnace diameter and on maximum calculated tube plate ligament metal temperature given in section three are intended to ensure reliable service of the boiler unit in an environment of good engineering control and maintenance. It is, therefore, important that the heat input for which the boiler is designed should not be exceeded in service.

D.1.2 It is also important that combustion quality is maintained throughout the life of the boiler in order to obtain efficient operation and to avoid damage to heat transfer surfaces. Particular attention is drawn to the effects of poor fuel/air mixing which can result in carbon monoxide, generated within the furnace tube, burning at the first tube pass entrance, causing increased metal temperature. A systematic maintenance programme to discover and correct the effects of wear, and loosening and fouling of the combustion equipment is recommended.

D.2 Feed and boiler water

D.2.1 *General.* The two main functions of a steam boiler are to transfer heat to the water to produce steam and to separate the steam from the water in the boiler. The boiler can only carry out these functions effectively if the qualities of the feed water and of the boiler water are properly controlled.

D.2.2 *Objectives of water treatment.* The objectives of water treatment are to keep those parts of the plant that are in contact with water and steam clean and intact and to facilitate the production of clean steam. The selection, application and control of water treatment should be consistent with these aims.

Steel in contact with water or steam quickly forms upon its surface a film of iron oxide which may or may not be protective. Water treatment to prevent corrosion should so adjust the quality of the water that a film of protective oxide is maintained.

D.2.3 *Filling the boiler*. On initial start up and on subsequent refilling after the boiler and/or system have been drained down, the boiler and system should be filled only with fully treated water. If the system is a large one, it may be advisable to fill with demineralised water. Before filling the system and boiler, the water should be analysed and the pH and oxygen scavenger content should be adjusted to conform with Table 2 of BS 2486:1978. Neglect of this has been known to cause serious failures with hot water boilers.

D.2.4 *Contact with the atmosphere.* It is not correct to assume that a hot water system is fully closed. There will be some leakages from the system thus requiring make-up and, at some stage, system water may be in contact with the atmosphere, e.g. in a header tank or over-flow vessel. The requirements for feed water and boiler water in BS 2486 should be followed.

D.2.5 *Deposits.* Impurities introduced into the boiler with feed water can produce scale or other deposits which impede the transfer of heat and may restrict the flow of water. In addition to reducing boiler efficiency, either effect leads to insufficient cooling of the metal heat transfer surface which may then become so hot that it is no longer strong enough to withstand the operating pressure. Deposits may also lead to corrosion by shielding the underlying metal from protective conditions in the water or steam.

D.2.6 *Scale.* Calcium, magnesium and silicon compounds are the main constituents and can form scales of widely differing characteristics with thermal conductivities varying from 216 to 3 450 $W \cdot mm/(m^2 \cdot K)$. In practice this means that some silicon based scales of only 0.1 mm thickness can impede the transfer of heat as effectively as a calcium sulphate scale 1.6 mm thick. It is therefore important that any scale build-up is detected and removed as soon as possible. It is essential that the cause also be investigated and corrected as in many instances it is not possible to determine the composition of the scale without chemical analysis. Some silicon-based scales are almost invisible to the naked eye and are detected more easily by the use of a special instrument.

D.2.7 *Foam*

D.2.7.1 There is always a small unavoidable degree of carry-over of water with the steam generated from a boiler. However, under certain conditions when contaminants are present the boiler water may foam badly and this can cause the following difficulties.

a) Gross carry-over of boiler water into the steam main can occur. Traps may be overloaded and pipes flooded leading to a dangerous water hammer. Slugs of water travelling at speeds approaching one hundred and fifty kilometres an hour can cause serious damage.

b) Float switches are designed to float in water not in foam. Lockout of the boiler may result from malfunctioning of float switches.

c) Foam in contact with heated surfaces does not conduct heat away from them as effectively as water. The boiler metal may overheat, perhaps dangerously.

D.2.7.2 Causes of foam include the following.

a) Detergents, oils, and fats.

b) Excessive alkalinity (this can cause other problems, e.g. chemical attack on gauge glasses).

c) Suspended solids.

d) High total dissolved solids content.

D.2.8 *Corrosion.* Corrosion is most commonly due to the presence of oxygen in the boiler water and it is therefore necessary to ensure that the oxygen content of the feed water is at the lowest possible level. The use of hot feed water and, where economically feasible, the installation of deaeration equipment is recommended, but in all cases a suitable oxygen scavenging agent should be present in reserve in the boiler water at all times, even when the boiler is idle.

D.3 Some modes of failure

D.3.1 Overheating in a boiler can be caused by shortage of water following the failure of water level controls to operate correctly, the accumulation of scale and internal deposits, which can affect the satisfactory operation of water level controls, or the use of contaminated feed water. The following damage can result.

a) Collapse or deformation of the furnace, sometimes resulting in rupture of the plate in the location of the bulged area or tearing at the end plate connections.

b) Collapse or deformation of the reversal chamber in a wet back boiler.

c) Hogging or sagging of smoke tubes.

d) Leakage from tube expansions.

e) Cracking of welds and of tube ends at the tube plate attachments.

f) Bulging of tube plates and cracking of ligaments.

D.3.2 Lack of oxygen scavenging of the boiler water can result in severe pitting and wasting internally and cracking at areas of maximum stress concentration such as at the toes of the internal fillet welds of end plate to furnace and shell connections.

Boiler cracking can occur, due to a combination of causes, including oxygen attack. As a boiler cools, a partial vacuum can be created resulting in air being drawn in. This can be eliminated by following correct shut-down procedures which should include closing steam valves.

D.3.3 If boilers are used on hot water service, gas-side corrosion can occur if care is not taken to avoid dewpoint conditions.

D.3.4 High metal temperature at the entrance to the first tube pass owing to incomplete combustion can cause cracking of tube plate ligaments and cracking of welds and tube ends at the tube plate attachments.

D.4 Bibliography

1. *The treatment of water for shell boilers,* Shell Boiler Group of the PGCA[3)]

2. Guidance Note PM5: *Safe operation of automatically controlled steam and hot water boilers,* Health and Safety Executive[4)]

Appendix E Recommendations for access and internal inspection

The provision of adequate inspection and cleaning facilities should be considered as an integral part of the design concept of a boiler and internal components, wherever practicable, should be designed and arranged so that they do not prevent adequate inspection being carried out.

In particular good inspection facilities should be provided for all corner joints, such as the shell and furnace attachments to the boiler end plates, subject to high bending moments and for all components, such as furnace and reversal chamber crowns, subject to high heat flux.

For boilers that are capable of being entered it is recommended that a clear space of 400 mm be provided above or below the manhole to permit axial traverse of the bottom of the boiler or axial traverse above the tube nest.

It is recommended also that, if the design pressure permits, the distance between the centre stay bars below the manhole be not less than 400 mm.

Where necessary a vertical clear space not less than 200 mm wide should be provided between the tube nests above the furnace to permit inspection of the furnace and reversal chamber crowns.

Where internal access is not provided or is only partially provided a sufficient number of head-holes, hand-holes or sight holes should be positioned so that a general view of the furnace and reversal chamber crowns can be obtained.

Boilers should be installed so that entry and inspection openings are readily accessible.

3) Obtainable from the Power Generation Contractors Association, Westminster Tower, 3 Albert Embankment, London SE1 7SL.
4) Obtainable from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS.

Appendix F Example of a calculation, carried out in accordance with Appendix G of BS 5500:1991, to determine the shell stresses for a boiler with leg supports

NOTE All references in this Appendix to BS 5500 refer to the 1991 edition.

F.1 Design data assumed [see also Figure F(1)]

Material	BS 1501-151 grade 430A
Boiler mass fully flooded	15 000 kg
Design pressure (P)	1.38 N/mm^2
Internal diameter (corroded) (D_i)	1 800 mm
Mean radius (r)	906 mm
Length between end plates (L)	4 000 mm
Distance from the centre of support to the mid-length of the boiler (d)	1 250 mm
Circumferential length of the loaded area (2 C_ϕ)	320 mm
Axial length of the loaded area ($2C_x$)	400 mm
Shell thickness (corroded) (t)	12 mm
Design stress (f)	120 N/mm^2

F.2 Limits of applicability (see also **G.2.2** of BS 5500). The condition that the length L is to be greater than r is satisfied where $L = 4\ 000 > r = 906$.

The condition that the distance A [see Figure F(1)] is to be not less than $r/2$ is satisfied where $A = 550 > r/2 = 453$.

The condition that the C_ϕ/r ratio is not to exceed the value derived from Figure G.2(0) of BS 5500 is satisfied where $C_\phi/r = 160/906 < 0.182$ from Figure G.2(0) of BS 5500 where $r/t = 906/12 = 75.5$.

F.3 Radial lead from support reaction

An approximate and conservative value for the radial lead, W shall be obtained from the formula $W = W_1/\cos\theta$, where W_1 is the vertical reaction at the support.

Using the approximate formula:

Reaction per support: $W_1 = 15\ 000 \times 0.25 = 3\ 750$ kg

$\sin\theta = \frac{600}{906} = 0.662$ therefore $\theta = 41.5\,°$ [see Figure F(1)]

Radial load: $W = \frac{3750}{\cos 41.5} = 5007$ kg $= 49\ 119$ N

NOTE At higher values of θ this formula may substantially over-estimate the radial lead and, if desired, a detailed analysis may be undertaken to establish a more accurate value. Such an analysis should consider the specific geometry of the support, its method of connection to the shell, and in cases where expansion of the shell between supports is subject to a degree of restraint, any arising thermally induced reaction force.

F.4 Determination of circumferential and longitudinal moments and membrane forces (see also **G.2.2.1.2** of BS 5500)

Equivalent length for off centre loading:

$$L_e = L - \left(\frac{4d^2}{L}\right) = 4000 - \left(\frac{4 \times 1250^2}{4000}\right) = 2437.5 \text{ mm}$$

Values required for application in Figures G.2(5) to G.2(8) of BS 5500:

$$64\frac{r}{t}\left(\frac{C_x}{r}\right)^2 = 64 \times \frac{906}{12}\left(\frac{200}{906}\right)^2 = 235.5$$

$$\frac{2C_x}{L_e} = \frac{400}{2437.5} = 0.164$$

$$\frac{C_\phi}{C_x} = \frac{160}{200} = 0.8$$

The quantities $M_ø/W$, M_x/W, $N_øt/W$, N_xt/W for values of $C_ø/C_x = 0.8$ and $64r/t\,(C_x/r)^2 = 235.5$ are obtained from Figures G.2(5) to G.2(8) of BS 5500. It is necessary to interpolate a value of $2C_x/L_e = 0.164$ between $2C_x/L_e = 0.05$ and $2C_x/L_e = 0.2$.

$\frac{M_\phi}{W} = 0.0524$ therefore $M_ø$ $= 0.0524 \times 49\,119$
$= 2\,574$ N mm/mm

$\frac{M_x}{W} = 0.0212$ therefore M_x $= 0.0212 \times 49\,119$
$= 1\,041$ N mm/mm

$\frac{N_\phi t}{W} = -\,0.0562$ therefore $N_ø$ $= -\,0.0562 \times \frac{49\,119}{12}$
$= -\,230$ N/mm

$\frac{N_\phi t}{W} = -0.101$ therefore N_x $= -\,101 \times \frac{49\,119}{12}$
$= -\,413.4$ N/mm

	Circumferential moment, $M\phi/W$ [see Figure G.2(5)]	Longitudinal moment, M_x/W [see Figure G.2(6)]	Circumferential membrane force, $N\phi\,t/W$ [see Figure G.2(7)]	Longitudinal membrane force, $N_x\,t/W$ [see Figure G.2(8)]
$\frac{2C_x}{L_e} = 0.05$	0.06	0.025	– 0.06	– 0.12
$\frac{2C_x}{L_e} = 0.164$	0.0524	0.0212	– 0.0562	– 0.101
$\frac{2C_x}{L_e} = 0.2$	0.05	0.02	– 0.055	– 0.095

F.5 Determination of stresses considering boiler fully flooded and no internal pressure (see also **G.2.2.1.2** of BS 5500)

F.5.1 *Membrane stresses.* These are calculated as follows:

$$\text{circumferential} = \frac{N_\phi}{t} = \frac{-\,230}{12} = -\,19.17\ \text{N/mm}^2$$

$$\text{longitudinal} = \frac{N_x}{t} = \frac{-\,413.4}{12} = -\,34.45\ \text{N/mm}^2$$

F.5.2 *Membrane plus bending stresses.* These are calculated as follows:

$$\text{circumferential}\ \frac{N_\phi}{t} \pm \frac{6M_\phi}{t^2}$$

$$= -\,19.17 \pm \frac{6 \times 2574}{12^2} = \begin{matrix} +88.08\ \text{N/mm}^2 \\ -126.42\ \text{N/mm}^2 \end{matrix}$$

$$\text{longitudinal} = \frac{N_x}{t} \pm \frac{6M_x}{t^2}$$

$$= -\,34.45 \pm \frac{6 \times 1041}{12^2} = \begin{matrix} +8.93\ \text{N/mm}^2 \\ -77.83\ \text{N/mm}^2 \end{matrix}$$

F.6 Effect of internal pressure. In **G.2.2.1.3** of BS 5500 it is stated that a conservative result will be obtained by adding the pressure stresses to those due to local loads.

From **B.3.2** of BS 5500:

circumferential stress (pressure)

$$= \frac{PR_i}{t} = \frac{1.38 \times 900}{12} = 103.50 \text{ N/mm}^2$$

longitudinal stress (pressure)

$$= \frac{PR_i^{\ 2}}{(2R_i + t)t} = \frac{1.38 \times 900^2}{(2 \times 900 + 12)12} = 51.41 \text{ N/mm}^2$$

NOTE The longitudinal stress (pressure) calculated as above does not take into account the effect of end-to-end staying and it is permissible to reduce the longitudinal stress (pressure) if necessary by applying the loaded area supported by the shell to evaluate the shell longitudinal stress due to pressure.

Therefore, the membrane plus bending plus pressure stresses are as follows:

circumferential = + 88.08 + 103.50 = + 191.58 N/mm^2
– 126.42 + 103.50 = – 22.92 N/mm^2

longitudinal = + 8.93 + 51.41 = + 60.34 N/mm^2
– 77.83 + 51.41 = – 26.42 N/mm^2

F.7 Allowable stress values. From **A.3.3.1** of BS 5500:

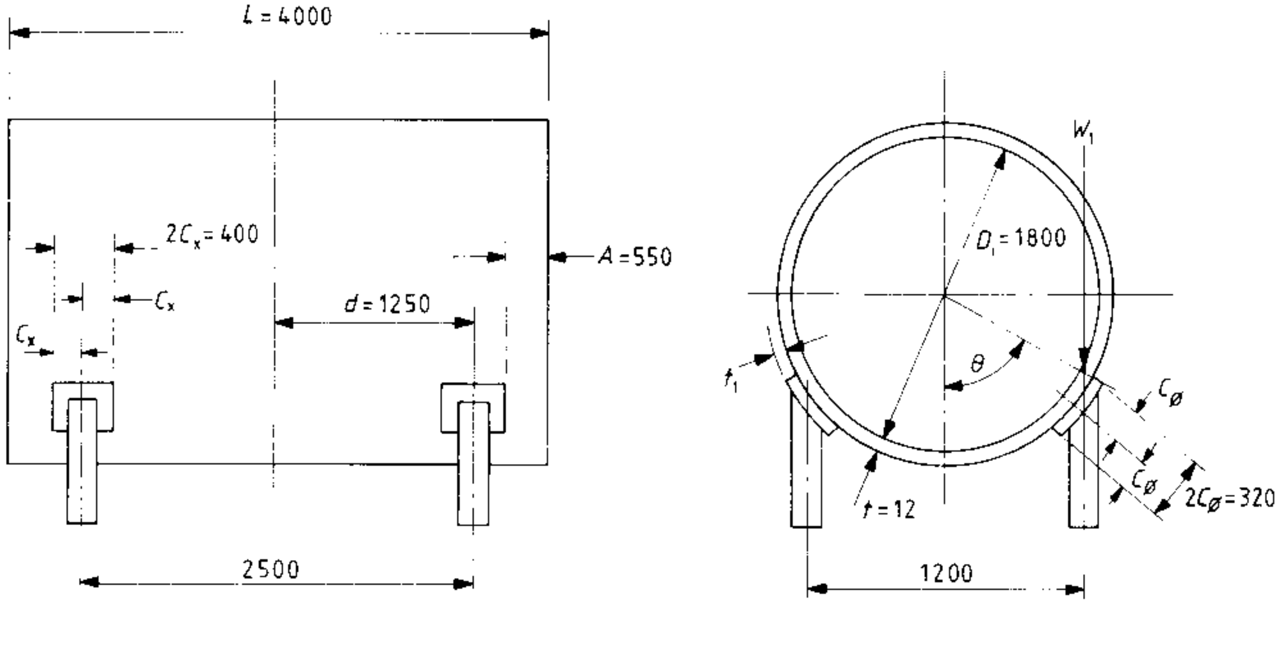
the membrane stress is not to exceed $1.2f = 1.2 \times 120 = 144$ N/mm^2;

the membrane plus bending stress is not to exceed $2f = 2 \times 120 = 240$ N/mm^2;

the membrane plus bending plus pressure stress is not to exceed $2f = 2 \times 120 = 240$ N/mm^2.

From **A.3.3.3** of BS 5500, the membrane plus bending stress (total compressive stress) is not to exceed $-0.9E_t = -0.9 \times 180 = -162$ N/mm^2, where E_t is as defined in **2.3.1**. Hence, all calculated stresses are within the limits specified.

F.8 Stresses in reinforcing plates (see also **G.3.1.5** of BS 5500). The stresses in the reinforcing plate which occur at the edge of the loaded area $2C\phi \times 2\ C_x$ corresponding to the leg dimensions should also be investigated. The stresses are calculated in a manner similar to the calculations in **F.1** to **F.7**, assuming a shell thickness of $(t + t_1)$, where t_1 is the thickness of reinforcing plate (in mm). It is assumed that the reinforcing plate and boiler shell share the moments $M\phi$ and M_x in proportion to the cube of their thicknesses and the membrane forces $N\phi$ and N_x in direct proportion to their thicknesses.



All dimensions are in millimetres.

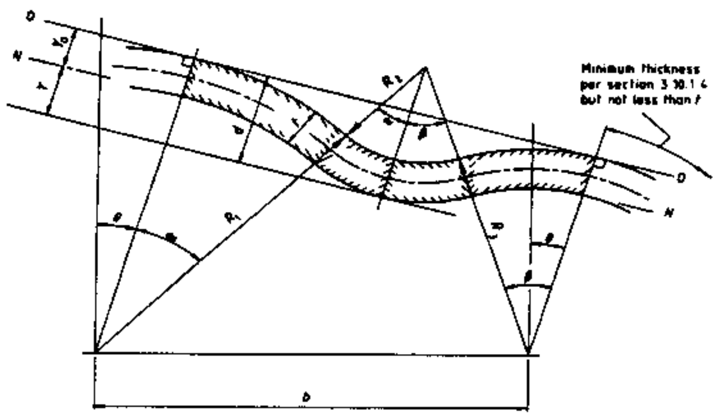
Figure F(1) — Assumed boiler dimensions for example of a calculation of the shell stresses in a boiler with leg supports

Appendix G Calculation of sustainable pressure for "Walker" type reversed curvature sections of non-circular reversal chambers

The following suggested working form presents a method whereby the sustainable pressure of reversed curvature sections of non-circular reversal chambers may be calculated as required by **3.10.2.1**.

Suggested working form — "Walker" type reverse curve sections or corrugations

Design pressure	=	N/mm²
Design temperature	=	°C
Design stress, f	=	N/mm²
R_1	=	mm
R_2	=	mm
R_3	=	mm
b	=	mm
t (corroded)	=	mm
distance between centres of support, L	=	mm



$r_1 = R_1 - t/2$ = mm	$r_2 = R_2 + t/2$ = mm	$r_3 = R_3 - t/2$ = mm

$\theta = \sin^{-1}\left(\frac{r_1 - r_3}{b}\right)$ = °

$\alpha = 90 - \cos^{-1}\left[\frac{(r_1 + r_2)^2 + b^2 - (r_2 + r_3)^2}{2\,(r_1 + r_2)\,b}\right] - \theta$ = °

$\beta = 90 - \cos^{-1}\left[\frac{(r_2 + r_3)^2 + b^2 - (r_1 + r_2)^2}{2\,(r_2 + r_3)\,b}\right] + \theta$ = °

$d = r_2 - (r_1 + r_2)\cos\alpha + r_1 + t$ = mm

considering areas of each section

$a_1 = r_1\,\alpha\,\frac{t\,\pi}{180}$ = mm²	$a_3 = r_2\,\beta\,\frac{t\,\pi}{180}$ = mm²
$a_2 = r_2\,\alpha\,\frac{t\,\pi}{180}$ = mm²	$a_4 = r_3\,\beta\,\frac{t\,\pi}{180}$ = mm²
$A = \Sigma a$ = mm²	

for positions of centroids

$Y_1 = r_1 + t/2 - \frac{\sin\alpha}{\alpha} \times \frac{2}{3}\left[\frac{(r_1 + t/2)^3 - (r_1 - t/2)^3}{(r_1 + t/2)^2 - (r_1 - t/2)^2}\right]\frac{180}{\pi}$ = mm

$Y_2 = d - r_2 - t/2 + \frac{\sin\alpha}{\alpha} \times \frac{2}{3}\left[\frac{(r_2 + t/2)^3 - (r_2 - t/2)^3}{(r_2 + t/2)^2 - (r_2 - t/2)^2}\right]\frac{180}{\pi}$ = mm

$Y_3 = d - r_2 - t/2 + \frac{\sin\beta}{\beta} \times \frac{2}{3}\left[\frac{(r_2 + t/2)^3 - (r_2 - t/2)^3}{(r_2 + t/2)^2 - (r_2 - t/2)^2}\right]\frac{180}{\pi}$ = mm

$Y_4 = r_3 + t/2 - \frac{\sin\beta}{\beta} \times \frac{2}{3}\left[\frac{(r_3 + t/2)^3 - (r_3 - t/2)^3}{(r_3 + t/2)^2 - (r_3 - t/2)^2}\right]\frac{180}{\pi}$ = mm

moments about O – O

$Y_0 = \frac{a_1 Y_1 + a_2 Y_2 + a_3 Y_3 + a_4 Y_4}{\Sigma a}$ = mm	$Y = d - Y_0$ = mm

for second moments of area about neutral axis N – N

$I_1 = \left[\frac{\alpha\pi}{90} + \sin 2\alpha\right] \times \left[\frac{(r_1 + t/2)^4 - (r_1 - t/2)^4}{16}\right] - a_1\,(r_1 + t/2 - Y1)^2 + a_1\,(Y_0 - Y_1)^2$ = mm⁴

$I_2 = \left[\frac{\alpha\pi}{90} + \sin 2\alpha\right] \times \left[\frac{(r_2 + t/2)^4 - (r_2 - t/2)^4}{16}\right] - a_2\,(r_2 + t/2 - d + Y_2)^2 + a_2\,(Y_2 - Y_0)^2$ = mm⁴

$I_3 = \left[\frac{\beta\pi}{90} + \sin 2\beta\right] \times \left[\frac{(r_2 + t/2)^4 - (r_2 - t/2)^4}{16}\right] - a_3\,(r_2 + t/2 - d + Y_3)^2 + a_3\,(Y_3 - Y_0)^2$ = mm⁴

$I_4 = \left[\frac{\beta\pi}{90} + \sin 2\beta\right] \times \left[\frac{(r_3 + t/2)^4 - (r_3 - t/2)^4}{16}\right] - a_4\,(r_3 + t/2 - Y_4)^2 + a_4\,(Y_0 - Y_4)^2$ = mm⁴

$I_n = \Sigma I$ = mm⁴

$P_{max} = \frac{8\,f\,I_n}{Y\,L^2\,b\cos\theta}$ = N/mm²	If $P_{max} > P_{design}$ then the section under consideration is acceptable

BS 2790:1992 Specification for design and manufacture of shell boilers of welded construction

Enquiry Cases — Introduction

In accordance with the provisions of **1.5**, the publication of Enquiry Cases will be notified in *BSI Update* and will be made available for inclusion in the ring-binder in a separate section following the text of the specification and the appendices.

The table below is for recording cases as they are published and included in the binder, and for noting their subsequent routeing.

In general, cases will be extant, as adjuncts to the standard and open to public comment, until the text of the standard is amended to incorporate the substance of particular cases. This will be done in the course of the normal updating procedure and each case so dealt with will be recorded on the relevant amendment.

When a new edition of the standard is published, embracing all previously issued amendments, the relevant enquiry cases will be removed from the list and only those remaining extant, as described above, will be referred to. Consequently, the numerical sequence of Enquiry Case number in the first column will not be continuous because of these omissions.

Enquiry Case No.	**Date of publication**	**Subject of the Enquiry Case**	**Subsequent Enquiry Case routeing** (e.g. incorporated in BS 2790)	**Summary of pages**	
				Page No	**Issue**
2790/15	March 1986	Allowable stresses in shells under hydraulic test conditions at boiler supports		163	2
2790/23	April 1988	Ultrasonic examination of welds		165	
2790/26	July 1993	Incorporation of design temperature in boiler making		167	
2970/27	July 1993	Furnace stiffening rings		169	
2790/28	July 1996	Weld production control test plates		171-173	

Enquiry Case 2790/15

Allowable stresses in shells under hydraulic test conditions at boiler supports

Enquiry

The shell design stress used in the Appendix F sample calculation is derived from the 250 °C minimum mean metal temperature requirement of **3.1.3.2**. Is it permissible when considering the fully flooded hydraulic test condition to derive an allowable design stress based upon the material yield strength property at 20 °C?

Reply

No.

All boilers should be considered fully flooded at the design temperature which should not be taken as less than 250 °C.

The reference standard, BS 5500 has no explicit limit on local stresses in shells at supports under hydraulic test conditions; the stress limits in Appendix A of BS 5500 apply to design conditions.

blank

Enquiry Case 2790/23

Ultrasonic examination of welds

Enquiry

BS 3923-1:1986 refers to Examination Levels based on the use of a 3 mm hole, whereas BS 2790:1986 refers to specific defect sizes for acceptance purposes. Can the committee give guidance as to how to proceed when the BS 2790:1986 defect size limit is less than 3 mm.

Reply

Until further data becomes available, as an interim solution it is recommended, subject to agreement between the manufacturer and Inspecting Authority, that either Table 5.7 of BS 2790:1986 or an Examination Level in BS 3923:1986 appropriate to the defect size limit of Table 5.7 in BS 2790:1986, be applied.

blank

Enquiry Case 2790/26
Incorporation of design temperature in boiler marking

Enquiry

Item g) of **7.3.2** of BS 2790:1992 requires that any other necessary particulars shall be marked on a boiler. In the UK, Regulation 5(4) and Schedule 4 of the Pressure Systems and Transportable Gas Containers Regulations (PSR 1989) apply. Item 7 of Schedule 4 is "the design temperature". Noting that several different design temperatures may apply to the various elements within a shell boiler, advice is requested on how compliance with the legal requirements may be achieved.

Reply

The committee recognizes the difficulty presented by the wording of PSR 1989 Regulation 5(4) and Schedule 4 in relation to the case of shell boilers. It does not however have the authority or competence to make a legally binding determination of this issue.

The committee can however advise its opinion that the intent of the regulation in respect to design temperature might be met by including in the marking the following primary information:

a) for steam boilers, the saturation temperature corresponding to the design pressure;

b) for hot water boilers, the design outlet water temperature.

The committee is further of the opinion that design temperatures for individual elements of a steam boiler are generally derived from, or supplemental to, this primary information, and that marking of such temperatures, which may in any case be impracticable, should not be essential to meet the intent of the regulation.

blank

Enquiry Case 2790/27
Furnace stiffening rings

Enquiry

The requirements for furnace stiffening rings are contained in **3.10.1.9** of the standard, but the material requirements are not. Do stiffening rings have to be manufactured from the same material as that for the furnace to which they are attached?

Reply

No. Stiffening rings can be manufactured from a different material, providing it conforms to **2.1** of the standard.

blank

Enquiry Case 2790/28
Weld production control test plates

Enquiry

5.4.6 of the standard defines the number of test plates that are required and **5.4.7** defines the associated levels of destructive testing.

The draft European Standard for shell boiler manufacture also defines these requirements.

For consistency, should the requirements of section 9 of the draft EN Shell Boiler standard be adopted for these items?

The requirements for weld production control test plates for class III boilers are not clearly defined in BS 2790. Can this also be clarified at the same time?

Reply

Yes. The requirements of the draft EN Shell Boiler standard can be adopted as follows.

Production control test plates

In order to control the continuing quality of the manufacture and the compliance of the mechanical properties of the welded joints with the specification, test plates should be welded to the boiler plates prior to commencement of the production weld.

For Class I boilers with a weld factor of $v = 1.0$ the material for the production control test plates should be from the same batch of plates as the shell plates, and for Class II boilers with a weld factor $v = 0.85$ the material for the production control test plates should be to the same specification as the shell plates local to the seam being welded.

When Class II boilers are manufactured along with Class I boilers and are welded to the same procedure, destructive tests are not required for the Class II boilers, provided that sufficient test plates are produced to cover the total length of welding involved.

Production control test plates are not required for Class III boilers.

A production control test plate only applies to main shell longitudinal and circumferential welds.

Production control test plates for longitudinal seams should be welded as a continuation of a longitudinal seam weld.

If so desired, production control test plates may be provided at both ends of a longitudinal seam, in which case the dimensions of the test plates should be sufficient to take the required test specimens out of one of them and the specimens for any necessary re-testing out of the other.

The test plates should be supported or reinforced during the welding in order to prevent undue warping.

The test plates should be subjected to the same heat treatment as required for the work piece to which they belong.

Test plates which have warped during welding may be straightened at a temperature below the temperature of heat treatment of the shell to which they belong. Straightening should be done before final heat treatment.

Frequency of testing

The frequency of testing of production control test plates should be as follows:

a) one test plate per boiler in the case of υ = 1.0 (Class I);

b) one test plate per 100 m of longitudinal joints which are welded to the same procedure in the case of υ = 0.85 (Class II);

c) one test plate per year, where the circumferential seams are welded to a procedure different to the longitudinal seams.

NOTE 1 If the circumferential welds are made to the same procedure as the longitudinal welds, no test plates need be provided for the circumferential seams.

NOTE 2 After 10 test plates have successfully passed the tests, testing may be reduced to the following:

a) one test plate per 100 m of longitudinal joints which are welded to the same procedure in the case of υ = 1.0 (Class I);

b) one test plate per 1 000 m of longitudinal joints which are welded to the same procedure in the case of υ = 0.85 (Class II);

c) one test plate per year, where the circumferential seams are welded to a procedure different to the longitudinal seams.

If the circumferential welds are made to the same procedure as the longitudinal welds no test plates need be provided for the circumferential seams.

Destructive testing of test plates

The number and type of test specimens to be taken from the test plate are dependent on the plate thickness and are derailed in Table 1, and the symbols for the table are given in Table 2.

Table 1 — Number and type of specimens

Plate thickness mm	Specimens
$e \leq 12$	1-FB, 1-RB, 1-MA
$12 < e \leq 35$	3-IW, 1-MA
$35 < e \leq$	3-IW, 1-TT, 1-LT, 1-MA

Table 2 — Symbols

Designation	Symbol
Face bend test to BS EN 910	FB
Root bend test to BS EN 910	RB
Transverse tensile test to BS EN 895	TT
Longitudinal tensile test to BS EN 876	LT
Impact test, weld to BS EN 875	IW
Impact test, HAZ to BS EN 875	IH
Macro examination	MA

Test plates should be of sufficient size to allow for the required number of specimens, including an allowance for re-tests.

The results of all tests should be recorded. If any test specimen shows an unsatisfactory result, the reason for the failure should be investigated and two re-test specimens should be prepared and tested. If it can be shown that the failure has resulted from a local or accidental defect and the re-test results are satisfactory, the re-test results should be accepted.

Re-tests

Production factors may result in scatter of mechanical test results which may occasionally fall below the agreed specification level. Where individual tests do not comply with the above requirements, the reasons for this failure should be investigated and if no unacceptable imperfections are found the following re-tests should be made:

a) tensile test: two re-tests;

b) bend test: two re-tests;

c) impact test: three additional tests.

Should any of the re-tests fail to comply with these requirements, then the joints/boiler represented by the test plate should be deemed not to be in compliance with this standard.

Publications referred to

BS 10, *Specification for flanges and bolting for pipes, valves and fittings (obsolescent).*

BS 21, *Specification for pipe threads for tubes and fittings where pressure-tight joints are made on the threads (metric dimensions).*

BS 499, *Welding terms and symbols.*

BS 499-1, *Glossary for welding, brazing and thermal cutting.*

BS 639, *Specification for covered carbon and carbon manganese steel electrodes for manual metal-arc welding.*

BS 709, *Methods of destructive testing fusion welded joints and weld metal in steel.*

BS 759, *Valves, gauges and other safety fittings for application to boilers and to piping installations for and in connection with boilers — Part 1: Specification for valves, mountings and fittings.*

BS 806, *Specification for design and construction of ferrous piping installations for and in connection with land boilers.*

BS 970, *Specification for wrought steels for mechanical and allied engineering purposes.*

BS 970-1, *General inspection and testing procedures and specific requirements for carbon, carbon manganese, alloy and stainless steels.*

BS 1113, *Specification for design and manufacture of water-tube steam generating plant (including superheaters, reheaters and steel tube economizers).*

BS 1387, *Specification for screwed and socketed steel tubes and tubulars and for plain end steel tubes suitable for welding or for screwing to BS 21 pipe threads.*

BS 1501, *Steels for fired and unfired pressure vessels: plates.*

BS 1501-1, *Specification for carbon and carbon manganese steels (withdrawn).*

BS 1502, *Specification for steels for fired and unfired pressure vessels: sections and bars.*

BS 1503, *Specification for steel forgings for pressure purposes.*

BS 1560, *Circular flanges for pipes, valves and fittings (class designated).*

BS 1560-3.1, *Specification for steel flanges.*

BS 2486, *Recommendations for treatment of water for land boilers.*

BS 2600, *Radiographic examination of fusion welded butt joints in steel.*

BS 2600-1, *Methods for steel 2 mm up to and including 50 mm thick.*

BS 2600-2, *Methods for steel over 50 mm up to and including 200 mm thick.*

BS 2910, *Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes.*

BS 3059, *Steel boiler and superheater tubes.*

BS 3059-1, *Specification for low tensile carbon steel tubes without specified elevated temperature properties.*

BS 3059-2, *Specification for carbon, alloy and austenitic stainless steel tubes with specified elevated temperature properties.*

BS 3601, *Specification for carbon steel pipes and tubes with specified room temperature properties for pressure purposes.*

BS 3602, *Steel pipes and tubes for pressure purposes: carbon and carbon manganese steel with specified elevated temperature properties.*

BS 3602-1, *specification for seamless and electric resistance welded including induction welded tubes.*

BS 3602-2, *Specification for longitudinally arc welded tubes.*

BS 3920, *Derivation and verification of elevated temperature properties for steel products for pressure purposes.*

BS 3920-1, *Method for driving the minimum elevated temperature yield or proof stress properties when data on a minimum of 50 casts are available.*

BS 3923, *Ultrasonic examination of welds.*

BS 3923-1, *Methods for manual examination of fusion welds in ferritic steels.*

BS 3971, *Specification for image quality indicators for industrial radiography (including guidance on their use).*

BS 4490, *Methods for micrographic determination of the grain size of steel.*

BS 4504, *Circular flanges for pipes, valves and fittings (PN designated).*
BS 4504-3.1, *Specification for steel flanges.*
BS 4870, *Specification for approval testing of welding procedures.*
BS 4870-1, *Fusion welding of steel (withdrawn).*
BS 4871, *Specification for approval testing of welders working to approved welding procedures.*
BS 4871-1, *Fusion welding of steel (withdrawn).*
BS 4882, *Specification for bolting for flanges and pressure containing purposes.*
BS 5044, *Specification for contrast aid paints used in magnetic particle flaw detection.*
BS 5135, *Specification for arc welding of carbon and carbon manganese steels.*
BS 5289, *Code of practice for visual inspection of fusion welded joints.*
BS 5500, *Specification for unfired fusion welded pressure vessels.*
BS 5750, *Quality systems.*
BS 5996, *Methods for ultrasonic testing and specifying quality grades of ferritic steel plate.*
BS 6072, *Method for magnetic particle flaw detection.*
BS 6443, *Method for penetrant flaw detection.*
BS 6693, *Diffusible hydrogen.*
BS 6693-2, *Method of determination of hydrogen in manual metal-arc weld metal.*
BS 6759, *Safety valves.*
BS 6759-1, *Specification for safety valves for steam and hot water.*
BS EN 287, *Approval testing of welders for fusion welding.*
BS EN 287-1, *Steels.*
BS EN 288, *Specification and approval of welding procedures for metallic materials.*
BS EN 288-3, *Welding procedure tests for the arc welding of steels.*
BS EN 10002, *Tensile testing of metallic materials.*
BS EN 10002-1, *Method of test at ambient temperature.*
BS EN 10002-5, *Method of test at elevated temperatures.*
BS EN 10028, *Flat products made of steel for pressure purposes.*
BS EN 10028-2, *Non-alloy and alloy steels with specified elevated temperature properties.*
BS EN 10045, *Charpy impact test on metallic materials.*
BS EN 10045-1, *Test method (V- and U-notches).*
Standards significant to Health and Safety at work[5)]
Welding steels without hydrogen cracking, F.R. Coe[6)].

[5)] Published by the Health and Safety Executive and obtainable from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS.
[6)] Published by and obtainable from The Welding Institute, Research Laboratory, Abington Hall, Abington, Cambs. CB1 6AL.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: 020 8996 7002. Fax: 020 8996 7001.

BSI
389 Chiswick High Road
London
W4 4AL