BRITISH STANDARD

BS 1113:1999

Incorporating Corrigenda Nos. 1 and 2

Specification for

Design and manufacture of water-tube steam generating plant (including superheaters, reheaters and steel tube economizers)

ICS 27.040

Committees responsible for this British Standard

This British Standard has been prepared by Technical Committee PVE/2, Water-tube boilers, upon which the following bodies were represented:

Electricity Association
Engineering Equipment and Materials Users' Association
Health and Safety Executive
Lloyd's Register of Shipping
Power Generation Contractors' Association
Safety Assessment Federation
UK Steel Association

This British Standard, having been prepared under the direction of the Engineering Sector Board, was published under the authority of the Standards Board and comes into effect on 15 November 1999

First published July 1943
Second edition March 1951
Third edition December 1958
Fourth edition March 1969
Fifth edition April 1985
Sixth edition January 1989
Seventh edition January 1992
Eighth edition January 1998
Ninth edition November 1999

The following BSI references relate to the work on this standard:
Committee reference PVE/2

ISBN 0 580 33079 6

Amendments issued since publication

Amd. No.	Date	Text affected
10880 Corrigendum	April 2000	Updates Foreword, sidelining and minor printing errors
12026 Corrigendum	October 2000	Updates Section 1, Figure 3.6.2.1-1 and Table 4.5.4

Contents

		Page
Committees responsible		Inside front cover
Foreword		viii
Summary of pages		xi
Section 1. General		
1.1	Scope	1/1
1.2	Interpretation	1/2
1.3	Definitions	1/2
1.4	Responsibilities	1/3
1.4.1	Responsibilities of the purchaser	1/3
1.4.2	Responsibilities of the manufacturer	1/3
1.4.3	Responsibilities of the Inspecting Authority	1/3
1.5	Information and requirements to be agreed and to be documented	1/3
1.5.1	Information to be supplied by the purchaser	1/3
1.5.2	Requirements to be agreed and documented	1/4
Section 2. Materials and design stresses		
2.1	Materials	2/1
2.1.1	General	2/1
2.1.2	Materials for pressure parts	2/1
2.1.3	Materials for non-pressure parts	2/2
2.2	Design stresses	2/2
2.2.1	General	2/2
2.2.2	Terminology	2/2
2.2.3	Time-independent design stresses for carbon, carbon manganese and low alloy steels	2/3
2.2.4	Time-independent design stresses for austenitic steels	2/3
2.2.5	Time-dependent design stresses	2/3
2.2.6	Cast steels	2/3
2.2.7	Design temperature	2/3
2.2.8	Design lifetime	2/4
Section 3. Design		
3.1	General	3/1
3.2	Metal wastage	3/1
3.3	Cylindrical shells of drums and headers	3/2
3.3.1	Shell thickness	3/2
3.3.2	Basic calculation	3/2
3.3.3	Ligament efficiency	3/3
3.3.4	Combined stresses in drum or header shells	3/5
3.3.5	Boiler drum supports	3/6
3.3.6	Other stresses in cylindrical shells	3/6
3.4	Openings and branches in cylindrical shells and integral pipes	3/7
3.4.1	General	3/7
3.4.2	Notation	3/7
3.4.3	Application	3/7
3.4.4	Design of isolated openings and branch connections	3/8
3.4.5	Design of groups of openings and branches	3/11
3.4.6	Reinforcing pads	3/12
3.4.7	Branches	3/12

		Page
3.4.8	Studded connections	3/12
3.4.9	Screwed connections into shell	3/12
3.4.10	Screwed socket connections	3/12
3.4.11	Socket welded connections	3/12
3.5	Headers of rectangular section	3/13
3.5.1	Thickness of straight headers	3/13
3.5.2	Corner radius of straight headers	3/14
3.5.3	Headers of rectangular section which are not straight	3/14
3.6	Ends of drums and headers	3/14
3.6.1	Dished ends	3/14
3.6.2	Flat ends of headers	3/16
3.6.3	Branches and connections	3/17
3.7	Tubes and integral pipes	3/17
3.7.1	Thickness of straight tubes and integral pipes	3/17
3.7.2	Tube bends	3/17
3.7.3	Integral pipe bends	3/17
3.7.4	Flexibility of integral piping systems	3/19
3.7.5	Structural attachments to tubes	3/19
3.7.6	Fitting and jointing of tubes	3/20
3.7.7	Joints in integral piping	3/20
3.8	Pressure parts of irregular shape	3/20
Section 4. Manufacture and workmanship		
4.1	Pressure parts	4/1
4.1.1	Drums	4/1
4.1.2	Headers and similar pressure parts	4/1
4.1.3	Material identification	4/1
4.1.4	Marking	4/1
4.2	Cutting, forming and fabrication tolerances	4/1
4.2.1	Cutting of material	4/1
4.2.2	Forming of drums, headers and ends	4/2
4.2.3	Forming of integral piping bends	4/2
4.2.4	Forming and bending of tubes	4/3
4.2.5	Fabrication tolerances	4/5
4.3	Welding	4/7
4.3.1	General	4/7
4.3.2	Welded joints and connections	4/9
4.4	Mechanical connections	4/11
4.4.1	General	4/11
4.4.2	Access openings	4/11
4.4.3	Branches and standpipes	4/12
4.4.4	Tubes and integral pipes	4/12
4.4.5	External or internal non-pressure part attachments	4/13
4.5	Thermal treatment	4/13
4.5.1	General	4/13
4.5.2	Heat treatment associated with forming operations	4/14
4.5.3	Preheating	4/17

		Page
4.5.4	Post-weld heat treatment (for stress relief)	4/17
4.5.5	Heat treatment of test materials	4/20
4.5.6	Heat treatment of production test plates	4/20
4.5.7	Local adjustment of components	4/20
Section 5. Inspection and testing		
5.1	Inspection during construction	5/1
5.1.1	General	5/1
5.1.2	Welded drums and headers	5/1
5.1.3	Seamless drums and headers	5/1
5.1.4	Tubes and integral piping	5/2
5.1.5	Completed boiler unit	5/2
5.2	Approval of fusion welding procedures	5/2
5.2.1	Approval	5/2
5.2.2	Performance	5/2
5.2.3	Substantiation	5/2
5.2.4	Additional tests	5/2
5.2.5	Procedures	5/2
5.2.6	Flash butt welding	5/2
5.2.7	Welded water-wall panels	5/2-A
5.2.8	Previous approval	5/2-A
5.2.9	Additional requirements	5/2-A
5.3	Welder and welding operator approval	5/2-A
5.4	Production control test plates for boiler drums	5/2-A
5.5	Details of destructive tests for boiler drum production control test plates	5/3
5.5.1	General	5/3
5.5.2	Transverse tensile test	5/3
5.5.3	All weld tensile test at elevated temperature	5/3
5.5.4	Macro-examination	5/3
5.5.5	Root bends (for all welds made from one side only)	5/4
5.5.6	Side bend test (for plate > 10 mm thickness)	5/4
5.5.7	Charpy V-notch impact test	5/4
5.5.8	Retests of production test plate tensile and bends tests	5/4
5.6	Non-destructive examination of components	5/4-A
5.6.1	General requirements	5/4-A
5.6.2	Ultrasonic examination	5/4-B
5.6.3	Non-destructive examination reports	5/4-C
5.7	Extent of non-destructive examination and acceptance standards for parent materials	5/5
5.7.1	General	5/5
5.7.2	Examination of, and standards of acceptance for, plates for drums	5/6
5.7.3	Examination of, and standards of acceptance for, forgings for drum courses and drum nozzles	5/6
5.7.4	Examination of, and standards of acceptance for, headers, pipes and tubes	5/6

		Page
5.7.5	Examination of, and standards of acceptance for, steel castings for pressure purposes	5/7
5.8	Extent of non-destructive examination for welds	5/7
5.8.1	Boiler drums	5/7
5.8.2	Headers	5/7
5.8.3	Tubes and integral piping	5/7
5.9	Standards of acceptance	5/8
5.9.1	General requirements	5/8
5.9.2	Visual examination	5/8
5.9.3	Surface flaw detection	5/8
5.9.4	Radiographic examination	5/8
5.9.5	Ultrasonic examination	5/8
5.10	Hydrostatic pressure tests	5/14
5.10.1	General	5/14
5.10.2	Hydrostatic test pressure for completely assembled boilers	5/14
5.10.3	Hydrostatic tests on individual components	5/14
5.10.4	Test procedure	5/14
5.10.5	Repaired components	5/14
Section 6. Documentation and marking		
6.1	Documents	6/1
6.2	Certificate of conformity	6/1
6.3	Marking	6/1
Section 7. Valves, gauges and fittings		
7.1	General	7/1
7.2	Safety valves	7/1
7.2.1	General	7/1
7.2.2	Discharge capacity	7/1
7.2.3	Installation of safety valves	7/1
7.2.4	Drainage and discharge piping	7/2
7.3	Water level gauges	7/2
7.4	Water level or low water flow alarms	7/2
7.5	Connecting pipes for water level fittings	7/2
7.6	Pressure gauges	7/2
7.7	Boiler feedwater valves	7/2
7.8	Boiler blowdown and drain mountings	7/2
7.8.1	General	7/2
7.8.2	Continuous and automatic blowdown mountings	7/3
7.8.3	Drains	7/3
7.8.4	Safety arrangements	7/3
7.9	Boiler main stop valves	7/3

		Page
Annexes		
A	Design stresses for British Standard materials	A/1
B	Example of the design of a boiler drum	B/1
C	Recommended forms of connections	C/1
D	Basis of the design charts for openings and branches	D/1
E	Area replacement design method	E/1
F	*Text deleted*	
G	Inspection and testing facilities	G/1
H	Tube bending procedure tests (normative)	H/1
J	Manufacture of welded tubewalls (informative)	J/1
Tables		
2.1.2	List of materials covered by BS EN material standards	2/5
3.4.4a	Design values of t_r/T_r for flush nozzles in cylindrical shells ($0 < d/D < 0.3$)	3/9
3.4.4b	Design values of t_r/T_r for protruding nozzles in cylindrical shells ($0 < d/D < 0.33$)	3/10
3.4.4c	Design values of CT_r/T at $t_r/T_r = 0$ for nozzles in cylindrical shells	3/10
3.7.1.1	Minimum thickness of straight tubes	3/17
3.7.3	Minimum bending radii for pipes of thickness determined by **3.7.3.1**	3/18
4.2.3	Requirement for heat treatment of cold bent ferritic pipes	4/3
4.2.4.6	Post-bend heat treatment applicable to cold formed tube bends	4/5
4.2.5.4.1	Alignment tolerances of tube bores	4/6-A
4.3.1.1.4	Spacing for welding	4/7
4.4.4.2	Belling dimensions for tubes propulsively expanded	4/12
4.5.2.2	Heat treatment type and temperature ranges for ferritic pipe bends	4/15
4.5.2.3	Heat treatment of tube bends	4/16
4.5.3.1-1	Recommended preheating temperatures for thermal-cutting of plates, forgings, castings, tubes and pipes	4/17
4.5.3.1-2	Recommended preheating temperatures for welding of plates, forgings, castings, tubes and pipes	4/18
4.5.4	Post-weld heat treatment	4/28
5.4.2	Specimens required for production control test plates for boiler drums	5/3
5.6.1.3-1	Extent of NDE of boiler drums	5/4-D
5.6.1.3-2	Extent of NDE of headers	5/4-D
5.6.1.3-3	Extent of NDE of tubes and pipes	5/4-E
5.9.2	Acceptance criteria for weld surface imperfections	5/9
5.9.4	Acceptance criteria for volumetric imperfections in welds found by radiography	5/11
A.1	Design stress values (N/mm^2)	A/2
B.3	Properties of the cross-section	B/2
H.2.3	Examples of validity range	H/2
J.3.2.3	Limits of weld imperfections in fin to tube welds	J/5

		Page
Figures		
3.3.3.2	Compensation of welded tube stub	3/21
3.3.3.4	Irregular drilling	3/22
3.3.3.5-1	Spacing of holes on a diagonal line	3/22
3.3.3.5-2	Regular saw-tooth pattern of holes	3/22
3.3.3.5-3	Efficiency of ligaments along a diagonal line	3/23
3.3.3.5-4	Regular staggering of holes	3/24
3.3.3.5-5	Efficiency of ligaments between holes	3/25
3.3.4.4	Determination of ligament efficiency on diagonal line	3/26
3.4.2-1 **3.4.2-2**	Notation applicable to cylinders	3/26
3.4.4-1	Design curves for flush nozzles in cylindrical shells ($0 < d/D < 0.3$)	3/27
3.4.4-2	Design curves for flush nozzles in cylindrical shells ($0.2 < d/D \leq 1.0$)	3/28
3.4.4-3	Design curves for protruding nozzles in cylindrical shells ($0 < d/D < 0.33$)	3/29
3.4.4-4 **3.4.4-5** **3.4.4-6**	Notation applicable to cylinders	3/30
3.4.4-7	Modified protruding branch compensation	3/31
3.4.4-8	Modified flush branch compensation	3/32
3.4.4-9 **3.4.4-10**	Notation applicable to cylinders	3/33
3.4.4-11	Rims	3/34
3.4.5-1	Arrangement factor g	3/34
3.4.5-2	Branch compensation	3/35
3.5.1-1	Notation for ligaments in rectangular headers	3/36
3.5.1-2	Notation for rectangular headers	3/36
3.6.1-1	Typical dished ends	3/37
3.6.1-2	Shape factor K	3/38
3.6.1-3	Openings in ends	3/39
3.6.1-4	Limits of reinforcement	3/39
3.6.2.1-1	Factor C for header ends with butt weld in shell	3/40
3.6.2.1-2	Factor C for header ends with tee butt weld	3/41
3.6.2.1-3	Coefficient Z for non-circular flat ends	3/42
3.7.5.1	Typical structural attachments to tubes	3/43
3.7.5.3	Allowable attachment loading	3/44
3.7.7.4	Socket welds	3/46
4.2.4.5	Limits of departure from circularity	4/21
4.2.5.4.2	Angular alignment of butt welded tubes	4/21
4.3.2.1-1	Butt welds in plates of unequal thickness	4/22
4.3.2.1-2	Butt welds with offset of median lines	4/23
4.4.2.4-1	Fillet-welded manhole frame	4/24
4.4.2.4-2	Fusion-welded manhole frame	4/24
4.5.1.1.3-1	Length of branch, nozzle or stub subjected to post-weld heat treatment	4/25
4.5.1.1.3-2	Minimum heated band widths for local heat treatment	4/26
4.5.4.1.3	Typical examples of controlling thickness	4/27

		Page
B.3	Position of tube holes in drum	B/4
C.1	Transverse and longitudinal sections of branch connections	C/1
C.2	Standard weld preparation details	C/2
C.3	Weld details for set-in branches	C/3
C.4	Set-on branches	C/4
C.5	Set-on branches	C/5
C.6	Set-on branches	C/7
C.7	Set-on branches	C/8
C.8	Set-on branches	C/9
C.9	Set-on branches	C/10
C.10	Set-in branches: fillet welded connections	C/11
C.11	Set-in branches: partial penetration butt-welded connections	C/12
C.12	Set-in branches: full penetration connections	C/13
C.13	Set-in branches: full penetration connections	C/14
C.14	Set-in branches: full penetration connections with asymmetrical butt joints	C/15
C.15	Set-in branches: full penetration connections welded from one side only	C/16
C.16	Forged branch connections	C/17
C.17	Forged branch connections	C/18
C.l8	Set-on branches with added compensation plates	C/19
C.l9	Set-on branches with added compensation plates	C/20
C.20	Studded connections	C/21
C.21	Socket welded and screwed connections	C/23
C.22	Minimum dimensions for external profile of welds at branches: class 1 welding	C/24
E.2	Compensation of welded branch or standpipe	E/2
J.1.2	Examples of tubewall construction	J/2
J.3.2.2-1	Weld requirements for fin to tube welds	J/3
J.3.2.2-2	Allowable excessive convexity for fin to tube welds	J/4
J.4	Allowable misalignment for fin to tube welds	J/6

Foreword

This British Standard, first published in 1943 under the title 'Water tube boilers and their integral superheaters' and subsequently revised in 1951, 1958, 1969, 1985, 1989, 1992 and 1998 has been prepared under the direction of the Engineering Sector Board. This edition supersedes the 1998 edition, which is withdrawn.

The 1969 edition incorporated the requirements of ISO/R 831 published by the International Organization for Standardization (ISO). The 1985 edition deviated from these requirements and incorporated a number of developments from BS 5500. Most of these developments, and particularly the adoption of stress tables incorporating a range of design lifetimes related to the creep rupture properties of the material, were subjects of amendments to the 1969 edition. Where design stresses in the creep range were significantly different from those hitherto used successfully, provision was made for alternative design stresses to be used in conjunction with a 'continued service' review at a specified fraction of the design life.

This approach recognized the limitations inherent in any simple design method for boiler components operating in the creep range and also provides a flexible basis that might be used in cases where the design stress values, which have been derived from ISO data, are significantly different from those used with success in the past.

Whilst recognizing that in practice the operating life of a component designed on a time-dependent basis might be extended beyond design lifetime, this aspect of plant operation was recognized as being under the control of the plant owner and therefore outside the scope of this standard. It is the subject of other British Standard publications.

The 1998 edition introduced many of the manufacturing practices contained in the draft European Standard currently being developed by CEN/TC 269.

These were:

– forming of drums, headers, and ends;

– forming and bending of tubes and associated procedure tests;

– manufacture of welded tubewalls;

– modification of seal welding requirements;

– modification of post weld heat treatment requirements;

– modification of production control test plate requirements;

– modification of hydrostatic pressure test requirements.

In addition, steel 91 tubes and pipes had been incorporated into table 2.1.2.

Safety valve clauses had been modified to remove ambiguities in the UK requirements.

This 1999 edition has been issued to incorporate several additional manufacturing and inspection requirements from the proposed European Standard on water-tube boilers, where they can be introduced without major changes and will be of an economic advantage to users of this British Standard.

They include:

– incorporation of EN materials;

– design considerations for welding;

– welder procedure and welder approval requirements;

– production control test plates; and

– non-destructive examinations.

This new edition should ease the introduction of the European Standard on water-tube boilers when it is published.

Because of the wide range of types of water-tube steam generating plant that may be designed and manufactured in accordance with this 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.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people. It is recognized that clauses concerning inspection facilities and testing facilities which have traditionally been incorporated into boiler standards are a contractual matter. Nevertheless their importance is such that the purchaser in agreeing a contract should not overlook them. These clauses are reproduced in annex G.

Technical changes, made since the last amendment of this standard was published, are indicated by a sideline in the margin. Presentational changes have not been marked in this way.

The purchaser is recommended, as an aid to demonstrating the boiler supplier's capability of achieving the required quality level, to specify in the contract, that the manufacturer operates a quality system in compliance with the appropriate parts of BS EN ISO 9000.

This standard is included in the list of 'Standards significant to health and safety at work' published by the UK Health and Safety Executive (HSE) and is also referred to by HSE in giving guidance.

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.

blank

Summary of pages

This standard is kept up to date by the issue, from time to time, of replacement or additional pages. Each replacement or added page will carry a copyright date indicating its date of issue.

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

The following table identifies the current issue date of each page.

Page No.	Issue date
Front cover	10-2000
Inside front cover	10-2000
i	10-2000
ii to viii	11-1999
ix	10-2000
x	*blank*
xi to xii	10-2000
Section 1	
1/1	1998
1/2	04-2000
1/3	11-1999
1/4	10-2000
1/5	10-2000
1/6	*blank*
Section 2	
2/1	11-1999
2/2	04-2000
2/3 to 2/7	11-1999
2/8	*blank*
Section 3	
3/1 to 3/3	1998
3/4	04-2000
3/5 to 3/10	1998
3/11	11-1999
3/12	04-2000
3/13 to 3/16	1998
3/17	04-2000
3/18	1998
3/19	1998
3/20	04-2000
3/21 to 3/39	1998
3/40	10-2000
3/41 to 3/46	1998
Section 4	
4/1	1998
4/2 to 4/4	04-2000
4/5 to 4/6-A	11-1999
4/6-B	*blank*
4/7	04-2000
4/7-A	11-1999
4/7-B	*blank*
4/8	1998
4/9	1998
4/10	11-1999
4/11	1998
4/12	04-2000
4/13	04-2000
4/14	1998
4/15 to 4/18	04-2000
4/19 to 4/21	11-1999
4/22 to 4/25	1998
4/26 to 4/28	04-2000
4/29	10-2000
4/30	11-1999
4/31	11-1999
4/32	*blank*
Section 5	
5/1	1998
5/2	04-2000
5/2-A	11-1999
5/2-B	*blank*
5/3 to 5/4-C	11-1999
5/4-D	04-2000
5/4-E	04-2000
5/4-F	*blank*
5/5	11-1999
5/6 to 5/8	04-2000
5/9 to 5/13	11-1999
5/14	04-2000
Section 6	
6/1	04-2000
6/2	*blank*

Page No.	Issue date	Page No.	Issue date
Section 7		*Annex E*	
7/1 to 7/3	04-2000	E/1	1998
7/4	*blank*	E/2	1998
Annex A		*Annex F (deleted)*	
A/1 to A/4	11-1999	F/1	04-2000
A/5	04-2000	F/2	*blank*
A/6 to A/28	11-1999	*Annex G*	
A/29	04-2000	G/1	1998
A/30	*blank*	G/2	*blank*
Annex B		*Annex H*	
B/1 to B/4	1998	H/1	04-2000
Annex C		H/2	04-2000
C/1	04-2000	*Annex J*	
C/2	04-2000	J/1 to J/6	04-2000
C/3	1998	*References*	
C/4	1998	I	04-2000
C/5	04-2000	II	11-1999
C/6 to C/21	1998	III	04-2000
C/22	04-2000	IV	04-2000
C/23	1998	Inside back cover	*blank*
C/24	1998	Back cover	11-1999
Annex D			
D/1	1998		
D/2	1998		

Section 1. General

1.1 Scope

1.1.1 This British Standard specifies requirements for the design and the manufacture, including materials and design stresses, workmanship, inspection, testing, documentation and marking, valves, gauges and fittings of:

a) water-tube steam generating plant subject to internal pressure; and

b) parts of steam and water heating plant used in association with steam generating plant.

1.1.2 In addition to the definitive requirements, this standard also requires the items detailed in **1.5** to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

1.1.3 This British Standard applies to the following types of plant.

a) Water-tube boilers including their integral steel tube economizers and superheaters and all other parts connected to the boiler without the interposition of a shut-off valve with the exception of valves and fittings specified in section **7**.

Water-tube boilers are divided, for the purposes of this British Standard, into the following three classes.

1) Natural circulation boilers, in which the circulation of the water through the tubes is a result of the thermo-syphonic head produced by heating.

2) Forced, assisted or controlled circulation boilers, in which a pump is used either entirely or partly to promote circulation of the water through the tubes.

3) Once-through boilers, in which the feed pump is used to force the flow of water and steam through the tubes.

b) Steam reheaters (either integral with the boiler unit or independently fired) receiving steam which has passed through part of a turbine or other prime mover.

c) Independently fired steam superheaters.

d) Integral superheaters separated by a shut-off valve from the evaporative circuits.

e) Steel tube economizers (either integral with the boiler or independently fired) separated by a shut-off valve from the boiler.

NOTE. For convenience, the term 'boiler' used throughout this standard includes the types of plant described in a) to e).

1.1.4 This standard applies to the pressure parts of boilers and superheaters (as described in **1.1.3**a) and d)) containing water and steam up to and including the valves separating these water and steam spaces from the steam pipes to other equipment, water supply pipes, drain pipes and the surrounding atmosphere (safety valves and vents).

In the case of reheaters (see **1.1.3**b), this standard applies to pressure parts from the piping connection(s) at the inlet header to the piping connection(s) at the outlet header except that where a device is provided in reheat piping to blank off the reheater for hydraulic testing, this standard applies up to and including this device. In the case of independently fired superheaters (see **1.1.3**c), and economizers (see **1.1.3**e), the standard applies to the pressure parts containing steam and water respectively between the inlet and exit valves, including the respective valves and connections to drain pipes and to the atmosphere.

1.1.5 Section **4** of this standard (manufacture and workmanship) includes requirements applicable to the normal function of the boilermaker. Requirements for the quality of workmanship of plates, tubes, forgings and castings in the condition in which they are normally supplied to the boilermaker are included in the standards in the series specifying such materials.

1.1.6 This standard does not apply to brickwork or other settings or supports, or to insulation, or to air preheaters, mechanical stokers, fuel burning or ash disposal equipment, forced or induced draught equipment or their accessories. These items are matters for mutual agreement between the purchaser and the manufacturer.

NOTE. Where such items are required or contemplated, it is recommended that all particulars which could affect the boiler(s) should be disclosed by the purchaser to the manufacturer at the time of the enquiry.

1.1.7 This standard applies only to boilers manufactured under the survey of a competent engineering Inspecting Authority or organization. The intent of this requirement may be regarded as satisfied where inspection is carried out by competent personnel of a separate engineering inspection department maintained by the purchaser of the boiler. An inspection department maintained by the manufacturer does not satisfy this requirement except:

a) that specific responsibilities may be delegated at the discretion of the Inspecting Authority or organization; or

b) in the case of boilers for the manufacturer's own use and not for resale.

This standard applies only to boilers made by manufacturers who can satisfy the Inspecting Authority or organization that they are competent and suitably equipped to fulfil the requirements specified.

In assessing the competence of a manufacturer, the Inspecting Authority or organization shall take into consideration any related nationally approved certification against the BS 5750 series of quality system standards.

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

1.2 Interpretation

If any ambiguity be found or doubt arise as to the meaning or effect of any part of this standard or as to whether anything ought to be done or omitted to be done in order that this standard should be complied with in full, the question shall be referred to the Boiler Technical Committee (PVE/2) of the British Standards Institution, whose interpretation of the requirements of this standard upon the matter at issue shall be given free of charge and shall be final and conclusive. Parties adopting this standard for the purposes of any contract shall be deemed to adopt this provision unless they expressly exclude it or else import an arbitration provision in terms extending to interpretation of this standard. However, this provision is limited to questions of interpretation and does not confer upon the committee any power, duty or authority 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 interpretation arrived at by the committee.

Findings or rulings of the committee upon all enquiries, including matters of interpretation, which are of sufficient importance that both enquiries and replies be made public as soon as possible will be published in an enquiry-reply form for inclusion in the BS 1113 ring binder as Enquiry Cases. Their availability will be notified in *Standards Update*.

After taking into account any public comment thereon, Enquiry Cases may be incorporated, as appropriate, into the standard as amendments which will form part of the next convenient annual updating.

1.3 Definitions

For the purposes of this British Standard the following definitions apply.

1.3.1 purchaser

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

1.3.2 manufacture

The organization that designs, fabricates and erects the boiler in accordance with the purchaser's order. The design, fabrication and erection functions may be carried out by separate organizations.

1.3.3 Inspecting Authority

The body or association that checks that the design, materials and construction comply with this standard.

1.3.4 Regulating Authority

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

1.3.5 maximum permissible working pressure

For design purposes, one of the following:

a) for natural or assisted circulation boilers and directly connected economizers, the highest set pressure of any safety valve mounted on the steam drum;

b) for once-through boilers, the highest set pressure of any safety valve mounted on the final superheater outlet; or

c) for steam reheaters, independently fired superheaters and economizers separated by a shut-off valve from the boiler, the highest pressure of any safety valve mounted on the steam or water outlet.

1.3.6 calculation pressure

For calculation purposes, either:

a) except as defined in b), the maximum permissible working pressure as defined in **1.3.5**, increased where applicable to take account of the pressure drop and hydraulic head corresponding to the most severe conditions of operation; or

b) for those components whose design stresses are time-dependent (see table 2.1.2 and **A.4**), the lowest set pressure of any superheater or reheater safety valve mounted on the steam outlet, increased to take account of the pressure drop corresponding to the most severe conditions of operation.

1.3.7 design temperature

The temperature to be used in the establishment of the minimum scantling thickness of pressure parts.

1.3.8 design lifetime

The operating lifetime to be used in the evaluation of design stresses for a component whose design temperature at calculation pressure is such that its design stress value is time-dependent.

1.3.9 continued service review

A review or series of reviews carried out to establish if a component, designed to the higher of alternative design stresses in the creep range is fit for continued service up to its design life.

1.3.10 design stress

The stress value, f, used in the equations in this standard for the calculation of the minimum scantling thickness of pressure parts.

1.3.11 pressure part

A component that contains pressurized water or steam or a mixture of the two.

1.3.12 drum

A cylindrical pressure part having a diameter sufficiently large to admit personnel, by design intent, for which purpose an access opening or branch is provided.

NOTE. A drum may have the function of a header, or additionally or alternatively other functions, such as to separate steam from water or to act as a reservoir for boiler water.

1.3.13 header

A pressure part whose principal purpose is to collect fluid from, or distribute fluid to, arrays of tubes directly connected to it.

1.3.14 tube

A tubular pressure part that is either exposed over much of its length to hot gases for purposes of heat transfer, or is directly butt welded to such a tubular pressure part.

NOTE. This definition includes a tube stub on a drum or header.

1.3.15 integral pipe

A tubular pressure part that is not a tube, drum or header.

NOTE 1. The term 'pipe' implies there is no design intent to effect heat transfer through the wall of the pressure part.

NOTE 2. The term 'integral' implies that the pressure part is connected directly to other pressure parts without any intervening valve.

NOTE 3. The term 'integral pipe', subject to note 2, includes those parts of pipes that carry a flow of steam or water during normal operation, those that carry intermittent flow, e.g. drain pipes, and those in which no flow occurs, e.g. instrument piping.

NOTE 4. The terms tube and pipe are used freely in British Standards for material and certain standards (e.g. BS 3602) state that they are interchangeable. The use of the term pipe or tube in any standard for material does not pre-empt the definitions given in **1.3.14** and **1.3.15** and likewise material described as pipe or tube may be used for any duty defined, if appropriate. The selective reference to British Standard materials in section 4 of this standard is intended for guidance based on the general usage of these standards.

1.4 Responsibilities

1.4.1 Responsibilities of the purchaser

The purchaser shall be responsible for furnishing the manufacturer with the information required by **1.5.1**.

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

1.4.2 Responsibilities of the manufacturer

The manufacturer shall be responsible for the completeness and accuracy of all design calculations and for compliance with all applicable requirements of this standard for the whole boiler. During fabrication, unexpected factors may arise which justify deviations from the specified requirements but which do not affect the safety as intended by this standard. Such deviations shall be submitted to the Inspecting Authority for approval and shall be recorded as part of the boiler dossier (see **6.1.3**b).

In cases where the design, fabrication and erection 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 **1.5.2.2**a).

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

A certificate of conformity shall be provided by the manufacturer; see section **6**.

1.4.3 Responsibilities of the Inspecting Authority

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

1.5 Information and requirements to be agreed and to be documented

1.5.1 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser and shall be fully documented (see **6.1.3**c). Both the definitive requirements specified throughout the standard and the documented items shall be satisfied before a claim of compliance with the standard can be made and verified.

a) A specification of the normal 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.

b) The name of the Inspecting Authority to be commissioned by the purchaser, see **1.1.7**.

c) Any additional requirements not given in this standard (see **2.2.1.2**a, **2.2.1.2**b, **3.7.1.2** and **4.1.3**).

d) Any special statutory or other regulations with which the finished boiler is required to comply.

e) The name of the Regulating Authority (if any).

1.5.2 Requirements to be agreed and documented

1.5.2.1 *General*

The items listed in **1.5.2.2** and **1.5.2.3** 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 **1.5.2.3**, 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 (**1.5.2.3**) from those listed under **1.5.2.2**, which do need to be agreed and documented when the contract or order is placed.

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

The following items, as appropriate, shall be agreed and documented (see **6.1.3**d).

a) 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 (see **1.4.2**).

b) Increased design stresses for certain alloy steels (see **2.2.8**).

c) The design lifetime, related to the creep rupture properties of the material, for each component whose design temperature is such that the design stress is time-dependent (see **2.2.8**).

d) Design stress values and the basis for extrapolation for design temperatures above those for which design stress values are available (see **2.2.7.1** and note b) and note 1c) to table A.1).

e) The maximum values for forces and moments imposed by external piping at the boiler terminals for main steam, reheat steam and feedwater (see **3.1.2**).

f) If applicable, design parameters for wind and earthquake loads (see **3.1.2**).

1.5.2.3 *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** and **6.1.3**j).

a) The use, for pressure parts, of materials not covered by **2.1.2.1** (see **2.1.2.2**) and whether elevated temperature yield point or proof stress properties related to tests in accordance with BS EN 10002-5 are not required for such materials (see **2.1.2.2.5**).

b) The heat treatment condition for materials not covered by **2.1.2.1**, if an alternative to the condition appropriate to the nearest equivalent British Standard material is required (see **2.1.2.2.7**).

c) The use of design stress values (f) determined by reference to **2.2.1.1** from the properties of the actual materials, where these properties have been proved by test to be higher than those given in the relevant material specification (see **2.2.1.1**c).

d) The method of calculating the thicknesses of the cylindrical shells of drums and headers, for time-dependent (creep) conditions where the resultant thickness exceeds half the internal diameter (see **3.3.2.2**b).

e) The scantlings for headers of rectangular section that are not straight (see **3.5.3**).

f) Assembly tolerances for middle line alignments (see **4.2.5.1.1**).

g) The welding materials to be used if these are not covered by British Standards (see **4.3.1.2**b).

h) For post-weld heat treatment:

1) the heat treatment conditions if other than those given in table 4.5.4 (see **4.5.4.1.2**a)2)); or

2) waiver of post-weld heat treatment (see **4.5.4.1.2**b).

i) Post-weld heat treatment of joints between any combinations of ferritic steels not included in table 4.5.4 (see **4.5.4.4.3**).

j) The requirement for heat treatment of austenitic steel tubes or pipes that are hot or cold bent for integral piping (see **4.2.3.5**),the bending temperature range to be used for hot bending, and the post-bend heat treatment procedures to be used (see **4.5.2.2.3**).

k) Where necessary, acceptance, as fit for the intended purpose, of welds represented by charpy V-notch impact test specimens from boiler drum production control test plates that give impact values less than required by **5.5.7.3** (see **5.5.7.4**b).

l) Where necessary, acceptance of computations if any tensile test specimen from the boiler drum production control test plates fails to comply with specified requirements (see **5.5.8**).

m) Where necessary, remedial measures to be adopted if either of the bend retest specimens from the boiler drum production control test plates fails to comply with the specified requirements (see **5.5.8**).

n) A reduction in the percentage rate of non-destructive examination for welds, where the manufacturer has demonstrated that the welds consistently comply with the standards of acceptance given in **5.9** (see **5.6.1.6**).

o) Non-destructive examination before final stress relief, for the following weld types in carbon, carbon manganese type 620 and type 621 steels (see **5.6.1.9**):

i) butt welds in drums and headers;

ii) branch, nozzle and stub welds;

iii) attachment welds.

p) Where necessary, the use of a fitness for purpose analysis to assess the acceptability of particular flaws in excess of the acceptance levels specified in **5.9.3** to **5.9.5** (see **5.9.1**b)2)).

q) The procedure to be used with regard to small pockets of trapped air which may remain after filling following venting or evacuation of air prior to hydraulic testing (see **3.1.5**h).

Section 2. Materials and design stresses

2.1 Materials

2.1.1 General

2.1.1.1 The selection of the materials of construction for pressure-containing parts of boilers and their integral attachments shall take into account the suitability of the material with regard to fabrication, e.g. cold forming, weldability and expanding, as appropriate, and the conditions under which they will eventually operate.

2.1.1.2 Welding material shall conform to **4.3.1.2**.

2.1.1.3 Cast iron shall not be used in the construction of pressure parts, except for valves and fittings within the limits specified in BS 759 : Part 1 or BS 6759 : Part 1.

2.1.1.4 Studs, bolts and nuts shall be in accordance with the material specifications given in BS 4882.

2.1.1.5 Pipe fittings shall conform to BS 1640, BS 1965 : Part 1 or BS 3799, as appropriate.

2.1.1.6 Flanges shall conform to BS 10, BS 1560 : Section 3.1 or BS 4504 : Section 3.1.

2.1.2 Materials for pressure parts

2.1.2.1 ***General***

With the exceptions of the materials covered by **2.1.1.2** to **2.1.1.6**, all the materials used in the manufacture of pressure parts shall either:

a) conform to the appropriate BS EN steels given in table 2.1.2; or

b) conform to the appropriate British Standard steels given in table A.1; or

c) be agreed between the manufacturer and the purchaser and conform to **2.1.2.2** (see **1.5.2.3**a).

A combination of materials given in table 2.1.2 or table A.1 and corrosion resistant material is permitted for metallurgically bonded co-extruded tubes.

NOTE. The requirements of this British Standard have been drafted largely on the basis of experience with the materials specified in table 2.1.2 and table A.1; the selection of such materials should therefore be preferred. However, it is accepted that special circumstances may occur in which the selection of materials other than those covered by table 2.1.2 or table A.1 is necessary; the requirements of **2.1.2.2** have been specified to provide a basis for material selection in such circumstances.

2.1.2.2 ***Materials not covered by table 2.1.2 or table A.1***

2.1.2.2.1 The material shall be covered by a written specification at least as comprehensive as the British Standards listed in table A.1 for the nearest equivalent material. For ferritic steels, the phosphorus and sulfur content shall not exceed 0.05 % (*m/m*) each in the ladle analysis.

NOTE. For ferritic steels intended for welding, the upper limit of the carbon range (in the ladle analysis) should not exceed 0.25 % (*m/m*). Steels with a higher carbon content that are intended for welding may be used subject to appropriate welding procedures and heat treatment.

2.1.2.2.2 The design stresses shall be determined in accordance with **2.2**.

2.1.2.2.3 The deoxidation practice shall be appropriate to the type of steel ordered. Semi-killed steel shall be used only for plates, and seamless and welded tubes in carbon and carbon manganese steels with an upper limit of the specified tensile strength range of 640 N/mm^2 and with a thickness not exceeding 100 mm. Rimming steel shall be used only for welded tubes in carbon and carbon manganese steel with an upper limit of the specified tensile strength range of 490 N/mm^2 and under service temperature conditions of 400 °C or less.

2.1.2.2.4 Mechanical properties at room temperature shall be determined by means of acceptance tests covering tensile strength, yield stress and elongation.

The specified minimum percentage elongation at fracture referred to a gauge length of $5.65\sqrt{s_o}$[1] shall be appropriate to the type of steel, with a lower limit of 16 % for plates, 15 % for castings and 14 % for tubes and forgings.

The rate of testing and methods of acceptance testing shall be generally in alignment with the appropriate British Standards for similar product forms.

2.1.2.2.5 For all pressure parts, elevated temperature yield point or proof stress properties related to tests in accordance with BS EN 10002-5 shall be specified unless otherwise agreed between the manufacturer and Inspecting Authority (see **1.5.2.3**a).

Where no elevated temperature yield point or proof stress property values exist or where the material cannot be related to another material for which values exist, property values shall be verified using the procedure described in BS 3920 or shall be established by the recognized standards of other countries.

2.1.2.2.6 Stress rupture properties shall be specified for materials which will be used in the creep range.

The manufacturer of the boiler shall be assured by the material supplier that the product supplied is capable of conforming to the specified properties by a statement that the manufacturing processes have remained equivalent to those for the steel for which the test results were obtained.

2.1.2.2.7 Materials shall be supplied in a heat treated condition appropriate to the nearest equivalent British Standard material unless otherwise agreed between the interested parties (see **1.5.2.3**b).

NOTE. Plates for hot forming may be supplied in any suitable condition, e.g. hot finished, normalized, normalized and tempered.

Carbon and carbon manganese steel plates for cold forming shall be supplied in the normalized condition.

[1] S_o is the original cross-sectional area of the gauge length of the tensile test specimen (see BS EN 10002-1).

Low alloy steel plates for cold forming shall be supplied in the normalized and tempered condition except that, where metallurgically suitable and where post-weld heat treatment will suffice as the tempering treatment, plates supplied in the normalized condition shall be permitted.

Electric resistance welded or induction welded tubes shall be used in the as welded condition only where the specified upper limit of tensile strength does not exceed 540 N/mm^2.

2.1.2.2.8 In the case of withdrawn British Standard materials listed in this and previous issues of this standard, by agreement between the manufacturer and Inspecting Authority (see **1.5.2.3**a), compliance with the requirements of **2.1.2.2.1** and **2.1.2.2.3** to **2.1.2.2.7** may be waived. The requirements of **2.1.2.2.2** for the determination of design stress shall however continue to apply.

NOTE. This waiver may be applied for a period of up to 3 years from the date of withdrawal of the material from listing in this standard.

2.1.3 Materials for non-pressure parts

Materials for supporting lugs, baffles, fins 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.

2.2 Design stresses

2.2.1 General

2.2.1.1 The design stress f shall be determined in one of the following ways.

a) Factors of safety shall be applied to the appropriate material property values of the BS EN steels listed in table 2.1.2 in the manner shown in **2.2.3**, **2.2.4** and **2.2.5.**

b) In the case of existing British Standard steels, f shall be taken directly from table A.1.

c) Where the materials used have time-independent properties proved by a test to be higher than those given in the relevant material specifications, the use of those higher properties to determine the design stress value f, at the design temperature, by application of the factors given in **2.2.3** and **2.2.4** shall be permitted subject to agreement between the manufacturer and the inspecting authority (see **1.5.2.3**c).

NOTE 1. Material property values at intermediate temperatures and intermediate times to those given in the material specifications should be obtained by linear interpolation. Interpolated values should be rounded to two decimal places in accordance with BS 1957.

NOTE 2. The design stresses obtained in accordance with a) and b) above are derived on the basis of accepted principles and established practice and are intended for general application. However, it is recognized that, during fabrication, unexpected situations may arise where use may be made of the design stresses derived from the mechanical properties of the actual materials being used; the provisions of c) are intended to be used in such special circumstances rather than as a general rule.

2.2.1.2 In determining the design stress the following points shall be taken into account.

a) *Carbon and carbon manganese steels.* The following points shall be taken into account.

1) The design stresses derived in accordance with **2.2.3**, **2.2.4** and **2.2.5** or taken directly from table A.1 of annex A are intended for general use with the steels listed and acceptance tests on material heat treated with a complete component are not required, any reduction in properties of such steels due to post weld heat treatment being consistent with the overall benefit obtained by stress relief of the structure. A purchaser requiring such tests, or tests on samples subject to non-standard heat treatments, shall specify them in the supplementary specification together with appropriate acceptance criteria (see **1.5.1**c).

2) In designs where slight deformation is important or where post-weld heat treatment conditions other than those specified in table 4.5.4 are agreed (see **4.5.4.1.2**a)2)), materials that will conform to the properties in the material specification in the normalized plus simulated post weld heat treated condition shall be specified.

b) *Alloy steels.* The following points shall be taken into account.

1) The time-independent design stresses derived in accordance with **2.2.3** and **2.2.4** or taken directly from table A.1 shall be used, provided that the proposed post weld heat treatment conditions are in accordance with **4.5.4** and table 4.5.4.

2) Where post weld heat treatment conditions other than those specified in table 4.5.4 are agreed, (see **4.5.4.1.2**a)2)), the effect of any proposed heating or reheating during fabrication shall be determined in liaison with the material supplier before selecting the appropriate time-independent design stress. The time-independent properties in the material specification, or such properties determined from the selected design stress, shall be satisfied by the testing of material in the simulated heat treated condition.

3) Acceptance tests on materials heat treated with the completed component are not required. A purchaser requiring such tests, or tests on samples subject to non-standard heat treatments, shall specify them together with the appropriate acceptance criteria (see **1.5.1**c).

2.2.2 Terminology

f is the design stress which shall be taken as the lesser of f_E and f_F.

f_E is the design stress corresponding to the short time tensile strength characteristics of the material (time-independent).

f_F is the design stress corresponding to the creep characteristics of the material (time-dependent).

R_e is the minimum value of specified yield stress for the grade of steel concerned at room temperature. Where a material standard specifies minimum values of R_{eL}, or $R_{p0.2}$ ($R_{p1.0}$ for austenitic steels), these values are taken as corresponding to R_e.

R_{eL} is the minimum value of the lower yield stress.

$R_{e(T)}$ corresponds to the minimum value of R_{eL}, or $R_{p0.2}$ ($R_{p1.0}$ for austenitic steels), specified for the grade of material concerned at a temperature T.

R_m is the minimum tensile strength specified for the grade of material concerned at room temperature.

$R_{p0.2}$ is the minimum value of the 0.2 % proof stress.

$R_{p1.0}$ is the minimum value of the 1.0 % proof stress.

S_{Rt} is the mean value of the stress required to produce rupture in time t at temperature T for the grade of steel in question.

2.2.3 Time-independent design stresses for carbon, carbon manganese and low alloy steels

2.2.3.1 ***Materials with specified elevated temperature values***

1) For design temperatures up to and including 250 °C, use material property data at 250 °C.

2) For design temperatures of 250 °C and above:

$$f_E = \frac{R_{e(T)}}{1.5} \text{ or } \frac{R_m}{2.7}$$

whichever gives the lower value.

2.2.3.2 ***Materials without specified elevated temperature values***

1) For design temperatures up to and including 250 °C use material property data at 250 °C.

2) For design temperatures of 250 °C and above:

$$f_E = \frac{R_{e(T)}}{1.6} \text{ or } \frac{R_m}{2.7}$$

whichever gives the lower value.

The values of $R_{e(T)}$ used above shall be taken as equal to those specified for otherwise similar materials having specified elevated temperature values.

2.2.4 Time-independent design stresses for austenitic steels

2.2.4.1 ***Materials with specified elevated temperature values***

1) For design temperatures up to and including 250 °C use material property data at 250 °C.

2) For design temperatures of 250 °C and above:

$$f_E = \frac{R_{e(T)}}{1.35} \text{ or } \frac{R_m}{2.7}$$

whichever gives the lower value.

2.2.4.2 ***Materials without specified elevated temperature values***

1) For design temperatures up to and including 250 °C use material property data at 250 °C.

2) For design temperatures of 250 °C and above:

$$f_E = \frac{R_{e(T)}}{1.45} \text{ or } \frac{R_m}{2.7}$$

whichever gives the lower value.

The values of $R_{e(T)}$ used above shall be taken as equal to those specified for otherwise similar materials having specified elevated temperature values.

2.2.5 Time-dependent design stresses

The time-dependent design stress is given by

$$f_F = \frac{S_{Rt}}{1.3}$$

NOTE. By agreement between the manufacturer and the purchaser (see **1.5.2.2**b), time-dependent values at design temperature, for 10 CrMo 9-10, 11 CrMo 9-10 and 12 CrMo 9-10 materials only, may be increased by up to 10 %, subject to both of the following conditions being met:

a) continued fitness for service reviews are instituted at two-thirds of the agreed design lifetime (see **2.2.8**);

b) the resulting values do not exceed the lower time-independent stress value at the same temperature, derived in accordance with **2.2.3** or **2.2.4**.

2.2.6 Cast steels

The design stress for castings tested in accordance with BS 1504 test category I shall not be greater than 90 % of the values given in table A.1, and for those tested in accordance with BS 1504 test category II shall not be greater than 80 % of the said value. The acceptance level of both test categories shall be in accordance with **5.7.5**.

2.2.7 Design temperature

2.2.7.1 ***General***

The design temperature shall not be less than the highest of:

a) the maximum mean wall temperature of the pressure part, calculated by the manufacturer. In the case of pressure parts carrying superheated steam the factors specified in **2.2.7.8** shall be taken into account;

b) the design temperatures specified in **2.2.7.2** to **2.2.7.7**.

NOTE. The design temperature should not exceed the upper temperature for which properties are available. Where extrapolation of the available values is required, the extrapolation method should be agreed between the manufacturer and the purchaser (see **1.5.2.2**d).

2.2.7.2 ***Drums and headers***

Where drums and headers are not heated by hot gases or are adequately protected by insulation from hot gases, the design temperature shall be equal to the maximum temperature of the internal fluid.

NOTE. A covering of refractory or insulating material that may be liable to become dislodged is not considered to be adequate protection.

Where drums and headers are heated by hot gases, the design temperature shall be taken as not less than 25 °C in excess of the maximum temperature of the internal fluid.

2.2.7.3 ***Boiler tubes***

The design temperature shall be taken as not less than:

a) 50 °C for tubes subject to radiant heat from the combustion chamber;

b) 25 °C for other tubes;

in excess of the saturated steam temperature at the calculation pressure.

2.2.7.4 ***Superheater and reheater tubes***

The design temperature shall be taken as not less than:

a) 50 °C for tubes subject to radiant heat from the combustion chamber;

b) 35 °C for other tubes;

in excess of the steam temperature expected in the part being considered.

2.2.7.5 ***Economizer tubes***

The design temperature shall be taken as not less than 25 °C in excess of the maximum temperature of the internal fluid.

2.2.7.6 ***Integral pipes and those parts of tubes not heated by gases***

The design temperature shall be taken as the maximum temperature of the fluid inside the pipe or tube.

2.2.7.7 ***Parts beyond the final superheater header(s)***

Where, because of design arrangements, factors such as inequalities in gas temperature and flow occurring in any cross section of the gas path cannot have any sustained effect on the steam temperature, the design temperature shall be the rated steam temperature at the superheater outlet, provided that in service:

a) the average temperature during any one year of operation does not exceed the design temperature; and

b) for systems having a rated temperature of 380 °C and below, fluctuations in temperature do not exceed the design temperature by more than 10 %; or

c) for systems having a rated temperature above 380 °C:

1) normal fluctuations in temperature do not exceed the rated temperature by more than 8 °C; and

2) abnormal fluctuations in temperature do not exceed the rated temperature by more than 20 °C for a maximum of 400 h in any one year or 30 °C for a maximum of 100 h in any one year or 40 °C for a maximum of 60 h in any one year.

Where the maximum temperature will exceed these limits, the design temperature shall be increased by the amount of the excess.

NOTE. The limits in a), b) and c) represent realistic figures for modern control systems and boilers meeting normal load demands. It is the responsibility of the purchaser to advise the manufacturer, before design of the plant is commenced, of any circumstances that could prevent these limits being complied with (see **1.5.1**a); it is the responsibility of the purchaser also to ensure that the boiler is operated within these or any other agreed limits.

2.2.7.8 ***Additional factors***

2.2.7.8.1 In determining the maximum temperature of superheated steam and the related pressure part mean wall temperature, the following factors shall be taken into account:

a) variation in the steam flow, from the mean value, in individual tubes of a tube bank, produced by entry and exit conditions and by manufacturing tolerances on thickness and diameter;

b) variation in the heat input to the tube bank under consideration, resulting from deviation in the performance of preceding heating surfaces and deviation from ideal combustion conditions;

c) variation in steam inlet temperature resulting from deviation in gas temperature and flow occurring in any cross section of the gas path.

2.2.7.8.2 For drums, headers and parts beyond the super-heater header(s), where the expected steam temperature is not in excess of 425 °C in the part under consideration, an addition of 15 °C shall be deemed to cover the factors listed in **2.2.7.8.1**.

2.2.7.8.3 For superheater and reheater tubes where, in the part under consideration:

a) the tube is not subjected to direct radiant heat from the combustion chamber;

b) the expected steam temperature is not in excess of 425 °C;

the factors listed in **2.2.7.8.1** shall be deemed to be included in the requirements of **2.2.7.4**.

2.2.8 Design lifetime

A design lifetime related to the creep rupture properties of the material shall be agreed between the manufacturer and the purchaser for each component whose design temperature is such that the design stress is time-dependent (see **1.5.2.2**c).

NOTE 1. it is not necessarily intended that one lifetime be used to cover all components; therefore replaceable items may be designed for lifetimes shorter than the general life expectancy of the boiler.

NOTE 2. The basis of the design in this standard is that no component remains in service after its operational hours have exceeded the design lifetime. However, experience has demonstrated that components designed to these rules can be expected to exceed their design life and reference may be made to PD 6510 for procedures for assessing whether the life could be extended.

Components of certain alloy materials designed using increased time-dependent stress values (see **2.2.5** or note 4 of table A.1) shall be identified on the drawings and listed by the manufacturer. Continued service reviews shall be instituted at not later than two-thirds of the design lifetime.

Table 2.1.2 List of materials covered by BS EN material standards

Product form	BS EN standard	Material description	Grade	Heat treatment[1]	Thickness mm min.	Thickness mm max.	Steel group according to EN ISO/TR 15608
Plate and strip	BS EN 10028-2	Elevated temperature properties	P235GH	N	0	150	1.1
Plate and strip	BS EN 10028-2	Elevated temperature properties	P265GH	N	0	150	1.1
Plate and strip	BS EN 10028-2	Elevated temperature properties	P295GH	N	0	150	1.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	P355GH	N	0	150	1.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	16Mo3	N	0	150	1.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	13CrMo4-5 (1)	NT	0	60	5.1
Plate and strip	BS EN 10028-2	Elevated temperature properties	13CrMo4-5 (2)	NT Q	60	100	5.1
Plate and strip	BS EN 10028-2	Elevated temperature properties	13CrMo4-5 (3)	Q	100	150	5.1
Plate and strip	BS EN 10028-2	Elevated temperature properties	10CrMo9-10 (1)	NT	0	60	5.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	10CrMo9-10 (2)	NT Q	60	100	5.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	10CrMo9-10 (3)	Q	100	150	5.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	11CrMo9-10 (1)	NT Q	0	60	5.2
Plate and strip	BS EN 10028-2	Elevated temperature properties	11CrMo9-10 (2)	Q	60	100	5.2
Plate and strip	BS EN 10028-3	Fine grain steel, normalized	P275N	N	0	150	1.1
Plate and strip	BS EN 10028-3	Fine grain steel, normalized	P275NH	N	0	150	1.1
Plate and strip	BS EN 10028-3	Fine grain steel, normalized	P355N	N	0	150	1.2
Plate and strip	BS EN 10028-3	Fine grain steel, normalized	P355NH	N	0	150	1.2
Plate and strip	BS EN 10028-3	Fine grain steel, normalized	P460NH	N	0	150	2.1
Tubes, seamless	prEN 10216-1	Room temperature properties	P195TR2	N	0	60	1.1
Tubes, seamless	prEN 10216-1	Room temperature properties	P235TR2	N	0	60	1.1
Tubes, seamless	prEN 10216-1	Room temperature properties	P265TR2	N	0	60	1.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	P195GH	N	0	16	1.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	P235GH	N	0	60	1.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	P265GH	N	0	60	1.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	16Mo3	N	0	60	1.2
Tubes, seamless	prEN 10216-2	Elevated temperature properties	10CrMo5-5	NT	0	60	5.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	13CrMo4-5	NT	0	60	5.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	10CrMo9-10	NT	0	60	5.2
Tubes, seamless	prEN 10216-2	Elevated temperature properties	11CrMo9-10	QT	0	60	5.2

Table 2.1.2 List of materials covered by BS EN material standards (*continued*)

Product form	BS EN standard	Material description	Grade	Heat treatment[1)]	Thickness mm		Steel group according to EN ISO/TR 15608
					min.	max.	
Tubes, seamless	prEN 10216-2	Elevated temperature properties	15NiCuMoNb5-6-4	NT	0	80	2.1
Tubes, seamless	prEN 10216-2	Elevated temperature properties	X11CrMo5+NT1	NT	0	100	5.3
Tubes, seamless	prEN 10216-2	Elevated temperature properties	X11CrMo5+NT2	NT	0	100	5.3
Tubes, seamless	prEN 10216-2	Elevated temperature properties	X11CrMo9-1+NT	NT	0	60	5.4
Tubes, seamless	prEN 10216-2	Elevated temperature properties	X10CrMoVNb9-1	NT	0	100	6.4
Tubes, seamless	prEN 10216-2	Elevated temperature properties	X20CrMoNiV11-1	NT	0	100	6.4
Tubes, seamless	prEN 10216-3	Fine grain steel	P275NL1	N	0	100	1.1
Tubes, seamless	prEN 10216-3	Fine grain steel	P275NL2	N	0	100	1.1
Tubes, seamless	prEN 10216-3	Fine grain steel	P355NH	N	0	100	1.2
Tubes, seamless	prEN 10216-3	Fine grain steel	P460NH	N	0	100	2.1
Tubes, seamless	prEN 10216-5	Stainless steel					
Tubes, welded	prEN 10217-1	Room temperature properties	P195TR2	N	0	40	1.1
Tubes, welded	prEN 10217-1	Room temperature properties	P235TR2	N	0	40	1.1
Tubes, welded	prEN 10217-1	Room temperature properties	P265TR2	N	0	40	1.1
Tubes, welded	prEN 10217-2	Elevated temperature properties	PH195GH	N	0	16	1.1
Tubes, welded	prEN 10217-2	Elevated temperature properties	PH235GH	N	0	16	1.1
Tubes, welded	prEN 10217-2	Elevated temperature properties	PH265GH	N	0	16	1.1
Tubes, welded	prEN 10217-2	Elevated temperature properties	16Mo3	N	0	16	1.2
Tubes, welded	prEN 10217-3	Alloy fine grain steel	P275NL1	N	0	40	1.1
Tubes, welded	prEN 10217-3	Alloy fine grain steel	P275NL2	N	0	40	1.1
Tubes, welded	prEN 10217-3	Alloy fine grain steel	P355NH	N	0	40	1.2
Tubes, welded	prEN 10217-3	Alloy fine grain steel	P460NH	N	0	40	2.1
Tubes, welded	prEN 10217-5	Stainless steel					
Forging	prEN 10222-2	Elevated temperature properties	P245GH (1)	A	0	35	1.1
Forging	prEN 10222-2	Elevated temperature properties	P245GH (2)	N NT QT	35	160	1.1
Forging	prEN 10222-2	Elevated temperature properties	P280GH (1)	N	0	35	1.2
Forging	prEN 10222-2	Elevated temperature properties	P280GH (2)	NT QT	35	160	1.2
Forging	prEN 10222-2	Elevated temperature properties	P305GH (1)	N	0	35	1.2

Table 2.1.2 List of materials covered by BS EN material standards (*continued*)

Product form	BS EN standard	Material description	Grade	Heat treatment[1)]	Thickness mm		Steel group according to EN ISO/TR 15608
					min.	max.	
Forging	prEN 10222-2	Elevated temperature properties	P305GH (2)	NT	35	160	1.2
Forging	prEN 10222-2	Elevated temperature properties	P305GH (3)	QT	0	70	1.2
Forging	prEN 10222-2	Elevated temperature properties	16Mo3 (1)	N	0	35	1.2
Forging	prEN 10222-2	Elevated temperature properties	16Mo3 (2)	QT	35	100	1.2
Forging	prEN 10222-2	Elevated temperature properties	16Mo3 (3)	QT	100	500	1.2
Forging	prEN 10222-2	Elevated temperature properties	13CrMo4-5 (1)	NT	0	70	5.1
Forging	prEN 10222-2	Elevated temperature properties	13CrMo4-5 (2)	NT QT	70	500	5.1
Forging	prEN 10222-2	Elevated temperature properties	14MoV6-3	NT QT	0	500	6.1
Forging	prEN 10222-2	Elevated temperature properties	11CrMo9-10 (1)	NT	0	200	5.2
Forging	prEN 10222-2	Elevated temperature properties	11CrMo9-10 (2)	NT QT	200	500	5.2
Forging	prEN 10222-2	Elevated temperature properties	X16CrMo5-1 (1)	A	0	300	5.3
Forging	prEN 10222-2	Elevated temperature properties	X16CrMo5-1 (2)	NT	0	300	5.3
Forging	prEN 10222-2	Elevated temperature properties	X10CrMoVNb9-1	NT	0	130	6.4
Forging	prEN 10222-2	Elevated temperature properties	X20CrMoV11-1	QT	0	330	6.4
Forging	BS EN 10222-4	Fine grain, high proof strength	P285NH	N	0	70	1.2
Forging	BS EN 10222-4	Fine grain, high proof strength	P285QH	QT	70	400	1.2
Forging	BS EN 10222-4	Fine grain, high proof strength	P355NH	N	0	70	1.2
Forging	BS EN 10222-4	Fine grain, high proof strength	P355QH	QT	70	400	1.2
Forging	BS EN 10222-4	Fine grain, high proof strength	P420NH	N	0	70	2.1
Forging	BS EN 10222-4	Fine grain, high proof strength	P420QH	QT	70	400	2.1
Forging	prEN 10222-5	Stainless steel					

[1)] A annealed; NT normalized and tempered; Q quenched; N normalized; QT quenched and tempered

Section 3. Design

3.1 General

3.1.1 The thickness and other dimensions of pressure parts, sufficient to withstand the calculation pressure at the design temperature sustained (where relevant) for the design life time, shall be determined in accordance with this section.

NOTE 1. In determining the minimum permissible thickness in millimetres the calculated value may be rounded down to the next lowest single decimal place.

The design for loadings arising from the following shall also be determined in accordance with this section:

a) the bending of a drum or header as a beam under self-weight and imposed loads;

b) local support loads on drums;

c) thermally-induced forces and moments within or arising from systems of integral piping; and

d) local loading of tubes by structural attachments.

NOTE 2. The purpose of this section is to give specific design rules for common forms of loading to which boiler pressure parts are subject and general rules on how other loadings are to be considered. It does not give specific design methods for loadings other than those described in a) to d).

The design rules are adequate for boilers of established construction, installed and operated in accordance with the manufacturer's instructions.

In such cases, thermally-induced forces and moments within or arising from properly designed and erected tube systems do not require analysis.

Determination of the dimensions of pressure parts when any of the following conditions are present requires special consideration outside the scope of this standard:

1) abnormally corrosive products of combustion;

2) highly pressurized products of combustion;

3) poor feedwater;

4) abnormally rapid or frequent changes of pressure or temperature.

3.1.2 The strengths of the pressure parts shall be such as to withstand the following normally present loads:

a) the weight of all pressure parts, contents, components depending on them and any superimposed slag, ash or dust;

b) loads caused by pressure differentials over the flue gas containment envelope;

c) loads arising at connections between the boiler system and other plant. The maximum values for forces and moments imposed by external piping at the boiler terminals for main steam, reheat steam and feedwater shall be agreed between manufacturer and purchaser (see **1.5.2.2**e).

If applicable, the pressure parts shall adequately withstand wind and earthquake loads. Design parameters for such loads shall be agreed between the manufacturer and the purchaser (see **1.5.2.2**f).

3.1.3 The results of any stress calculations carried out for loadings not explicitly covered by equations in this section shall be assessed using the criteria given in annexes A and B of BS 5500 : 1997.

Transient, uncontrolled pressure differentials over the flue gas containment envelope shall be treated as wind loads not coincident with true wind loads, when using annex B of BS 5500 : 1997.

3.1.4 The cyclic loadings to which boilers are normally subject are such that fatigue analysis of pressure parts made from materials listed in table 2.1.2 is unnecessary. When pressure parts are to be subject to abnormal cyclic loading, the assessment of the need for a fatigue analysis and any resulting analysis shall be in accordance with annex C of BS 5500 : 1997.

3.1.5 Cognizance shall be taken of the following requirements in sections 4 and 5:

a) branches and nozzles (see **4.3.1.1.6** and **4.3.1.1.7**);

b) welds between dissimilar materials (see **4.3.2.5.4** and **4.5.4.6**);

c) the distance of nozzles or branches from locally heat treated butt welds (see **4.5.1.1.3**);

d) the length of branches to which pipes are to be butt welded and the weld stress relieved (see **4.5.1.1.4**);

e) design of joints subject to non-destructive examination (see **5.6.1.7**);

f) identification of load-bearing attachments (see **5.6.1.7**, **5.8.2.3**, **5.8.3.3** and **5.8.4.3.1**);

g) test category for pipes and tubes (see **5.7.4**);

NOTE. Pipes and tubes conforming to test category 2 of BS 3059 : Part 2, BS 3602 : Part 1, BS 3604 : Part 1 and BS 3605 conform to this standard. Selection of pipes and tubes to test category 1 of these standards is at the option of the designer, taking into account the service conditions of the boiler.

h) venting or evacuating of air prior to hydraulic testing (see **5.10.4.2**). Small pockets of trapped air may remain after filling and the procedure with regard to these shall be the subject of agreement between the Inspecting Authority and the manufacturer (see **1.5.2.3**r).

3.2 Metal wastage

NOTE. For the purpose of design in accordance with this section, metal wastage includes oxidation, corrosion, erosion and abrasion.

3.2.1 Internal wastage is normally small and shall not be considered for boilers operated with water in accordance with BS 2486.

NOTE. Suitable means should be provided within the boiler design to enable regular water analysis to be safely undertaken in order to ensure the water quality remains within acceptable limits.

3.2.2 External wastage of pressure parts not exposed to flue gases is normally small and the thickness determined by this section shall be adequate without further addition.

Tubes exposed to flue gases experience wastage to a varying extent. If the boiler design data indicate that wastage will be significant, the tubes shall be increased in thickness (see **3.7.1.2**). It is permitted to provide for wastage by means of metallurgically bonded co-extruded tubes.

NOTE. In such cases it may be necessary for the manufacturer and the purchaser to agree on a design life for components designed to time-independent stresses as well as for those for time-dependent stresses (see **2.2.4**).

For tubes designed to time-dependent stresses, integration of the effects of creep and wastage shall be permitted so that failure is predicted at a time not less than the design lifetime even though the tube thickness over the latter part of its life is less than that required by equations 31 and 32 (see **3.7.1.1**).

3.2.3 Unless exceptional conditions of chemical concentration are expected to occur, only austenitic materials shall be considered liable to the effect of stress corrosion. The phenomenon shall be considered adequately dealt with in the design if austenitic materials are not used to carry steam having at full boiler load an enthalpy less than 2900 kJ/kg or that corresponding to 425 °C, whichever is less.

Where exceptional chemical concentrations are predicted, consideration shall be given to the materials and heat treatment of components.

NOTE. It is not possible to provide compensation for stress corrosion by increasing the thickness of components.

3.3 Cylindrical shells of drums and headers

NOTE. This clause specifies the design rules for drums and headers. An example of the design of a boiler drum is given in annex B.

3.3.1 Shell thickness

3.3.1.1 The thickness of the shells of drums and headers shall be the greatest of those required by the following:

a) a minimum of 9.5 mm for headers 300 mm and above in outside diameter and a minimum of 6 mm for headers below 300 mm in outside diameter;

b) the requirements of **3.3.2** and **3.3.3**;

c) the requirements of **3.3.4**, **3.3.5** and **3.3.6**;

d) for those parts of shells drilled for tube expansions, such thickness as is required to provide a parallel belt of tube seat not less than 10 mm wide.

3.3.1.2 All welding of the main seams of boilers constructed in accordance with this standard shall be accounted as having a joint efficiency of 100 %.

3.3.2 Basic calculation

3.3.2.1 Except where the conditions described in **3.3.2.2** apply, the minimum thickness t (in mm) of a cylindrical shell shall be determined by either of the following equations:

$$t = \frac{pD_i}{2f\eta - p} \qquad (1)$$

or

$$t = \frac{pD_o}{2f\eta + p} \qquad (2)$$

where

- p is the calculation pressure (in N/mm^2);
- D_i is the nominal inside diameter of the shell (in mm) (see **3.3.2.3** and **3.3.2.4**);
- D_o is the nominal outside diameter of the shell (in mm) (see **3.3.2.3** and **3.3.2.4**);
- f is the design stress (in N/mm^2) (see **2.2**);
- η is the minimum efficiency of longitudinal, diagonal and circumferential ligaments, as determined in **3.3.3**.

3.3.2.2 The minimum thickness determined in accordance with **3.3.2.1** shall not be applicable in the following cases.

a) For time-independent (non-creep) conditions where the resultant thickness calculated using equation (1) or (2) exceeds one-quarter of the internal diameter. In this case, the thickness shall also be determined from either of the following equations and compared with the thickness determined from equation (1).

$$t = \frac{D_i}{2}\left[\sqrt{\left\{\frac{1.5f\eta + p(1-\eta)}{1.5f\eta - p(1+\eta)}\right\}} - 1\right] \qquad (3a)$$

$$t = \frac{D_o}{2}\left[1 - \sqrt{\left\{\frac{1.5f\eta - p(1+\eta)}{1.5f\eta + p(1-\eta)}\right\}}\right] \qquad (3b)$$

The required thickness shall be not less than the greater of the thicknesses determined from equation (1) or (3a), or (2) or (3b).

b) For time-dependent (creep) conditions where the resultant thickness exceeds one-half of the internal diameter. In such cases, the method of calculating the thickness shall be subject to agreement between the purchaser and the manufacturer (see **1.5.2.3**d).

3.3.2.3 Where a shell has tube and wrapper plates of different thicknesses and/or different radii, twice the respective radii shall be used for D_i or D_o, in equation (1), (2), (3a) or (3b).

3.3.2.4 Manufacturing tolerances in shell inside or outside diameters shall not be taken into account in calculating shell thickness.

3.3.3 Ligament efficiency

3.3.3.1 ***Limits of application***

Where openings such as tube holes are drilled in a definite pattern, the efficiency of the ligaments shall be determined by the methods given in **3.3.3.2** to **3.3.3.7**, provided that the diameter of the largest hole in the group does not exceed that permitted by the following.

a) The maximum diameter d (in mm) of any opening designed by this method shall be obtained from the following equation:

$$d = 8.08 \{(1 - K)\, D_o t\}^{1/3} \qquad (4)$$

where

D_o is the nominal outside diameter of the shell (in mm);

t is the actual thickness of the shell (in mm);

K is the factor given by:

$$K = \frac{pD_o}{1.82ft} \text{ (but not exceeding 0.99)}$$

where

p is the calculation pressure (in N/mm^2);

f is the design stress (in N/mm^2) (see **2.2**).

For elliptical or obround[2)] holes, d shall refer to the mean of the major or minor axes.

b) No opening designed by this method shall exceed 200 mm diameter.

Openings larger than those permitted in a) and b) shall be compensated in accordance with **3.4**.

3.3.3.2 ***Equivalent hole diameter***

Where a drum or header is drilled for tube stubs fitted by welding either in line or in staggered formation, the equivalent diameter of the holes d_e (in mm) shall be taken as:

$$d_e = d_a - \frac{A}{t} \qquad (5)$$

where

d_a is the actual diameter of the hole (in mm);

t is the thickness of the shell (in mm);

A is the compensating area provided by each tube stub and its welding fillets (in mm^2).

The compensating area A shall be measured in a plane through the axis of the tube stub parallel to the longitudinal axis of the drum or header and shall be calculated as follows (see figure **3.3.3.2**a).

a) The sectional area of the stub, in excess of that required by equation (31) or (32) for the minimum tube thickness disregarding the minimum thickness given in table 3.7.1.1, from the interior surface of the shell up to a distance b from the outer surface of the shell (see note).

b) Plus the sectional area of the stub projecting inside the shell within a distance b from the inner surface of the shell.

c) Plus the sectional area of the welding fillets inside and outside the shell.

For a) and b) above

$b = \sqrt{(d_a t_a)}$;

where

t_a is the actual thickness of the tube stub (in mm).

NOTE. ln the case of a set-on tube stub (see figure 3.3.3.2b), the compensation extends from the outer surface of the shell only.

Where the material of the tube stub has an allowable stress lower than that of the shell, the compensating sectional area of the stub shall be multiplied by the ratio:

$$\frac{\text{Design stress of stub at design temperature}}{\text{Design stress of shell at design temperature}}$$

No credit shall be taken for the additional strength of tube stub material having a higher stress value than that of the shell plate.

3.3.3.3 ***Regular drilling***

Where the distance between centres of adjacent tube holes is constant:

$$\eta = \frac{s - d}{s} \qquad (6)$$

where

s is the pitch of tube holes (in mm);

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see **3.3.3.2**).

[2)] An obround opening is, for the purposes of this standard, to be understood as an opening or hole that is neither circular nor elliptical; it is formed by the blending of two radii to give a rounded opening/hole, the major and minor axes of which are different.

3.3.3.4 ***Irregular drilling***

Where the distance between centres of adjacent tube holes is not constant (see figure 3.3.3.4):

$$\eta = \frac{s_1 + s_2 - 2d}{s_1 + s_2} \qquad (7)$$

where

s_1 is the shorter of any two adjacent pitches (in mm);

s_2 is the longer of the two adjacent pitches (in mm);

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see **3.3.3.2**).

When applying equation (7), the double pitch ($s_1 + s_2$) chosen shall be that which makes η a minimum, and in no case shall s_2 be taken as greater than twice s_1.

3.3.3.5 ***Diagonal ligaments***

3.3.3.5.1 Where bending stresses due to weight are negligible (otherwise refer to **3.3.4**) and tube holes are arranged either along a diagonal line with respect to the longitudinal axis as shown in figure 3.3.3.5-1, or in a regular pattern as shown in figure 3.3.3.5-2, the efficiency η to be applied in equation (1) shall be obtained from the series of curves given in figure 3.3.3.5-3 with the ratio b/a as abscissa and the ratio $(2a - d)/2a$ or d/a as parameter;

where

a and b are measured as shown in figures 3.3.3.5-1 and 3.3.3.5-2 on the median line of the plate;

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see **3.3.3.2**).

NOTE. The data in figure 3.3.3.5-3 are based on the following:

$$\eta = \frac{2}{A + B + \sqrt{\{(A - B)^2 + 4C^2\}}}$$

where

$$A = \frac{\cos^2 \alpha + 1}{2\left(1 - \frac{d \cos \alpha}{a}\right)}$$

$$B = ½\left(1 - \frac{d \cos \alpha}{a}\right)(\sin^2 \alpha + 1)$$

$$C = \frac{\sin \alpha \cos \alpha}{2\left(1 - \frac{d \cos \alpha}{a}\right)}$$

$$\cos \alpha = \frac{1}{\sqrt{\left(1 + \frac{b^2}{a^2}\right)}}$$

$$\sin \alpha = \frac{1}{\sqrt{\left(1 + \frac{a^2}{b^2}\right)}}$$

where

α is the angle of centre line of cylinder to centre line of diagonal holes.

3.3.3.5.2 Where there is regular staggered spacing of tube holes as shown in figure 3.3.3.5-4 the smallest value of the efficiency of all the ligament (longitudinal, circumferential and diagonal) shall be obtained from figure 3.3.3.5-5 with

the ratio S_c/S_l, as abscissa and the ratio $\frac{S_l - d}{S_l}$ or d/a

as parameter:

where

d is either the mean effective diameter of the tube holes after allowing for any serrations, counter-boring or recessing, or the equivalent diameter (d_e) after allowing for the compensating effect of the tube stub (in mm) (see **3.3.3.2**);

S_c is twice the distance (b) between axial rows of holes measured on the median line of the plate (in mm);

S_l is twice the distance (a) between circumferential rows of holes (in mm).

3.3.3.6 ***Irregular drilling not in a straight line***

For holes placed longitudinally along a drum or header which do not come in line, equation (7) in **3.3.3.4** shall apply except that an equivalent longitudinal width of the diagonal ligament shall be used. An equivalent longitudinal width shall be that width which gives, using equation (6), the same efficiency as would be obtained using figure 3.3.3.5-3 for the diagonal ligament in question.

3.3.3.7 ***Circumferential ligaments***

3.3.3.7.1 Where bending stresses due to weight are negligible (otherwise, refer to **3.3.4**) the efficiency of ligaments between holes measured on a circumferential line shall not be used to calculate the thickness of a cylindrical shell provided that the efficiency of the circumferential ligaments calculated in accordance with equations (6) and (7) is not less than one-half of that of the longitudinal ligaments.

3.3.3.7.2 Where the circumferential pitch between tube holes measured on the mean of the external and internal drum or header diameters is such that the circumferential ligament efficiency determined by equations (6) and (7) is less than one-half of the ligament efficiency on the longitudinal axis, then η in equations (1) to (3b) shall be taken as twice the circumferential efficiency.

3.3.4 Combined stresses in drum or header shells

3.3.4.1 ***General***

Notwithstanding the thickness of shells calculated in accordance with **3.3.2** and **3.3.3**, calculations shall be made to ensure that in no case does the average ligament stress resulting from the combination of stresses arising from internal pressure, the self-weight of the drum or header and its contents, and all externally applied loads, exceed the design stress f (see **2.2**) in any line of holes whether longitudinal, circumferential or diagonal.

The average ligament stress in ligaments between holes on a circumferential line shall be the sum of the longitudinal stresses calculated in accordance with **3.3.4.2** and **3.3.4.3**. The average ligament stress in ligaments between holes on a diagonal line shall be calculated in accordance with **3.3.4.4**.

3.3.4.2 ***Longitudinal direct pressure stress***

The maximum direct longitudinal stress f_d (in N/mm^2) due to internal pressure on the drum or header ends shall be calculated as follows:

$$f_d = \frac{pD_i^2}{1.273A} \qquad (8)$$

where

- p is the calculation pressure (in N/mm^2);
- D_i is the nominal inside diameter of the drum or header (in mm);
- A is the net cross-sectional area of the drum or header shell plate taken through the tube holes in a plane at right angles to its axis (in mm^2).

When a hole in the shell is wholly or partly reinforced by the attaching nozzle the hole size shall be reduced accordingly (see **3.3.3.2**).

Nozzles designed in accordance with **3.4** shall be considered as wholly reinforced.

3.3.4.3 ***Longitudinal bending stress***

3.3.4.3.1 The resultant bending moment M_R (in N·mm) at any section shall be the algebraic sum of the resultant bending moments due to the eccentricity of the end pressure M_E and due to externally applied loads M_W, i.e.

$$M_R = M_E + M_W \qquad (9)$$

The resultant bending moment M_E (in N·mm) due to eccentricity of end pressure shall be calculated from:

$$M_E = \frac{p\,D_i^2 e}{1.273} \qquad (10)$$

where

- p is the calculation pressure (in N/mm^2);
- D_i is the nominal inside diameter of the drum or header (in mm);
- e is the eccentricity of the net cross section (see figure B.3).

The resultant bending moment M_W (in N·mm) due to externally applied loads shall be calculated by treating the shell as a beam carrying the externally applied loads including its own weight and that of the contents under working conditions. M_W is the bending moment at the section subjected to the greatest bending from this cause.

3.3.4.3.2 The stress due to bending f_b (in N/mm^2) shall be calculated as follows:

$$f_b = \frac{M_R Y}{I_A} \qquad (11)$$

where

- M_R is the resultant bending moment (in N·mm) (see **3.3.4.3.1**);
- Y is the distance from the neutral axis of the net cross section to the extreme mid point of the shell thickness (in mm);
- I_A is the second moment of area of the net cross section through the tube holes taken about its neutral axis (in mm^4) (see also **3.3.4.3.3**).

If a welded nozzle has been designed to compensate fully for the removal of drum material (i.e. when $\eta = 1.0$) the nozzle and its opening shall be assumed to be absent in calculating the longitudinal bending stress. If the nozzle is designed to compensate only for part of the material removed from the drum, the second moment of area of the drum section shall be calculated assuming the size of the hole to be reduced by the amount of compensation provided by the nozzle (see **3.3.3.2**).

3.3.4.3.3 In calculating the longitudinal stress in a drum supported on stools or slings and connected to a second drum by a bank of tubes (so arranged as to form substantial struts or ties between the drums), an increase in the value of the second moment of area I_A (in mm^4) used in **3.3.4.3.2** shall be permitted to take account of the support received from the second drum as follows:

$$I_A = I_b + SI_c$$

where

- I_b is the second moment of area of the supported drum (in mm^4);
- I_c is the second moment of area of the second drum (in mm^4);
- S is a factor given by:

$$S = 1 - \frac{\alpha^2}{240} \qquad (12)$$

where

- α is the angle between the vertical and the line joining the centres of the two drums (in degrees);

where α is equal to or greater than 15.5 °, S shall be taken as 0.

In no case shall the actual value of l_A used in equation (11) be taken as more than 1.33 times the second moment of area of the supported drum l_b.

NOTE. In this context, 'bank of tubes' means four or more rows of tubes extending over at least three-quarters of the drum length between supports and pitched longitudinally at not greater than an average pitch of four tube diameters.

3.3.4.4 *Evaluation of stresses*

Where bending stresses due to weight, externally applied loads and eccentricity of end pressure are not negligible, the stress on ligaments which are on a line which is at an angle a to the longitudinal axis of the drum, as shown in figure 3.3.4.4, shall be evaluated as follows:

Let the circumferential stress on gross area of longitudinal section σ_1 (in N/mm²) be:

$$\sigma_1 = p\,\frac{(D_i + t)}{2t}$$

where

- p is the calculation pressure (in N/mm²);
- D_i is the nominal inside diameter of the shell (see **3.3.2.3** and **3.3.2.4**) (in mm);
- t is the minimum thickness of the shell before allowance for metal wastage (see equation (1)) (in mm).

Let the longitudinal stress on gross area of circumferential section σ_2 (in N/mm²) be:

$$\sigma_2 = \eta_2\,(f_d + f_b)$$

where

- f_d is the stress due to pressure end load (see equation (8)) (in N/mm²);
- f_b is the bending stress due to eccentricity of pressure end load added algebraically to bending stress due to weight loading calculated in accordance with equation (11) taking Y as the distance from the neutral axis of the net cross section to the mid point of the inclined ligament (in N/mm²);
- η_2 is the ligament efficiency on a circumferential section at the point where f_d and f_b act.

Where the ligament under consideration is between holes of equal size, the actual ligament efficiency (η_3) on the diagonal line shall be given by:

$$\eta_3 = 1 - \frac{d \cos a}{a}$$

Where holes are of unequal size, the ligament efficiency (η_3) on the diagonal line shall be given by:

$$\eta_3 = 1 - \frac{(d_1 + d_2) \cos a}{2a}$$

where the symbols are as shown on figure 3.3.4.4.

The average direct stress A_1 (in N/mm²) on the ligament shall be given by:

$$A_1 = \frac{1}{\eta_3}\left\{\frac{\sigma_1 + \sigma_2}{2} + \frac{(\sigma_1 - \sigma_2)\cos 2a}{2}\right\}$$

The average transverse stress B_1 (in N/mm²) on the ligament shall be given by:

$$B_1 = \eta_3\left\{\frac{\sigma_1 + \sigma_2}{2} - \frac{(\sigma_1 - \sigma_2)\cos 2a}{2}\right\}$$

The average shear stress C_1 (in N/mm²) on the ligament shall be given by:

$$C_1 = \frac{(\sigma_1 - \sigma_2)\sin 2a}{2\eta_3}$$

The stress f (in N/mm²) on the ligament shall be given by:

$$f = \frac{1}{2}\,[A_1 + B_1 + \sqrt{\{(A_1 - B_1)^2 + 4C_1^2\}}] \qquad (13)$$

and this shall not exceed the design stress (see **2.2**).

3.3.5 Boiler drum supports

Where large diameter but relatively thin drums are carrying heavyloads on stools or slings, equation (14) shall be used as a guide to assess whether precise calculations are needed to determine local stresses:

$$0.78\left(\frac{W}{St}\right)\sqrt{\left(\frac{R}{t}\right)} \leq f \qquad (14)$$

where

- R is the mean radius of the drum shell (in mm);
- t is the thickness of the drum shell (in mm);
- W is the load on the stool or sling (in N);
- S is the horizontal length of the stool or sling at right angles to axis of the drum but in any case not greater than the chord described by 120 ° (in mm);
- f is the design stress at the design temperature (in N/mm²).

Where application of this equation suggests that the design stress is exceeded, reference shall be made to the appropriate methods of analysis given in annex G of BS 5500: 1997.

3.3.6 Other stresses in cylindrical shells

In addition to the requirements of **3.3.2** and **3.3.4**, which cover general membrane stresses in the shell, and **3.3.5**, which covers local stresses at supports, any other local stresses shall also be considered. Local stresses shall not be included when applying **3.3.4**. Local stresses at nozzles carrying significant load shall be accounted for as required by **3.4.4.1**.

3.4 Openings and branches in cylindrical shells and integral pipes

NOTE. This clause specifies the design rules for openings and branches in cylindrical shells. Recommendations on the forms of connections to be used for branches are given in annex C, which additionally covers studded and welded sockets.

3.4.1 General

3.4.1.1 The amount of compensation to be provided at an opening for which the ligament efficiency method of **3.3.3** cannot be applied shall be not less than that specified in **3.4.1.2** to **3.4.11**.

3.4.1.2 Design charts are referred to in **3.4.4.3** that are based on approximate analysis considering internal pressure loading only, but the effects of other loads shall be taken into account.

NOTE 1. The basis on which the design charts (figures 3.4.4-1 to 3.4.4-3) are founded is outlined in annex D.

NOTE 2. The effects of loading other than that from internal pressure may be taken into account by the selection of an appropriate value for the factor C (see **3.4.2** and **3.4.4**).

Similarly, the effects of attachments and discontinuities in the proximity of the openings shall be taken into account and in no case shall branch connections be less than the thickness specified in **3.4.7**. Where material having a lower design stress than that of the shell is taken as compensation, its effective area shall be assumed to be reduced in the ratio of the allowable design stresses at the design temperature, except that in no case shall a material having an allowable stress less than 60 % of the shell material be used. Material having a design stress up to 50 % greater than that for the shell may be used but no credit shall be taken for this in calculating the necessary effective area of such compensation.

All branch connections, nozzles and openings not covered in **3.4.3** shall be designed on the basis of special analysis, experimental evidence, or tests to the satisfaction of the purchaser. The alternative method given in annex E shall be permitted where experience has shown it to be satisfactory.

NOTE 3. All dimensions exclude any wastage allowances.

3.4.2 Notation

For the purposes of the calculations in **3.4.3** to **3.4.6** the following symbols apply (see also figures 3.4.2-1, 3.4.2-2, 3.4.4-1 to 3.4.4-6, 3.4.4-9 to 3.4.4-11 and 3.4.5-2):

A_s, A_n and A_t, are cross-sectional areas used in the calculation of compensation for adjacent branches (see figure 3.4.5-2)

C is a factor applied to T_r/T

D is the mean diameter of the cylindrical shell

d is the bore of an opening not provided with a branch, or the mean diameter of a branch; in the case of non-circular openings (see **3.4.4.6**).

d_A is the average value of d for any two adjacent openings being considered

f_n is the design strength of the rim or forging

f_s is the design stress of the shell

g is the arrangement factor from figure 3.4.5-1

H is the distance along the shell within which the shell thickening is assumed to contribute to the reinforcement of an opening

h is the distance along the branch within which branch thickening is assumed to contribute to the reinforcement of an opening

P is the pitch measured between the centrelines of two openings along mid-thickness of shell

T is the shell thickness as calculated using either equations in **3.3.2** with η = 1.0 or equations (31) or (32) in **3.7.1**

T_r is the total thickness of the shell as required throughout **3.4**

T'_r is the modified thickness of the shell (see figures 3.4.4-7 and 3.4.4-8)

t is the branch thickness as calculated using the branch design stress by the equations for pressure loading only in **3.7.1** for a plain cylinder

t_r is the total thickness of the branch as required throughout **3.4**

t'_r is the modified thickness of the branch (see figures 3.4.4-7 and 3.4.4-8)

Y is a factor from figure 3.4.4-2

$\rho = \dfrac{d}{D}\sqrt{\left(\dfrac{D}{2T_r}\right)}$

3.4.3 Application

The rules specified in **3.4.4** to **3.4.9** shall be regarded as valid for the design of circular, elliptical and obround[3)] openings and nozzles (including oblique nozzles) arranged singly or in groups, in cylindrical shells, provided that the mean diameter to thickness ratio of the shell D/T satisfies $D/T \leq 100$ and provided that the following conditions are satisfied.

a) *Openings and nozzles normal to the shell.* The ratio of the major to minor axes of the opening does not exceed 2.

b) *Oblique nozzles.* The nozzle is of circular cross section and the angle between the axis of the nozzle and a line normal to the shell surface does not exceed 50 °.

c) *Protruding nozzles.* The mean diameter of the branch does not exceed one-third of the mean diameter of the shell.

---

3) See footnote to **3.3.3.1** for an explanation of 'obround'.

d) *All nozzles*. The nozzle connection is made by fully penetrating welds.

NOTE. This requirement therefore excludes connections similar to those shown in figure C.10 and C.11 and the fillet welded connections shown in figure C.20.

Nozzle connections made with other than fully penetrating welds shall be considered as openings not fitted with branch pieces (see **3.4.4.2**), the opening being that formed in the shell before the branch is attached.

NOTE. In cases where the design stress is time-dependent, the requirements of this clause should give adequate margins against creep rupture. However, for parts made from austenitic materials, it may be desirable to check that the end of life deformation is acceptable.

3.4.4 Design of isolated openings and branch connections

3.4.4.1 *General*

The thickness of shell, T_r, shall be not less than T and the thickness of a branch connection, t_r, shall be not less than t. Where external loads are negligible, the factor C shall be taken as not more than 1.1.

Where branch or nozzle connections are attached to a piping system designed with due allowance for expansion thrusts, etc. (e.g. conforming to the flexibility requirements of BS 806) C shall be taken as not more than 1.0.

Other loadings shall be evaluated in accordance with annex G of BS 5500 : 1997 and the thickness of shell or branch increased if necessary, such as by selection of a value of C less than 1.0.

For vessels operating in the creep range, $C \leq 1$.

3.4.4.2 *Openings not fitted with branches*

The value $t_r/T_r = 0$ shall be taken in figure 3.4.4-1 and the factor $C = 1.1$ used to obtain the shell thickness T_r. An iteration shall be performed using a revised value of ρ until the assumed and required values of T_r are equal.

3.4.4.3 *Openings fitted with branches*

Branch connections shall be permitted to be reinforced by means of an increase in shell thickness or nozzle thickness or by a combination of increases. In some cases, e.g. where external pipework loads are significant, or in order to meet the branch thickness limit specified in **3.4.4.4**c, thickening of the shell may be necessary. This will need to be considered at an early stage in the design process. The following design charts shall apply:

a) figure 3.4.4-1, for flush nozzles with $d/D < 0.3$;

b) figure 3.4.4-2, for flush nozzles with $d/D > 0.2$;

c) figure 3.4.4-3, for protruding nozzles with $d/D < 0.33$.

A value of shell thickness $T_r \geq T$ shall be chosen, and an estimate of the branch thickness $t_r \geq t$ made so that the mean branch diameter d and hence d/D and (where necessary) ρ can be calculated. Using an appropriate value of C from **3.4.4.1**, the appropriate design chart shall be entered to give the required value of t_r/T_r (figures 3.4.4-1 and 3.4.4-3) or Y (figure 3.4.4-2) from which t_r shall be determined. In the case of flush nozzles in cylindrical vessels where $0.2 < d/D < 0.3$, it is necessary to derive a value t_{r1} from figure 3.4.4-1 and t_{r2} from figure 3.4.4-2 and interpolate so that:

$$t_r = t_{r1} + 10(d/D - 0.2)\,(t_{r2} - t_{r1})$$

If the value of t_r obtained differs from the estimate a revised value shall be used and the calculation repeated until convergence is achieved. Figures 3.4.4-1, 3.4.4-2 and 3.4.4-3 are provided for ease of application in manual calculations. Definitive thicknesses shall be obtained from the tabulated data in tables 3.4.4a and 3.4.4b. Where it is required to determine t_r/T_r for CT_r/T and ρ values that are not explicitly tabulated, the following procedure shall be used.

1) For the nearest listed ρ value below that required, find the nearest tabulated CT_r/T values bounding the exact value above and below. Interpolate linearly to obtain t_r/T_r corresponding to the required value of CT_r/T.

2) Similarly obtain t_r/T_r for the exact CT_r/T value for the nearest tabulated ρ value greater than that required.

3) Finally interpolate linearly to obtain t_r/T_r for the exact value of ρ.

Extrapolation of the data beyond the limits presented is not allowed. No reinforcing of the branch is required if the chosen CT_r/T, value for the vessel is greater than CT_r/T, as read from the relevant figure, corresponding to $t_r/T_r = 0$ and for the relevant value of ρ. In this case the thickness of the branch is determined by **3.4.7**.

3.4.4.4 *Limits on reinforcement*

The extent of reinforcement shall be as follows.

a) Where reinforcement is provided by uniform branch thickening, the thickness t_r of the branch and protrusion, if fitted, shall not be reduced within a distance $h = \sqrt{(dt_r)}$ measured from the relevant surface of the shell of thickness T_r (see figures 3.4.4-4, 3.4.4-5 and 3.4.4-6).

It is permissible to modify the distribution of reinforcement so as to concentrate the material close to the opening in the shell. For flush nozzles one-half of the total cross-sectional area of the branch walls falling within the distance h as calculated and measured above shall be not less than ht_r (see figure 3.4.4-8). For protruding nozzles, the corresponding cross-sectional area shall be not less than $2ht_r$ and the reinforcement shall be (approximately) equally disposed about the shell mid-thickness (see figure 3.4.4-7). The value of h is established for the uniform branch thickening case and is not recalculated if t_r is varied.

b) Where reinforcement is provided by uniform shell thickening, the thickness T_r of the shell shall not be reduced within a distance H measured from the outer surface of the branch piece of thickness t_r or the bore of the opening if no branch is fitted (see figures 3.4.4-6, 3.4.4-9 and 3.4.4-10) where H is the smaller of $H = d/2$ or $H = \sqrt{(DT_r)}$.

It is permissible for reinforcing material to be concentrated close to the opening. In this case one-half of the total cross-sectional area taken between the outermost extremity of the dimension H on one side of the nozzle and a similar point on the opposite side of the nozzle, but excluding any area included in a), shall be not less than T_r $(H + t_r)$. The value of H is to be calculated and measured as above (see figures 3.4.4-7 and 3.4.4-8) and once established is not recalculated.

c) The required thickness of the branch t_r (except for studded pads, see **3.4.8**) shall be less than $(2 - d/D)$ T_r. Where the distribution of the reinforcement has been concentrated close to the opening as permitted in a) and b) the modified thicknesses t'_r and T'_r (see figures 3.4.4-7 and 3.4.4-8) shall be substituted in this relationship as appropriate.

d) The transitions between sections of shell of different thicknesses shall be achieved by means of smooth tapers no steeper than 1 : 4. The transitions between sections of branch or nozzle connections of different thicknesses shall be smoothly tapered.

Table 3.4.4a Design values of t_r/T_r for flush nozzles in cylindrical shells $(0 < d/D < 0.3)$

See also figure 3.4.4-1

CT_r/T \ ρ	**2.0**	**1.8**	**1.6**	**1.4**	**1.2**	**1.0**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
3.1	0.04														
3.0	0.11														
2.9	0.15	0.06													
2.8	0.19	0.13													
2.7	0.23	0.17	0.08												
2.6	0.27	0.22	0.13												
2.5	0.31	0.26	0.18	0.06											
2.4	0.35	0.30	0.22	0.12											
2.3	0.40	0.35	0.27	0.18	0.07										
2.2	0.45	0.39	0.32	0.23	0.15										
2.1	0.50	0.45	0.38	0.30	0.22	0.07									
2.0	0.56	0.50	0.44	0.36	0.27	0.16	0.06								
1.9	0.63	0.56	0.49	0.42	0.33	0.23	0.14	0.04							
1.8	0.70	0.63	0.56	0.48	0.39	0.28	0.21	0.14	0.03						
1.7	0.80	0.71	0.63	0.54	0.44	0.33	0.26	0.21	0.12						
1.6	0.92	0.82	0.72	0.62	0.51	0.38	0.32	0.27	0.20	0.11					
1.5	1.06	0.95	0.83	0.72	0.59	0.46	0.38	0.32	0.26	0.20	0.09				
1.4	1.23	1.11	0.98	0.84	0.70	0.55	0.46	0.39	0.33	0.27	0.19	0.03			
1.3	1.44	1.30	1.17	1.02	0.84	0.67	0.57	0.50	0.41	0.34	0.26	0.16			
1.2	1.77	1.60	1.42	1.26	1.05	0.85	0.72	0.61	0.50	0.42	0.34	0.26	0.14		
1.1			1.81	1.57	1.33	1.10	0.95	0.79	0.65	0.53	0.43	0.35	0.25	0.10	
1.0				1.96	1.68	1.42	1.22	1.04	0.82	0.66	0.54	0.45	0.34	0.22	0.10

Table 3.4.4b Design values of t_r/T_r for protruding nozzles in cylindrical shells ($0 < d/D < 0.33$)
See also figure 3.4.4-3

CT_r/T \ ρ	**2.0**	**1.8**	**1.6**	**1.4**	**1.2**	**1.0**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
3.2															
3.1	0.04														
3.0	0.11														
2.9	0.15	0.06													
2.8	0.19	0.13													
2.7	0.22	0.17	0.07												
2.6	0.25	0.21	0.13												
2.5	0.29	0.24	0.17	0.06											
2.4	0.33	0.28	0.21	0.13											
2.3	0.36	0.31	0.25	0.18	0.04										
2.2	0.40	0.35	0.29	0.22	0.13										
2.1	0.45	0.39	0.33	0.26	0.18	0.00									
2.0	0.49	0.44	0.37	0.30	0.23	0.12									
1.9	0.55	0.49	0.42	0.35	0.28	0.19	0.11								
1.8	0.61	0.54	0.46	0.39	0.32	0.25	0.20	0.10							
1.7	0.68	0.61	0.52	0.45	0.37	0.30	0.26	0.19	0.07						
1.6	0.75	0.68	0.59	0.51	0.42	0.35	0.31	0.26	0.17	0.04					
1.5	0.85	0.77	0.68	0.58	0.49	0.40	0.36	0.31	0.25	0.15	0.02				
1.4	0.95	0.88	0.79	0.68	0.58	0.47	0.43	0.37	0.32	0.24	0.15	0.01			
1.3	1.08	1.00	0.91	0.80	0.68	0.56	0.51	0.45	0.39	0.33	0.25	0.14			
1.2	1.22	1.14	1.04	0.93	0.81	0.68	0.61	0.55	0.48	0.41	0.34	0.25	0.14		
1.1	1.37	1.29	1.19	1.08	0.96	0.82	0.75	0.67	0.58	0.51	0.43	0.35	0.25	0.09	
1.0	1.53	1.44	1.35	1.24	1.13	0.99	0.91	0.81	0.71	0.62	0.52	0.44	0.34	0.21	0.06

Table 3.4.4c Design values of CT_r/T at $t_r/T_r = 0$ for nozzles in cylindrical shells

	ρ														
Type of nozzle	**2.0**	**1.8**	**1.6**	**1.4**	**1.2**	**1.0**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
Flush nozzle	3.14	2.94	2.76	2.54	2.36	2.15	2.04	1.94	1.82	1.70	1.56	1.42	1.29	1.16	1.05
Protruding nozzle	3.14	2.94	2.76	2.54	2.32	2.10	1.99	1.87	1.74	1.63	1.51	1.41	1.29	1.16	1.04

3.4.4.5 ***Rim reinforcements***

The design of rim reinforcements (see figure 3.4.4-11) shall be derived from that for branch connections in the following manner.

Proceeding as specified in **3.4.4.3**, a combination of T_r and t_r shall be determined using figure 3.4.4-3 if the rim is to be protruding (see figure 3.4.4-11a) and figure 3.4.4-1 for a flush rim (see figure 3.4.4-11b). The rim shall be designed to a smooth profile, concentrating material near the edge of the opening, such that one-half of the total cross-sectional area falling within the outermost extremities of the dimensions h and H as calculated and measured in **3.4.4.4**a and b) is not less than the following:

a) $|2ht_r + T(H + t_r)|\ (f_s/f_n)$ if the rim protrudes

b) $|ht_r + T(H + t_r)|\ (f_s/f_n)$ if the rim is flush.

For the protruding rim, the cross-sectional area shall be equally disposed about the shell mid-thickness.

NOTE. The cross-sectional area of the rim required in this derivation will vary depending on the particular combination of T_r and t_r. A trial procedure using different combinations of T_r and t_r may be employed to establish the minimum area required.

3.4.4.6 ***Obround[4]), elliptical and oblique openings and nozzles***

Non circular openings and oblique nozzles shall be treated according to the rules for circular openings and nozzles normal to the shell except the following.

a) For a cylindrical shell with the minor axis or the opening parallel to the axis of the shell, where a branch is not provided, d is the dimension measured on the chord across the minor axis of the opening and, where a branch is attached, d is the corresponding dimension of the opening plus the nozzle thickness.

For all other cases, where a branch is not provided, d is the dimension measured across the major axis of the opening and where a branch is attached, d is the corresponding dimension of the opening plus the nozzle thickness.

b) In determining dimensions H and h the value of d shall be as given in a).

c) In the case of multiple openings, the value of d_A used in **3.4.5** shall be determined using d as given in a).

3.4.4.7 ***Dissimilar materials***

Where the branch and shell are not of equal design strength and the design strength of the branch f_n is within the range $0.6f_s$ to $1.5f_s$, the following shall apply:

if $0.6f_s < f_n < f_s$ the calculated branch thickness (disregarding here the requirement of **3.4.7**) shall be increased to:

$$t_{rs} \text{ where } t_{rs} \geq t_r \frac{f_s}{f_n}$$

A check shall be made to ensure that t_{rs} meets the minimum thickness requirements of **3.4.7**.

[4]) See footnote to **3.3.3.1** for an explanation of 'obround'.

NOTE 1. Where the thickness t_r is modified in accordance with this subclause, it is not necessary to recalculate the mean branch diameter d, and iterate further. Neither is it necessary to recalculate h.

NOTE 2. If $f_n > f_s$ no reduction in t_r is allowed.

NOTE 3. Where reinforcement is concentrated near the opening, see also figures 3.4.4-7 and 3.4.4-8.

NOTE 4. For forged nozzle inserts, the procedure in **3.4.4.5** includes the necessary thickening correction factor.

3.4.5 Design of groups of openings and branches

A group of openings or branches is defined as a group in which the shortest pitch between any two branches or openings is less than $d_A + 3\sqrt{(DT)}$.

The compensation required shall be calculated as follows.

a) The reinforcement required shall be calculated as for the isolated case assuming that the full width H is available.

b) Where the shortest pitch between adjacent openings is such that $P < d_A + 2\sqrt{(DT)}$, the reinforcement calculated in a) shall be increased if required so that, for each ligament (see figures 3.4.5-1 and 3.4.5-2) $A_s + A_n - A_t \geq gPT$.

c) Where the shortest pitch between adjacent openings lies between $P_1 = d_A + 2\sqrt{(DT)}$ and $P_2 = d_A + 3\sqrt{(DT)}$, the reinforcement required shall be determined by linear interpolation as follows, using the dimensions determined in a).

1) The compensation ratio K for pitch P_2 shall be calculated, using the reinforcement required in a), as follows:

$$K = \frac{A_s + A_n - A_t}{gP_2T} \qquad (15)$$

(K shall be not greater than 1)

2) The compensation ratio K_2 required at the actual pitch P shall be:

$$K_2 = 1 - \frac{(P - P_1)}{(P_2 - P_1)}(1 - K) \qquad (16)$$

3) The dimensions calculated in a) shall be increased if required so that, for each ligament, $A_s + A_n - A_t \geq K_2gPT$.

d) The final thickness of the branch t_r shall be less than $(2 - d/D)\ T_r$.

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

3.4.6 Reinforcing pads

3.4.6.1 *General*

Reinforcing pads shall not be used where there is a possibility of severe corrosion or oxidation or of large temperature gradients across the thickness of the shell.

3.4.6.2 *Pressure considerations*

When reinforcing pads are used for reinforcement of penetrations or openings, the following conditions shall be observed.

a) The ratio *d/D* of the branch diameter to the cylinder diameter shall not be greater than the following unless the adequacy of the design is demonstrated by experience or by a hydraulic proof test in accordance with **3.8**.

1) ⅓ for double-sided pads;

2) ¼ for single-sided pads.

b) The width of the pad shall not be less than $H/2$, where H is the distance along the shell within which the shell thickening is assumed to contribute to the reinforcement of an opening.

c) The thickness of a pad shall not exceed 40 mm or the as-built shell thickness, whichever is the lesser.

d) The thickness of the pad shall not be less than $T/4$, where T is the shell thickness.

e) The amount of compensation to be provided shall be equal to the amount which would have been necessary had the compensation been integral.

f) The weld preparations shall be as shown in either figure C.18 or figure C.19.

3.4.6.3 *Non-pressure considerations*

Conditions a) to d) in **3.4.6.2** do not apply to reinforcing pads which are used to limit the local stresses due to mechanical loads on branches, supports or mountings. However, the maximum thickness of a pad which can be counted as effective reinforcement of a branch for pressure loading shall be limited to the value given in **3.4.6.2**c.

If the thickness of the reinforcing pad, t_1, is greater than the drum shell thickness, t, its size ($d_o \times d_x$), shall be such that the design leg length of the attachment welds to the drum shell does not exceed the drum thickness, t (see **G.2** of BS 5500 : 1997).

3.4.7 Branches

The design of branches shall be governed by the following four considerations.

a) The ability to withstand design pressure; for this purpose the minimum thickness of the branch shall be calculated in accordance with **3.7.1**.

b) Compensation requirements for openings in the main pressure part, which shall be determined, for cylindrical shells, in accordance with **3.4.4** or **3.4.5**.

c) The ability to withstand superimposed loading due to connected pipework or fittings; the requirements of **3.4.4.1** shall be taken into account.

d) Suitability for the recommended forms of branch to shell attachment welds shown in annex C.

The minimum thickness of the branch shall be the greatest of the values required by a) to d) and shall not be less than $0.015d_o + 3.2$ mm, where d_o is the outside diameter of the branch (in mm). The requirements of this subclause shall not apply to tube stubs, which shall be designed as tubes.

3.4.8 Studded connections

The attachment of connections by studding only shall be permitted where the design temperature does not exceed 400 °C. Where the thickness of the drum or header is inadequate to permit direct attachment, pads or saddles shall be secured to the pressure part by welding (see figure C.20). Where required by this section, reinforcement shall be incorporated. Studs and nuts shall be of a material suitable for the operating conditions (see BS 4882).

3.4.9 Screwed connections into shell

The attachment of connections by screwing into the shell shall be permitted only if the following are complied with.

a) The outside diameter of the connection does not exceed 60.3 mm.

b) The calculation pressure does not exceed 4 N/mm^2.

c) The design temperature does not exceed 400 °C.

d) Seal welding shall be applied if the design temperature is greater than 220 °C or the calculation pressure is greater than 2 N/mm^2.

e) The steel of the screwed component does not contain more than 0.25 % (*m/m*) carbon.

The design of connections shall conform to **3.4.7**; the minimum thickness shall be measured at the root of the thread.

The main pressure part shall be designed as having an uncompensated opening with a diameter equal to that of the root of the thread in the hole.

3.4.10 Screwed socket connections

Screwed socket connections (see figure C.21) shall be permitted only if the conditions given in **3.7.7.5** are complied with.

The main pressure part shall be designed as having an uncompensated opening.

3.4.11 Socket welded connections

Socket welded connections (see figure C.21) shall be permitted only if the conditions given in **3.7.7.4** are complied with.

The main pressure part shall be designed as having an uncompensated opening.

NOTE. To achieve the required throat dimension the leg lengths of the fillet weld shown in BS 2633 and BS 4677 will need to be increased.

3.5 Headers of rectangular section

3.5.1 Thickness of straight headers

3.5.1.1 To determine the thickness of headers of rectangular section with solid walls, the thickness required at the centre of the sides, at all the lines of holes and at the corners shall be considered. The required thickness shall be the greatest value so determined. In the case of staggered holes, the effect of the off-set shall be investigated by considering the diagonal ligaments (see figure 3.5.1-1).

The minimum thickness t (in mm) of the shell before allowance for wastage shall be given by the following equation:

$$t = \frac{Pn}{2f\eta} + \sqrt{\left(\frac{4\,YP}{f\eta'}\right)} \qquad (17)$$

where

- P is the design pressure (in N/mm^2);
- f is the design stress (in N/mm^2) (see **2.2**);
- Y is a coefficient given by equations (18), (19), (20) or (21);
- n is one-half of the internal width of the wall perpendicular to that referred to in the calculation (in mm);
- η is the ligament efficiency referring to the membrane stresses and is calculated by the use of the equation (22) or (23);
- η' is the ligament efficiency referring to the bending stresses and is calculated by the use of the equations (24), (25), (26) or (27).

3.5.1.2 The coefficient Y to be used in determining the thickness required at the centre of the side with internal width 2 m shall be determined as follows:

$$Y = \frac{1}{3}\left(\frac{m^3 + n^3}{m + n}\right) - \frac{1}{2}m^2 \qquad (18)$$

where

- m is one-half of the internal width of the wall referred to in the calculation (in mm) (see figure 3.5.1-2);
- n is one-half of the internal width of the wall perpendicular to that referred to in the calculation (in mm).

The coefficient Y to be used in determining the thickness required at a line of holes parallel to the longitudinal axis of the header on the wall of width $2m$ shall be determined as follows:

$$Y = \frac{1}{3}\left(\frac{m^3 + n^3}{m + n}\right) - \frac{m^2 - c^2}{2} \qquad (19)$$

where

- c is the distance from the centre of the holes to the centre line of the wall (in mm) (see figure 3.5.1-1a and b).

To check the effect of the off-set on a staggered hole arrangement where the holes are position equidistantly from the centre line of the wall, the coefficient Y shall be calculated as follows:

$$Y = \cos\alpha \left\{\frac{1}{3}\left(\frac{m^3 + n^3}{m + n}\right) - \frac{m^2}{2}\right\} \qquad (20)$$

where

- α is the angle indicated in figure 3.5.1-1b.

NOTE. If the value of Y is negative, the sign does not have to be considered.

The coefficient Y to be used in determining the thickness required due to the stresses at the corners, shall be determined as follows:

$$Y = \frac{1}{3}\left(\frac{m^3 + n^3}{m + n}\right) \qquad (21)$$

NOTE. In this case the value of η and η' in equation (17) will be equal to 1.0.

3.5.1.3 The ligament efficiency η in the case of a line of holes parallel to the longitudinal axis of the header shall be determined as follows:

$$\eta = \frac{p - d}{p} \qquad (22)$$

(See figure 3.5.1-1a and b.)

The ligament efficiency η to be considered in the calculation relating to the diagonals shall be determined as follows:

$$\eta = \frac{p_1 - d}{p_1} \qquad (23)$$

(See figure 3.5.1-1b.)

The ligament efficiency η' in the case of a line of holes parallel to the longitudinal axis of the header shall be determined as follows:

$$\eta' = \frac{p - d}{p}, \text{ when } d < 0.6\text{ m} \qquad (24)$$

or

$$\eta' = \frac{p - 0.6m}{p}, \text{ when } d \geq 0.6\text{ m} \qquad (25)$$

The ligament efficiency η' to be considered in the calculation relating to the diagonals shall be determined as follows:

$$\eta' = \frac{p_1 - d}{p_1}, \text{ when } d < 0.6\text{m} \qquad (26)$$

or

$$\eta' = \frac{p_1 - 0.6m}{p_1}, \text{ when } d \geq 0.6\text{ m} \qquad (27)$$

In the case of elliptical or obround[5)] holes, the value of d used in the equations for η and η' shall be the inside dimension of the hole measured parallel to the longitudinal axis of the header.

For evaluation of the two limiting values of d in equations (24) or (25) and (26) or (27), the value of d shall be the inside dimension of the hole measured perpendicular to the longitudinal axis of the header.

3.5.2 Corner radius of straight headers

To avoid excessive discontinuity stresses at the corners, the following condition shall be satisfied.

$$r \geq \frac{1}{3} e \geq 8 \text{ mm}$$

where

r is the internal corner radius (in mm) (see figure 3.5.1-2);

e is the mean of the nominal thicknesses of the two sides (in mm).

In any case r shall not be taken as less than 8 mm.

3.5.3 Headers of rectangular section which are not straight

The scantlings of rectangular section headers of the curved, staggered, sinuous or corrugated type shall be subject to agreement between the manufacturer, the purchaser and the Inspecting Authority (see **1.5.2.3**e). Where sufficient experience of previous satisfactory service of similar headers cannot be shown, the suitability of the headers shall be proved in accordance with **3.8**.

3.6 Ends of drums and headers

3.6.1 Dished ends

3.6.1.1 *Shape*

Torispherical and semi-ellipsoidal unstayed drum ends, dished from plate, having pressure on the concave side shall conform to the following;

a) *Torispherical ends (see figure 3.6.1-1a).*

The internal radius of dishing, R_i shall not be greater than D_o.

The internal corner radius r_i shall not be less than 10 % of D_o, nor less than $3t$.

The external height H shall not be less than $0.18D_o$.

b) *Semi-ellipsoidal ends (see figure 3.6.1-1b).*

The external height H shall not be less than $0.2D_o$.

For a) and b) above

D_o is the outside diameter of the parallel portion of the end (in mm);

t is the thickness of the end plate (in mm).

H shall be measured from the commencement of curvature (see figure 3.6.1-1b).

NOTE. No special shape requirements are specified for hemispherical unstayed drum ends.

3.6.1.2 *Thickness*

3.6.1.2.1 Subject to the limitations given in **3.6.1.1**, the thickness of torispherical, semi-ellipsoidal and hemispherical ends shall be calculated from the following equation:

$$t = \frac{pD_oK}{2f} \tag{28}$$

where

t is the minimum thickness after dishing (in mm);

p is the calculation pressure (in N/mm^2);

D_o is the outside diameter of the domed end (in mm);

K is a shape factor (see **3.6.1.2.2**);

f is the design stress (in N/mm^2) (see **2.2**).

The minimum thickness (t) shall in no circumstances be less than 9.5 mm.

For ends which are butt welded to the drum shell, the thickness of the edge of the skirt for connection to the shell shall not be less than the thickness of a seamless, unpierced shell, determined by equation (1).

NOTE 1. The external height of dishing H may, for ends of torispherical form, be determined as follows (see figure 3.6.1-1a):

$$H = R_o - \sqrt{\{(R_o - D_o/2) \times (R_o + D_o/2 - 2r_o)\}}$$

where R_o and r_o are as shown in figure 3.6.1-1.

NOTE 2. For deep ends with low values of K, and particularly for hemispherical ends, the limitation of the flange edge thickness may determine the end thickness and overrule the thickness resulting from equation (28).

5) See footnote to **3.3.3.1** for an explanation of 'obround'.

3.6.1.2.2 The shape factor K to be used in equation (28) shall be obtained from the curves in figure 3.6.1-2 and depends on the ratio of height to diameter H/D_o.

NOTE 1. 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 t/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.

NOTE 2. Figure 3.6.1-2 takes account of the highest stresses occurring in ends whose dishing radius R_i is not greater, and whose corner radius r_i is not less, than those of semi-ellipsoidal ends of the same height H. If, in exceptional circumstances, very shallow ends are used having a large internal radius R_i or a small internal radius r_i, it is recommended that instead of using the actual height H when reading K from figure 3.6.1-2, an equivalent height:

$$H_E = \frac{D_o^2}{4R_o}$$

or

$$H_E = \sqrt{\left(\frac{D_o r_o}{2}\right)}$$

whichever is the smaller, be used, if H_E is smaller than H.

3.6.1.3 *Openings in dished ends*

3.6.1.3.1 *Unreinforced openings*

Openings in dished ends shall be either circular, elliptical or obround[6)].

The curves drawn with broken lines in figure 3.6.1-2 provide values of K that shall be used in equation (28) for ends with unreinforced openings (e.g. manholes or tube holes). The selection of the correct curve depends on the value:

$$\frac{d}{\sqrt{(D_o t)}}$$

where

- d is the diameter of the largest opening in the end plate (in the case of an elliptical or obround[6)] opening, the major axis of the opening) (in mm);
- t is the minimum calculated thickness, after dishing (in mm);
- D_o is the outside diameter of dished end (in mm).

Trial calculation shall be made in order to select the correct curve.

In any case the following shall be satisfied:

a) t/D_o shall not exceed 0.1;

b) d/D_o shall not exceed 0.7.

Figure 3.6.1-2 shows that for values of H/D_o less than 0.25, certain of the broken line curves fall below the full curve t/D_o. In this region when the stresses in the knuckle are more severe than those in the crown, K shall be chosen as for a plain head and an uncompensated opening in the crown shall be permitted.

NOTE 1. The size of such an uncompensated opening may be determined as in the following example.

For an end with H = 190 mm and D_o = 1000 mm:

$H/D_o = 0.19$

$K = 1.56$

and

$d/\sqrt{(D_o t)} = 1.1$.

If the thickness calculated from equation (28) is 10 mm, then d = 110 mm.

These requirements 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.

Where openings are flanged, the radius r_m of the flanging shall not be less than 25 mm (see figures 3.6.1-1 and 3.6.1-3).

NOTE 2. The thickness of the flanged portion may be less than the calculated thickness t.

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 3.6.1-3.

NOTE 3. In figure 3.6.1-3, d_2 is equal to the diameter of the smaller hole.

3.6.1.3.2 *Reinforced openings*

Where it is desired to use an opening on a dished end of less thickness than would be required by the application of **3.6.1.3.1**, reinforcement of the end shall be provided.

NOTE 1. Reinforcement may consist of a ring and/or standpipe welded into the hole (see figure 3.6.1-4). Alternatively, forged reinforcement may be used.

Added reinforcing material shall be considered as effective reinforcement within the following limits:

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

b) the effective length l_2 of a reinforcing ring shall not exceed $\sqrt{(d_o l_t)}$.

6) See footnote to **3.3.3.1** for an explanation of 'obround'.

For a) and b) above

R_i is the internal radius of the spherical part of a torispherical end or, for a semi-ellipsoidal end, the internal radius of the meridian of the ellipse at the centre of the opening (in mm);

t is the actual thickness of the end (in mm);

l_t is the actual thickness of the ring (in mm);

d_o is the external diameter of the ring (in mm).

NOTE 2. The dimensions l_1 and l_2 are shown shaded in figure 3.6.1-4.

NOTE 3. The shape factor K for a dished end having a reinforced opening may be read from figure 3.6.1-2 using the value obtained from:

$\frac{d_o - A/t}{\sqrt{(D_o t)}}$ instead of from $\frac{d}{\sqrt{(D_o t)}}$

where

A is the effective cross-sectional area of reinforcement (in mm^2).

When required for the determination of K, the value of A (see note 3) shall be taken as twice the shaded area shown in figure 3.6.1-4.

The shaded area shown in figure 3.6.1-4 shall be calculated as follows.

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

2) 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.

3) Add to it the full sectional area of that part of the stem of the nozzle which projects outside the internal surface of the end plate up to the distance l_2 and deduct from it the sectional area which the stem would have if its thickness were calculated in accordance with equations (31) or (32) disregarding the minimum thickness from table 3.7.1.1.

If the material of the ring has an allowable stress lower than that of the end plate, then the effective cross section A shall be reduced below that calculated in proportion to the difference in the allowable stresses for the materials. As in **3.6.1.3.1**, trial calculation shall be made in order to select the correct curve.

3.6.1.3.3 *Thickness of internally fitted doors*

The minimum calculated thickness of doors of flat plate construction (i.e. unstiffened) made from one plate shall be not less than that determined by the following equations:

$$t = \sqrt{\left[\frac{0.35pd^2 + W}{f}\right]}$$ for circular doors, and

$$t = \sqrt{\left[\frac{0.35p(2 - a/b)\,a^2 + W}{f}\right]}$$ for ellipsoidal doors

where

t is the minimum calculated thickness of the flat door at or near the centre (in mm);

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 the allowable stresses when deriving W.

3.6.2 Flat ends of headers

3.6.2.1 *Unpierced flat ends*

The minimum thickness of an unstayed flat end without opening shall be that given by the following equations:

circular ends: $$t_e = Cd_i\sqrt{\left(\frac{p}{f}\right)} \quad (29)$$

rectangular ends: $$t_e = CZa\sqrt{\left(\frac{p}{f}\right)} \quad (30)$$

where

t_e is the minimum thickness of the end plate (in mm);

d_i is the internal diameter of the cylindrical shell (in mm);

a is the least width between walls of a rectangular header (in mm);

p is the calculation pressure (in N/mm^2);

f is the design stress (N/mm^2) (see **2.2**);

C is a constant, not less than 0.41, depending on the method of end attachment, derived from:

a) figure 3.6.2.1-1 for ends as shown in figure 3.6.2.1-1a and b for which shell and end materials are not restricted;

b) figure 3.6.2.1-2 for ends as shown in this figure for which shell and end materials are restricted to carbon and carbon manganese steels up to type 460 (see table 2.1.2);

Z is the coefficient for rectangular ends as given in figure 3.6.2.1-3;

b is the greatest width between walls of a rectangular header (in mm).

3.6.2.2 ***Pierced flat ends***

Where flat end plates are pierced concentrically or eccentrically, the thickness required by **3.6.2.1** shall be increased by 15 %. Where an end detail as shown in figure 3.6.2.1-2 is employed, care shall be taken that any eccentrically positioned hole does not encroach into the attachment weld.

3.6.3 Branches and connections

The requirements of **3.4.7** to **3.4.9** shall be complied with in so far as they are applicable to the ends of drums and headers.

Where branch or nozzle connections are attached to a piping system designed with due allowance for expansion thrusts, etc. (e.g. conforming to the flexibility requirements of BS 806), the thickness determined for the head or end in **3.6.1** or **3.6.2** shall be considered sufficient.

3.7 Tubes and integral pipes

3.7.1 Thickness of straight tubes and integral pipes

3.7.1.1 The minimum thickness of straight tubes, including drum or header connections or tube stubs, and integral pipes shall be determined by either of the following equations:

$$t = \frac{pd_o}{2f + p} \quad (31)$$

or

$$t = \frac{pd_i}{2f - p} \quad (32)$$

where

t is the minimum thickness of the straight tube or pipe exclusive of any wastage allowance (in mm);

p is the calculation pressure (in N/mm^2);

d_o is the outside diameter of the tube or pipe (in mm);

d_i is the inside diameter of the tube or pipe (in mm);

f is the design stress (in N/mm^2) (see **2.2**).

The thickness t, plus any wastage allowance (see **3.7.1.2**), shall however in no case be less than the minimum given in table 3.7.1.1.

NOTE 1. The value of thickness so determined is the minimum thickness of straight tubes and further provision will be needed for minus thickness tolerances where necessary.

NOTE 2. Diameters are subject to manufacturing tolerances which are not used in the calculation.

Table 3.7.1.1 Minimum thickness of straight tubes

Dimensions in millimetres

Nominal outside diameter	Minimum thickness
Not exceeding 38	1.7
Exceeding 38 not exceeding 51	2.2
Exceeding 51 not exceeding 70	2.4
Exceeding 70 not exceeding 76	2.6
Exceeding 76 not exceeding 95	3.0
Exceeding 95 not exceeding 102	3.3
Exceeding 102 not exceeding 127	3.5

3.7.1.2 In all cases where reduction of the wall thickness of the tubes or pipes is expected as a result of surface wastage, an increase in thickness sufficient for the design life of the tubes and pipes shall be provided over that required by the other design requirements of this clause. This allowance shall be determined by the manufacturer unless otherwise specified by the purchaser (see **1.5.1**c and **3.2.2**).

3.7.2 Tube bends

Where tubes are to be bent, the requirements of **4.2.4** shall be taken into account at the design stage.

3.7.3 Integral pipe bends

3.7.3.1 Where integral pipes are bent the minimum thickness (t_b) of a straight pipe, from which a pipe bent to a radius given in table 3.7.3 is to be made, shall be determined from equation (33) or (34) except where it can be demonstrated that the use of a thickness less than t_b would not reduce the thickness below t_a at any point after bending.

For pipes 219.1 mm outside diameter and below, and for pipes above 219.1 mm outside diameter bent to the radii given in column 2 of table 3.7.3, t_b shall be given by:

$$t_b = 1.1.25\ t \quad (33)$$

For pipes above 219.1 mm outside diameter where t is 32 mm or more bent to the radii given in column 3 of table 3.7.3, t_b shall be given by:

$$t_b = 1.1\ t$$

The value of t_b is the minimum thickness and provision shall be made for minus tolerances.

NOTE. Manufacturing considerations may make it necessary for pipes thicker than this minimum to be used.

Segmental and cut-and-shut bends shall not be used.

3.7.3.2 Pipes conforming to BS 3601 shall not be bent to radii less than those given in table 3.7.3. Other pipes of a thickness determined as in **3.7.3.1** shall not be bent to radii less than those given in table 3.7.3 unless:

a) it can be demonstrated that the use of this thickness will not reduce the thickness at any point after bending to below t, determined from equations (31) or (32);

b) for piping not less than 76.1 mm outside diameter where the design stress is time-dependent and the radius is less than three times the inside diameter, it can be additionally demonstrated that the thickness t_i (in mm) at the intrados of the bend is not less than that resulting from the following:

$$t_i \geq t \frac{2R - r}{2R - 2r}$$

where

t is the thickness derived from equations (31) and (32) (in mm);

R is the radius of the bend (in mm);

r is the mean radius of pipe (in mm).

NOTE. In general, it will be necessary to increase the thickness above that determined by **3.7.3.1** in order to comply with this subclause.

3.7.3.3 There is a minimum thickness for each size of pipe, dependent on bending procedure, below which the allowance for thinning will be exceeded, and in such cases the radius given in table 3.7.3 shall be increased where necessary to ensure that the thickness is not below t at any point after bending.

3.7.3.4 For pipes rolled to a specified inside diameter, the minimum bending radius and corresponding thinning allowance shall be that applicable to the nearest outside diameter given in table 3.7.3 greater than that resulting from the specified inside diameter plus $2t_b$.

Table 3.7.3 Minimum bending radii for pipes of thickness determined by 3.7.3.1

Dimensions in millimetres

Outside diameter	Radii measured to centre line of pipe	
	$t_b = 1.125\,t$ all thicknesses	$t_b = 1.1\,t$ t_b = 35 mm or above
26.9	65	
33.7	75	
42.4	100	
48.3	115	
60.3	150	
76.1	190	
88.9	230	
101.6	265	
114.3	305	
139.7	380	
168.3	460	
193.7	630	
219.1	710	
244.5	810	1140
273.0	1020	1270
323.9	1220	1520
355.6	1500	1780
406.4	1730	2030
457.0	2030	2280

3.7.4 Flexibility of integral piping systems

3.7.4.1 ***General***

The pipes shall be arranged so that the system is sufficiently flexible to absorb the whole of its own expansion and that of the connecting equipment without exceeding the requirements of **4.11** of BS 806 : 1993.

Account shall also be taken of end reactions in the design of branches to drums, headers, etc., in accordance with **3.4.4** or **3.6.3** as appropriate.

3.7.4.2 ***Analysis***

A flexibility analysis shall be used if there is any doubt as to the ability of the system to satisfy the specified requirements. The analysis shall be in accordance with **4.11** of BS 806 : 1993.

The designer shall be responsible for performing any necessary analysis, unless the system conforms to one of the following criteria.

a) The piping system duplicates a successfully operating installation or replaces a system with a satisfactory service record.

b) The piping system can be adjudged adequate by comparison with previously analysed systems.

NOTE. The pipes may be prestressed to reduce end effects under hot conditions of working and also to reduce hot stress levels. (For recommended methods, reference should be made to BS 806.)

3.7.4.3 ***Misalignment at site butt welds***

To avoid excessive stresses at the pipe bends, consideration shall be given to the permissible limits of pull-up to correct for misalignment at the final welds. Where template pipes are not provided, the cold alignment tolerances shall be assessed (refer to **3.7.4.2**) and specified.

3.7.5 Structural attachments to tubes

3.7.5.1 Where structural attachments such as lugs and brackets are welded to tubes for load-carrying purposes, the material of the attachment and of the weld shall be suitable for the environment and compatible with the tube material.

NOTE. Figure 3.7.5.1 is intended to illustrate typical details for the clarification of design requirements. Attention is drawn to the requirements of BS 2633 concerning the distance between a butt weld and an attachment weld.

3.7.5.2 The thickness of the attachment section, measured in the tube circumferential direction, shall not exceed one-quarter of the tube diameter at the point of attachment to the tube. The length of the attachment measured along the axis of the tube shall either conform to **3.7.5.3**, or be determined by stress analysis conforming to the criteria of annex A of BS 5500 : 1997.

3.7.5.3 The intensity of radial loading shall not exceed that given by figure 3.7.5.3 for tensile or compressive attachment loading:

where

- q is the greatest intensity of radial load (in N/mm);
- f is the design stress of tube material as used in **3.7.1** (in N/mm^2);
- t is the minimum tube thickness, i.e. nominal thickness less negative tolerance (in mm);
- d_o is the outside diameter of tube (in mm);
- a is the angle subtended by attachment at tube centre (see figure 3.7.5.l.) (in degrees).

3.7.5.4 For an attachment welded longitudinally along a tube, the greatest occurring tensile and compressive radial load intensities shall be calculated from the following equation:

$$q = \frac{R}{L} \pm \frac{6We}{L^2} \quad (35)$$

where

- W is the total load carried by attachment (in N);
- e is the eccentricity of line of action of load W about the line of attachment to the tube (in mm);
- R is the radial component of the load W (in N);
- L is the length of attachment (in mm).

NOTE. Where eccentric loading occurs, it may be necessary to check both compressive and tensile radial load intensities, which occur at opposite ends of the attachment. W, R and q are positive when tensile, and negative when compressive.

3.7.5.5 In calculating the strength of welds for structural attachments the allowable design stress shall correspond to that of the weaker of the tube or structural attachment, multiplied by the following weld reduction factors:

– 0.7 for fillet welds;

– 0.75 for partial penetration welds (with or without superimposed fillet welds);

– 1.0 for full penetration.

The loaded area of the weld shall be taken as the throat thickness × the length of weld. For the purpose of stress calculations the throat thickness shall be taken as:

– 0.7 of the leg length for fillet welds;

– the depth of groove for partial penetration welds;

– the thickness of the structural attachment for full penetration welds.

For compound welds the throat thickness shall be the sum of the constituent parts.

3.7.6 Fitting and jointing of tubes

3.7.6.1 Fitting of tubes to drums or headers shall be in accordance with **4.3.2.3** or **4.4.4**.

3.7.6.2 Jointing of tubes shall be by butt welds in accordance with **4.3.2.5**. Socket welds, sleeve welds, flanges and screwed joints shall not be used.

3.7.7 Joints in integral piping

3.7.7.1 Integral pipes shall be joined by welded or integral flanges, butt welds, socket welds, screwed, or screwed and seal welded joints. Screwed flanges and sleeve welds shall not be used. Flanges shall not be used where the bolts would be exposed to products of combustion.

3.7.7.2 The flanges and bolting for ordinary bolted flange joints shall be in accordance with BS 4504 : Section 3.1 or BS 1560 : Section 3.1 for flanges which are dimensioned in millimetres, or in accordance with BS 10 for flanges dimensioned in inches. For welded-on flanges, the weld preparations and flange types shall be selected according to BS 806. Gasket selection (e.g. material and dimensions) shall be such that the gasket factor and seating stresses are consistent with the flanges and bolting.

NOTE. Special joints and special types of flange may be used provided that they are shown to be suitable for the design conditions.

3.7.7.3 Butt welded joints shall be in accordance with **4.3.2.5**.

3.7.7.4 Socket weld joints shall not be used in service where fatigue, severe erosion or crevice corrosion is expected to occur, or for pipes exceeding 60.3 mm outside diameter.

The thickness of socket weld fittings shall be in accordance with **3.7.1.1** but shall not be less than 1.25 times the nominal thickness of the pipe. Leg lengths of the fillet weld shall be as shown in figure 3.7.7.4 so as to achieve the throat dimension not less than the nominal thickness of the pipe (t_n). The material shall be compatible with the associated piping. Socket weld fittings shall be of forged steel. The dimensions and clearances of the socket end shall be in accordance with BS 3799. The ratings of BS 3799 shall not be exceeded.

The welding of socket weld joints shall be in accordance with **4.3.2.5**.

3.7.7.5 Screwed or screwed and seal welded joints shall not be used in service where fatigue, severe erosion, crevice corrosion or shock is expected to occur, or for pipes exceeding 60.3 mm outside diameter. The screwing shall have a taper thread, and the steel component shall not contain more than 0.25 % (*m/m*) carbon if it is to be seal welded.

The calculation pressure shall not exceed 4 N/mm^2 and the design temperature shall not exceed 400 °C, but seal welding shall be applied if the calculation pressure is greater than 2 N/mm^2 or the design temperature is greater than 220 °C.

3.8 Pressure parts of irregular shape

Where pressure parts are of such irregular shape that it is impracticable to design their scantlings by the application of formulae, the suitability of their construction shall be determined by a proof hydraulic test of a prototype. The component design shall be considered suitable if the proof test pressure is achieved without significant permanent deformation of the prototype.

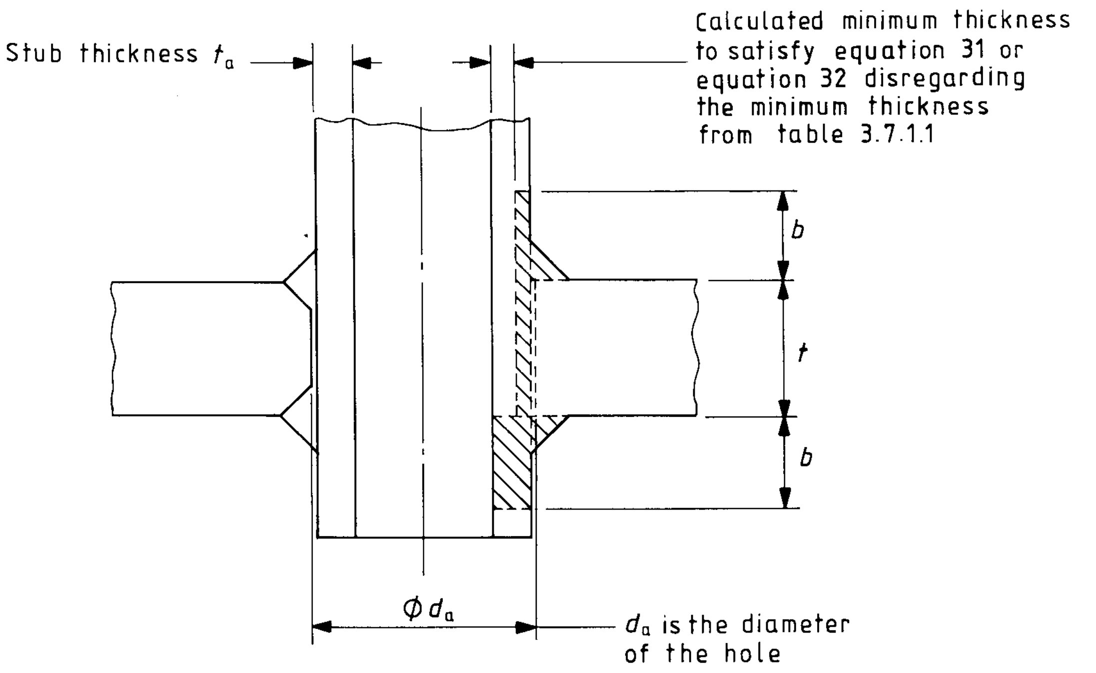
The proof test pressure P_t (in N/mm^2) shall not be less than that given by the following equation:

$$P_t = 0.9p \times \frac{\text{yield stress at test temperature}}{\text{design stress } f} \quad (36)$$

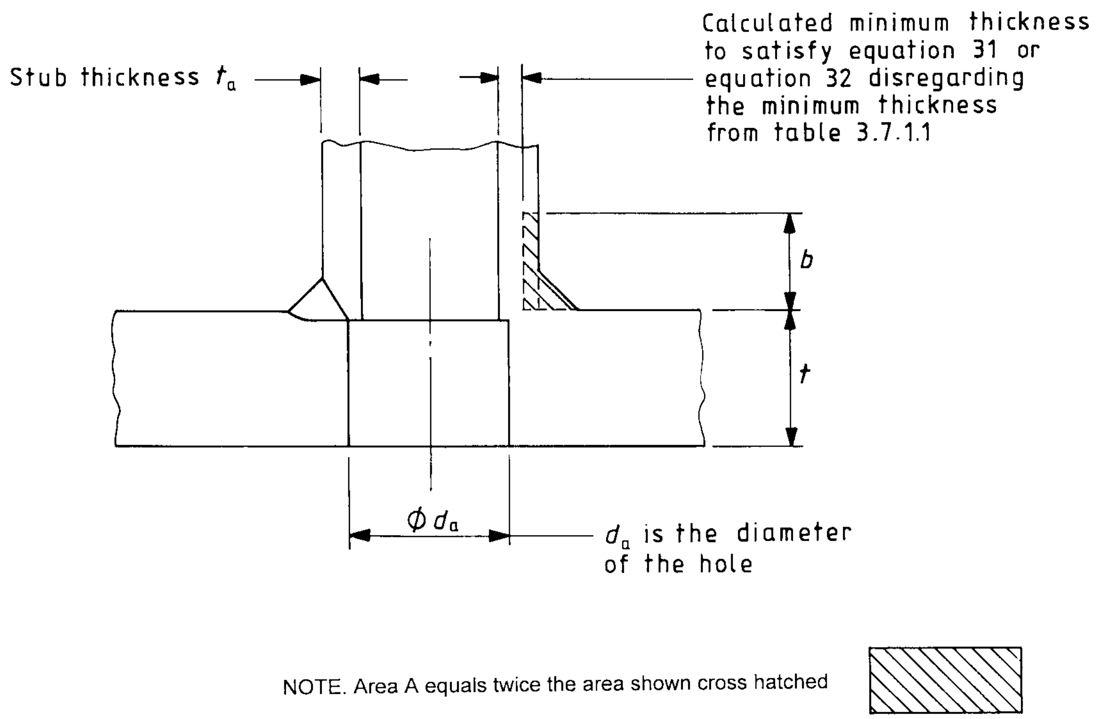
where

p is the calculation pressure (in N/mm^2).

NOTE. No requirements for pressure parts of irregular shape are specified for steels other than ferritic steels.



a) Set-through tube stub



b) Set-on tube stub

Figure 3.3.3.2 Compensation of welded tube stub

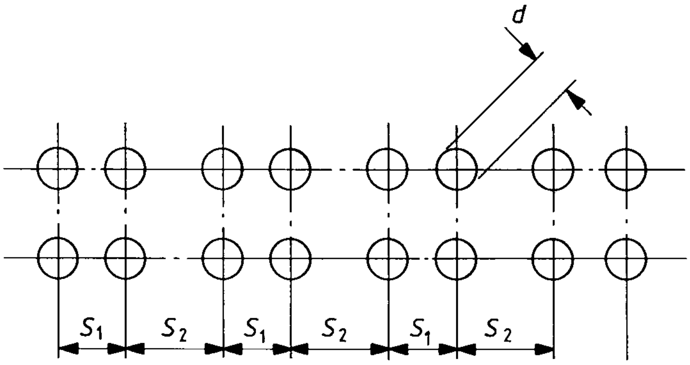


Figure 3.3.3.4 Irregular drilling

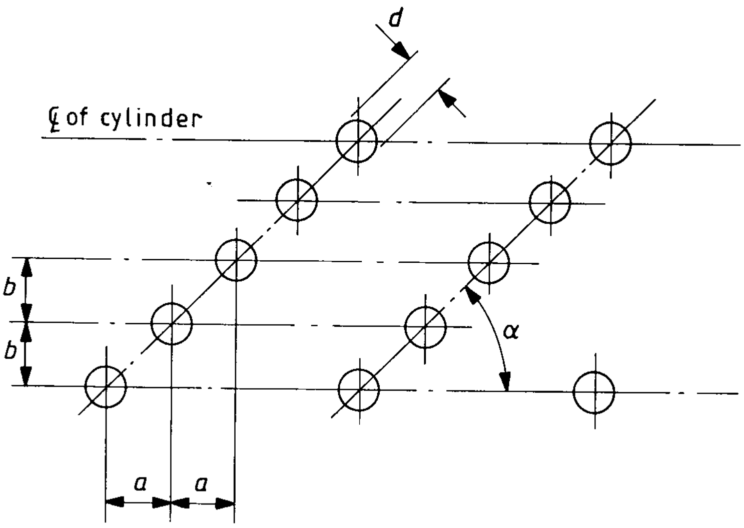


Figure 3.3.3.5-1 Spacing of holes on a diagonal line

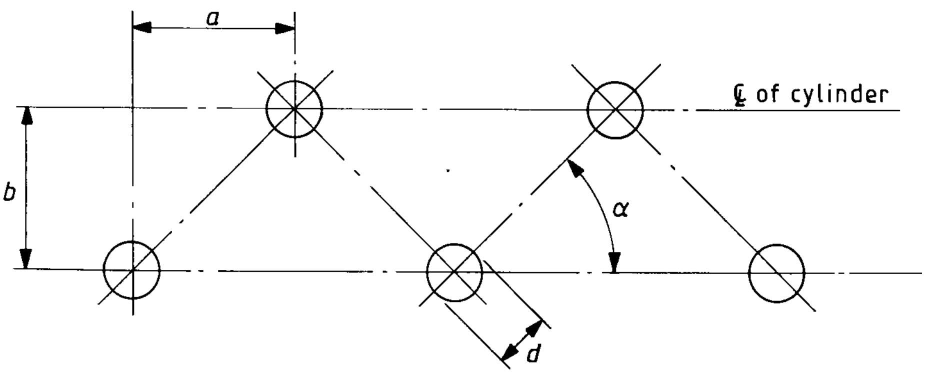


Figure 3.3.3.5-2 Regular saw-tooth pattern of holes

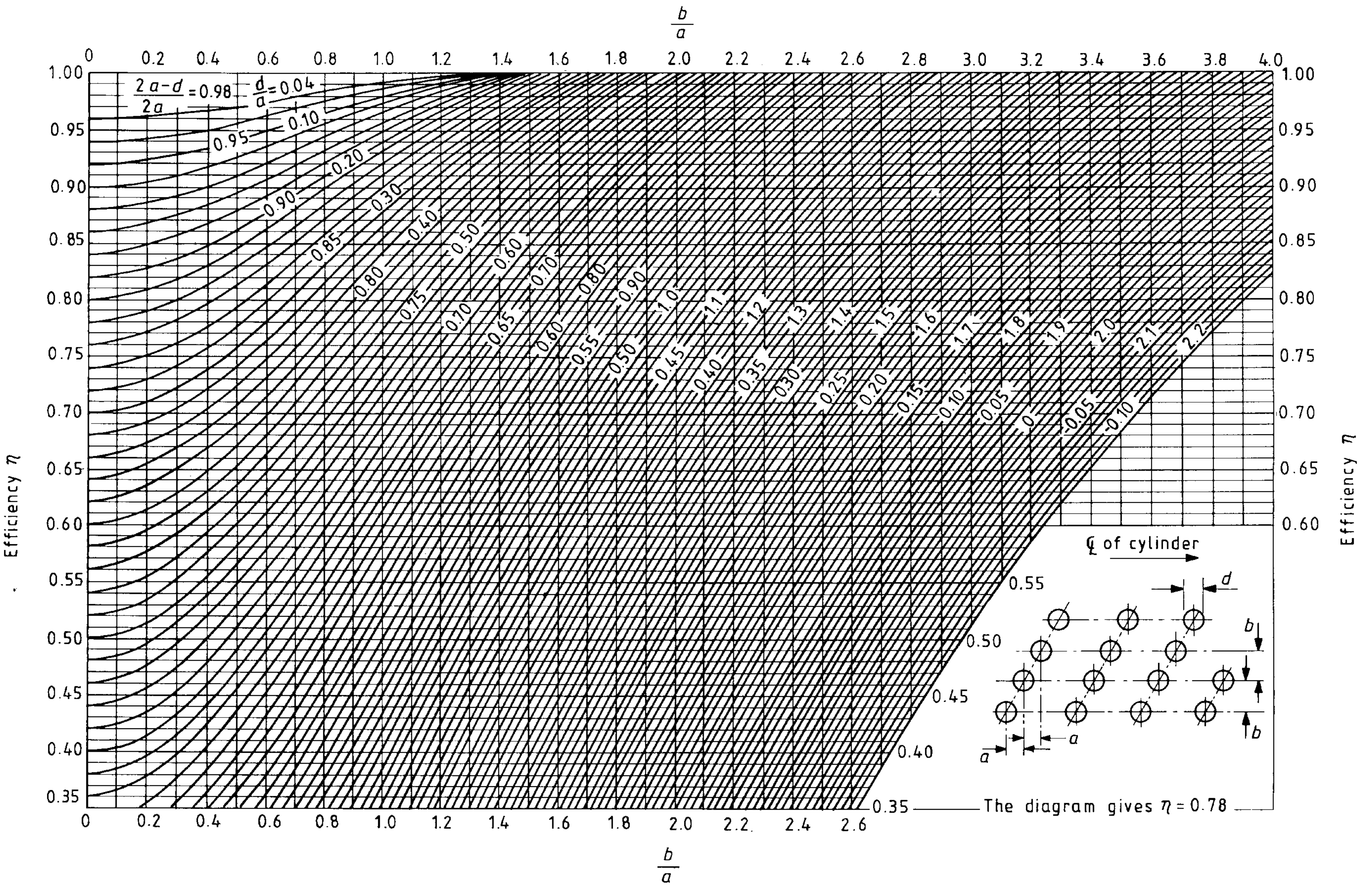


Figure 3.3.3.5-3 Efficiency of ligaments along a diagonal line

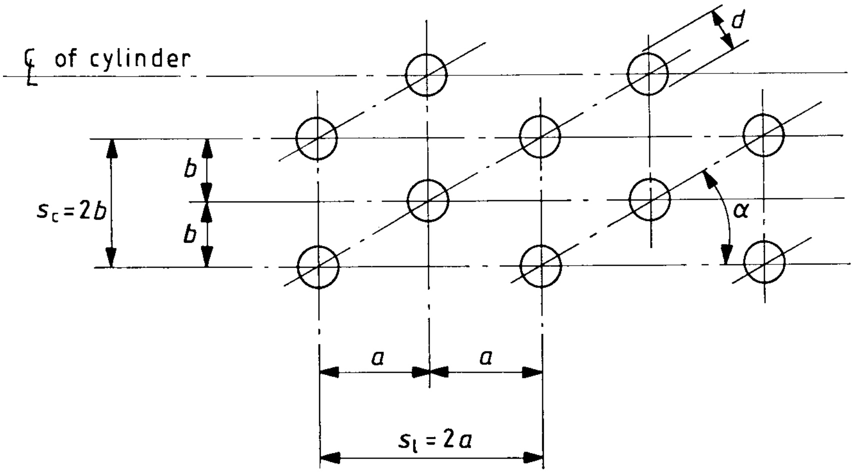


Figure 3.3.3.5-4 Regular staggering of holes

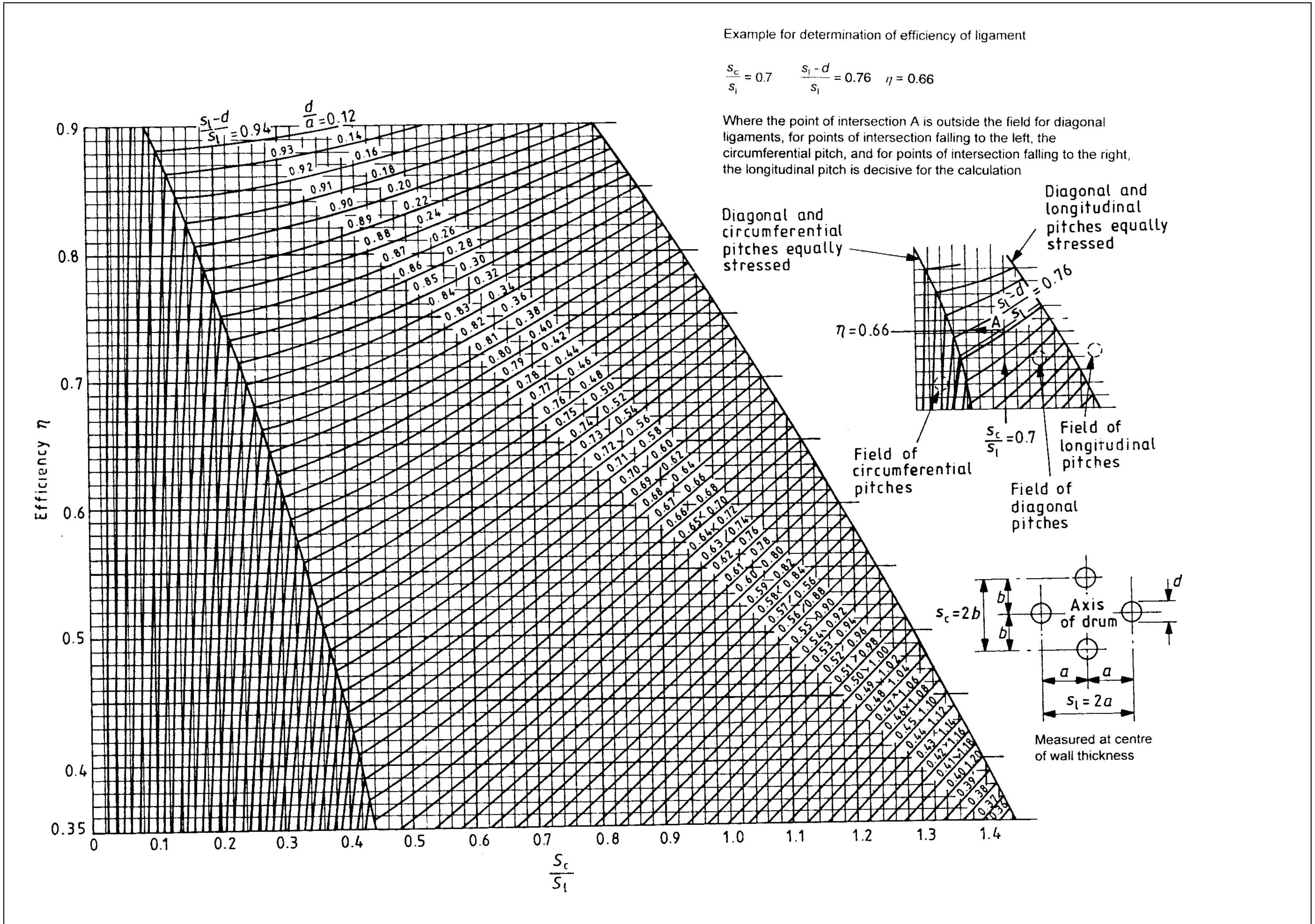


Figure 3.3.3.5-5 Efficiency of ligaments between holes

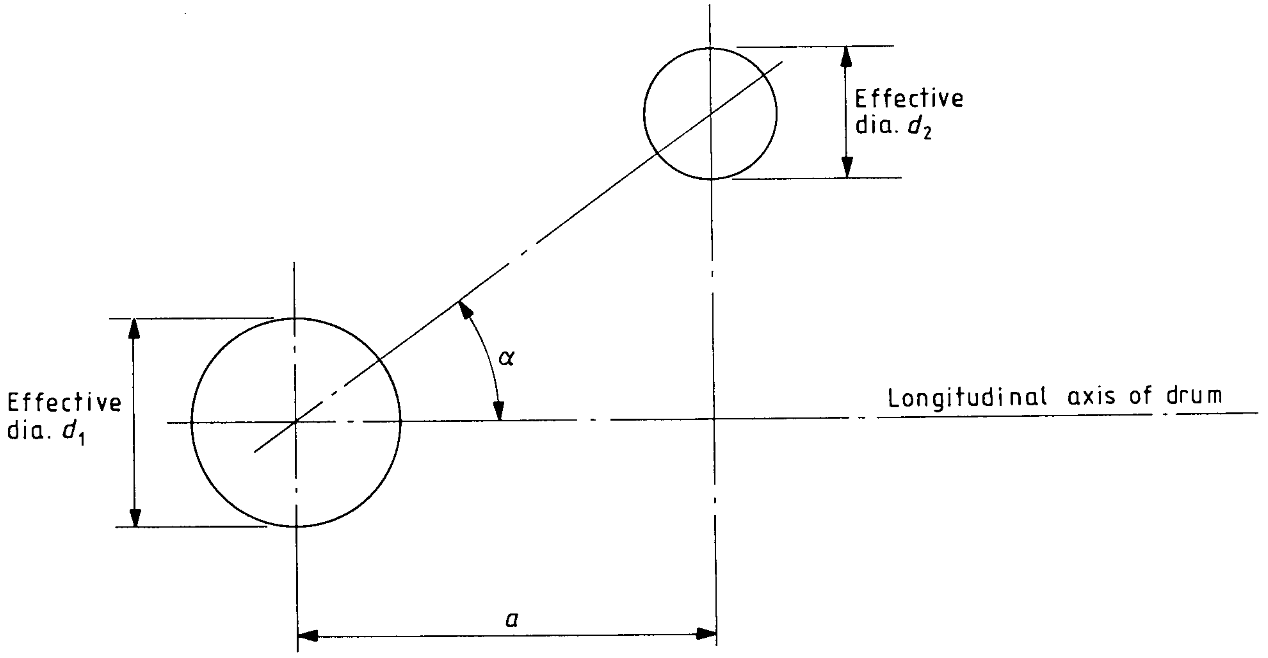


Figure 3.3.4.4 Determination of ligament efficiency on diagonal line

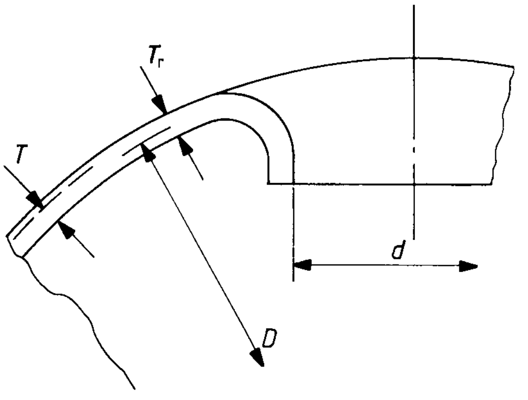


Figure 3.4.2-1 Notation applicable to cylinders

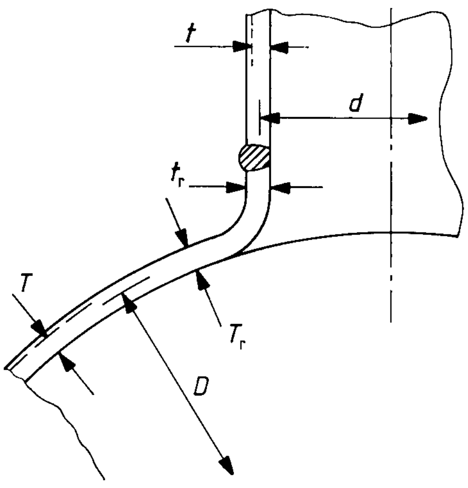
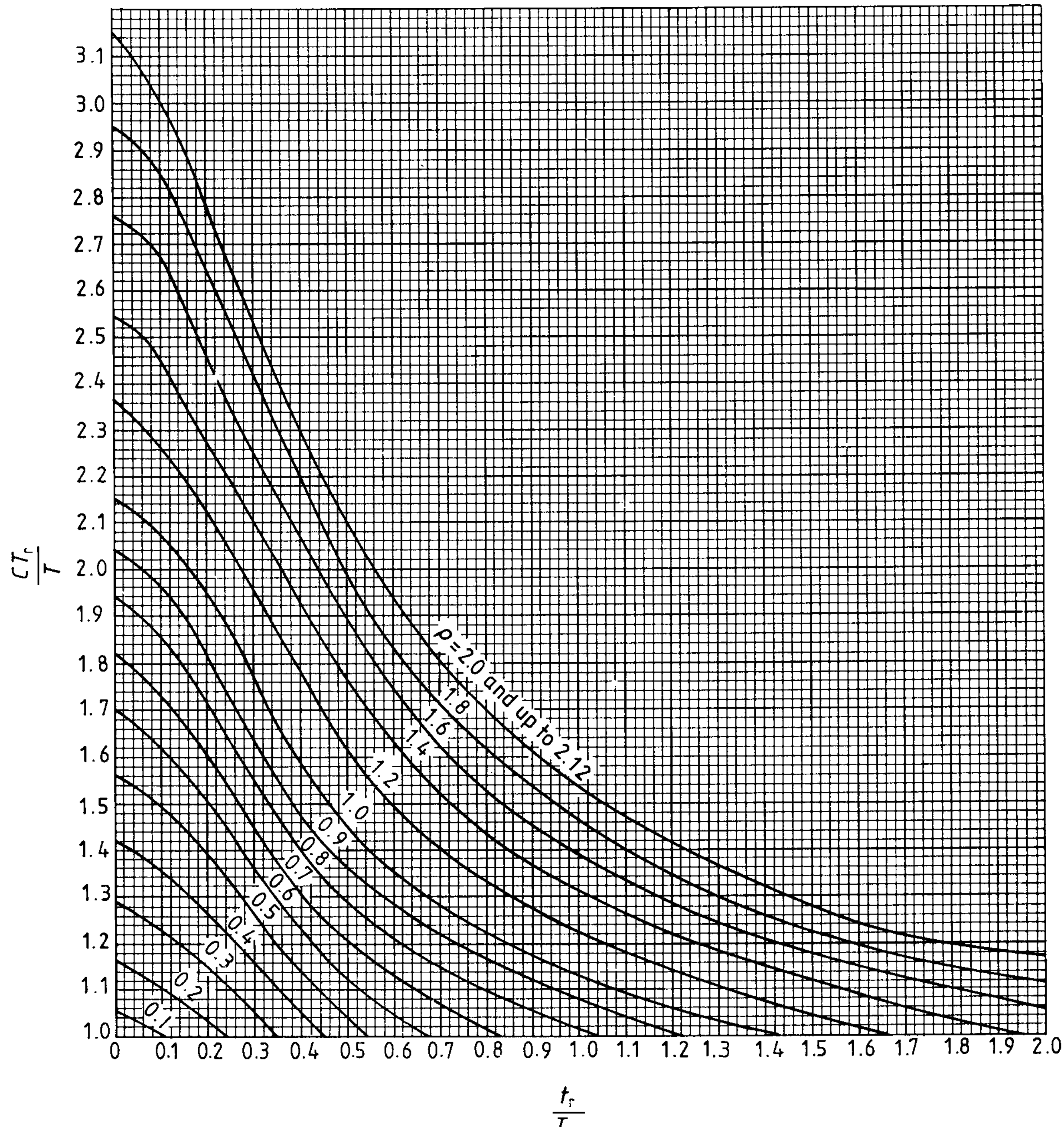
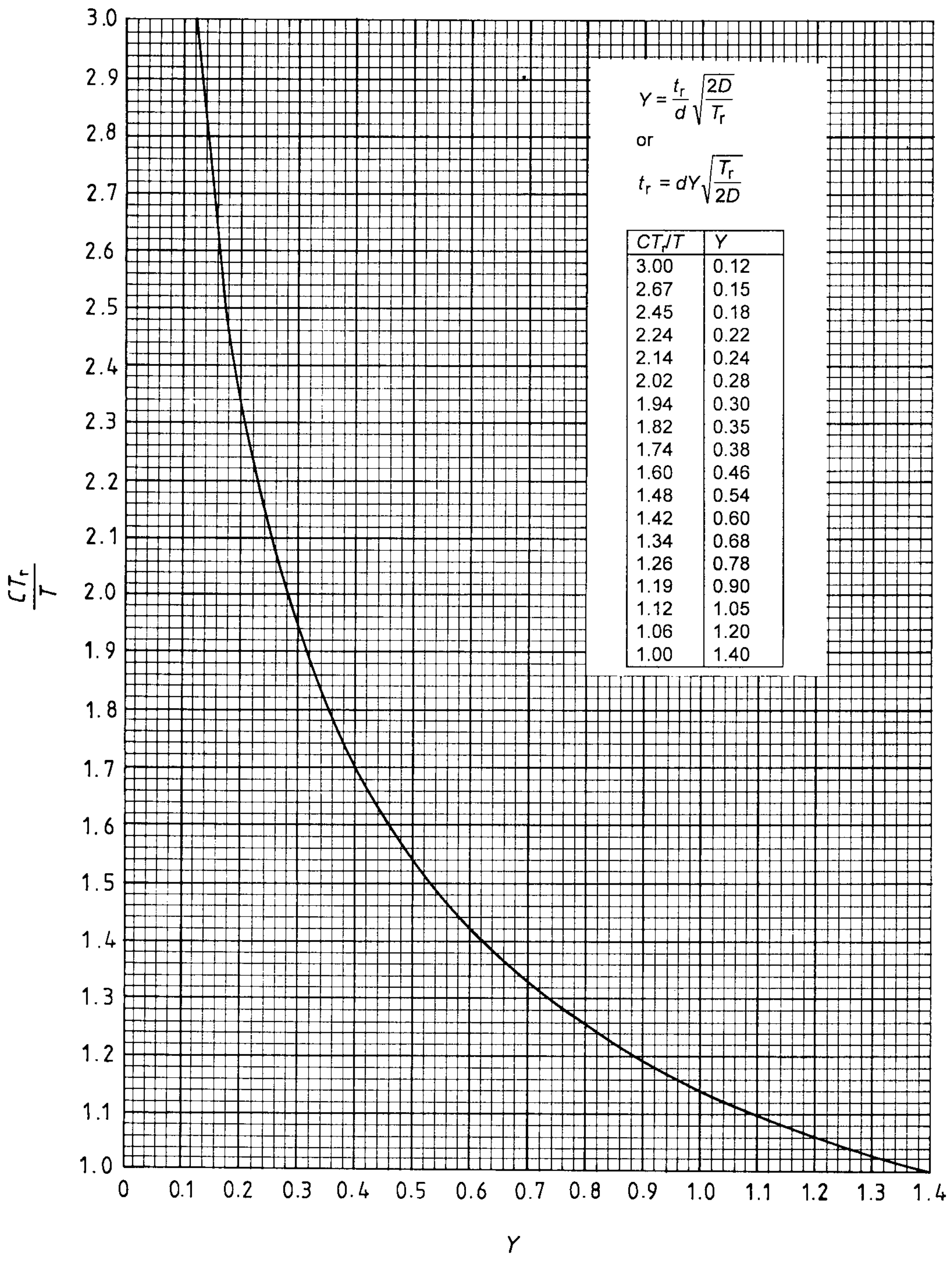


Figure 3.4.2-2 Notation applicable to cylinders



NOTE 1. See table 3.4.4 for tabulated values of t_r/T_r.
NOTE 2. For values of d/D : 0.2 < d/D < 0.3 see **3.4.4.3.**

Figure 3.4.4-1 Design curves for flush nozzles in cylindrical shells (0 < d/D < 0.3)



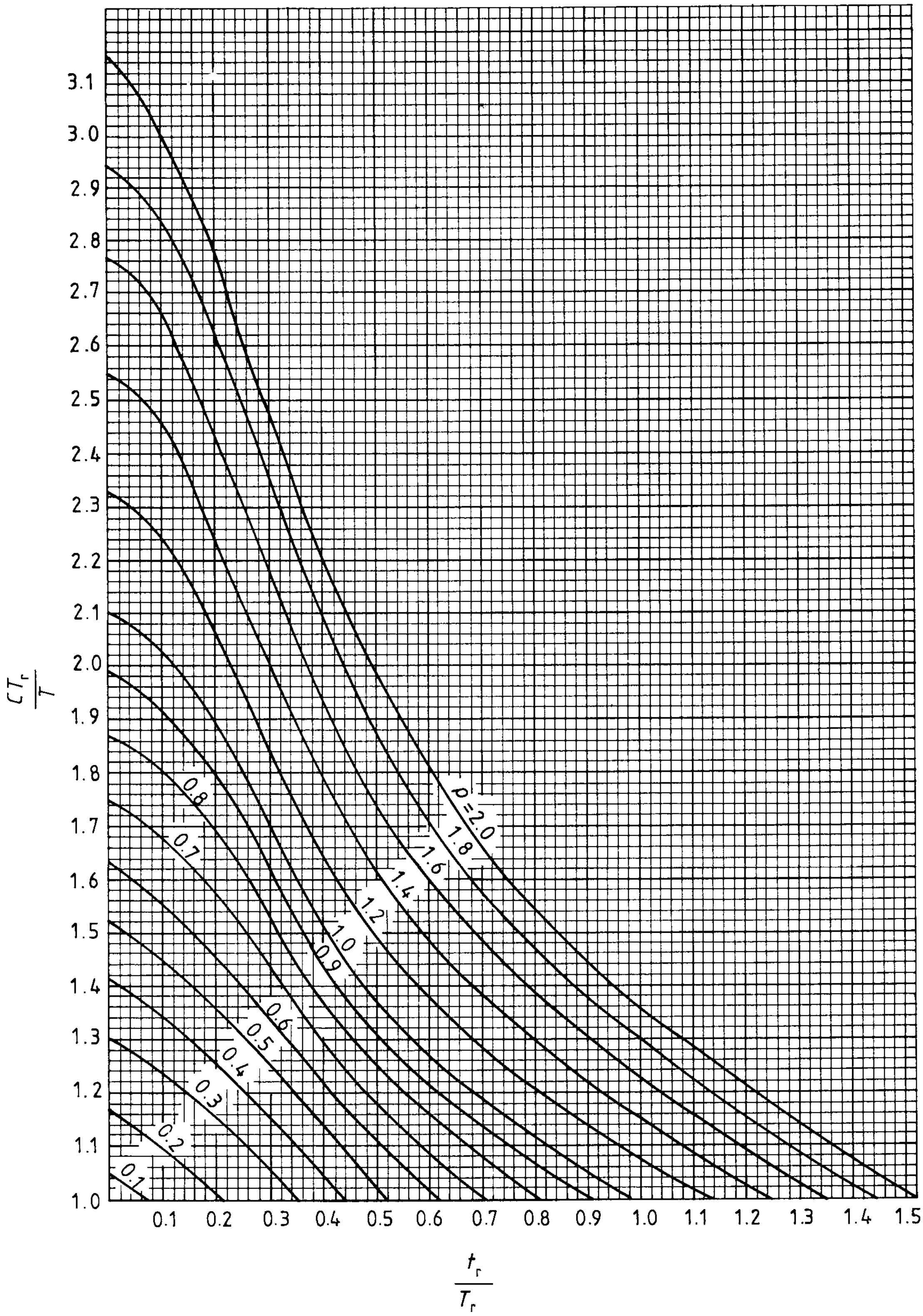
CT_r/T	Y
3.00	0.12
2.67	0.15
2.45	0.18
2.24	0.22
2.14	0.24
2.02	0.28
1.94	0.30
1.82	0.35
1.74	0.38
1.60	0.46
1.48	0.54
1.42	0.60
1.34	0.68
1.26	0.78
1.19	0.90
1.12	1.05
1.06	1.20
1.00	1.40

NOTE 1. This figure may be represented by the following expression which may also be used for CT_r/T values greater than 3:

$$Y = \frac{64}{[4CT_r/T + 0.8 + \{16(CT_r/T)^2 - 12.8CT_r/T + 0.64\}^{0.5}]^2}$$

NOTE 2. For values of d/D : $0.2 < d/D < 0.3$ see **3.4.4.3.**

Figure 3.4.4-2 Design curves for flush nozzles in cylindrical shells ($0.2 < d/D \leq 1.0$)



NOTE. See table 3.4.4 for tabulated values of t_r/T_r.

Figure 3.4.4-3 Design curves for protruding nozzles in cylindrical shells ($0 < d/D < 0.33$)

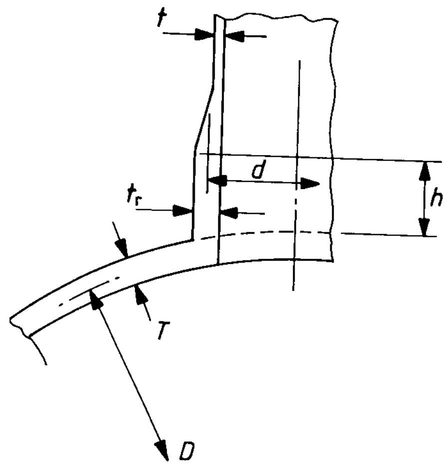


Figure 3.4.4-4 Notation applicable to cylinders

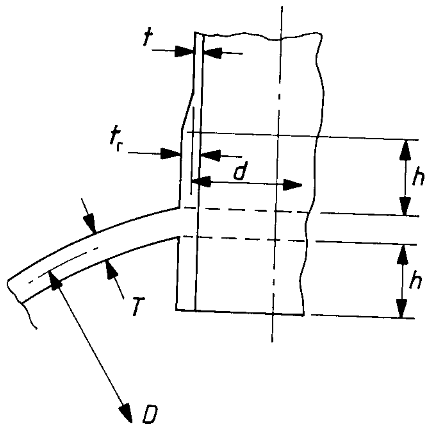


Figure 3.4.4-5 Notation applicable to cylinders

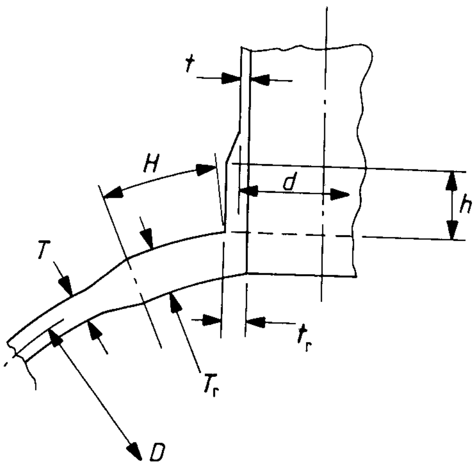


Figure 3.4.4-6 Notation applicable to cylinders

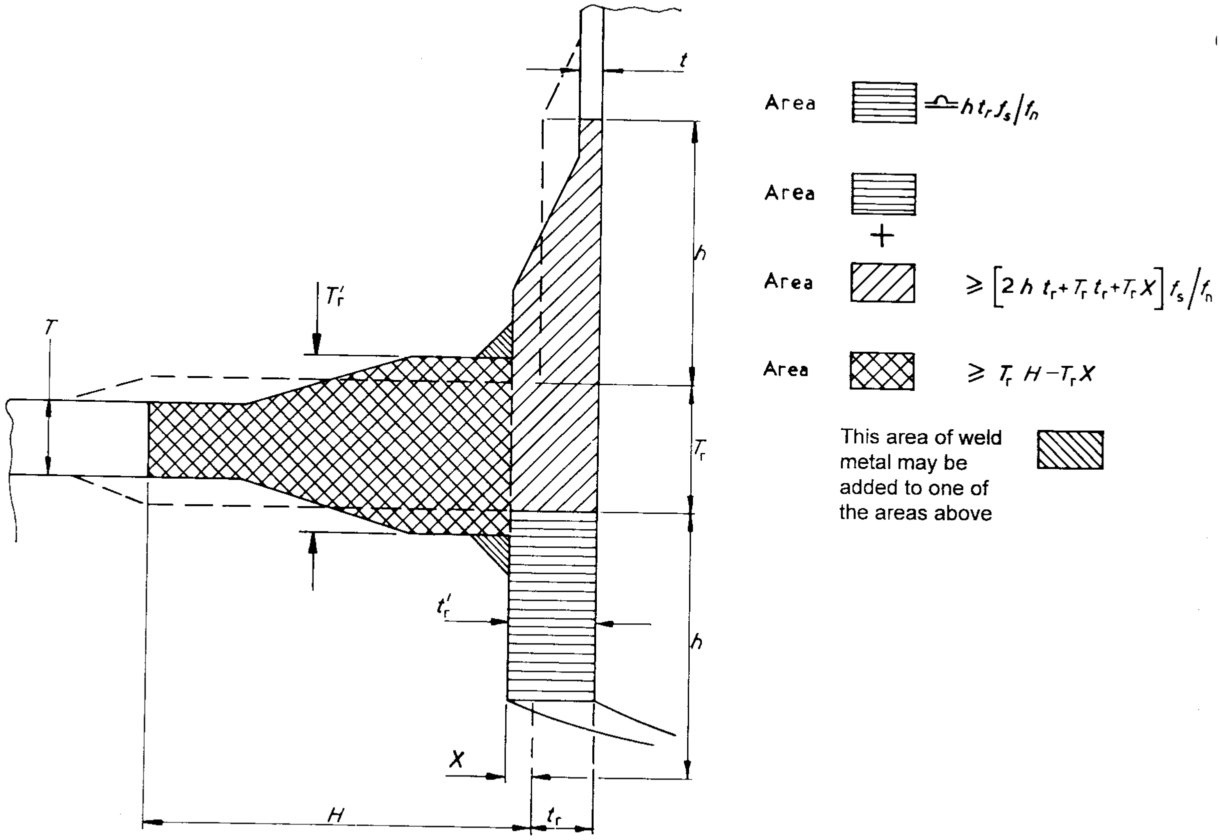
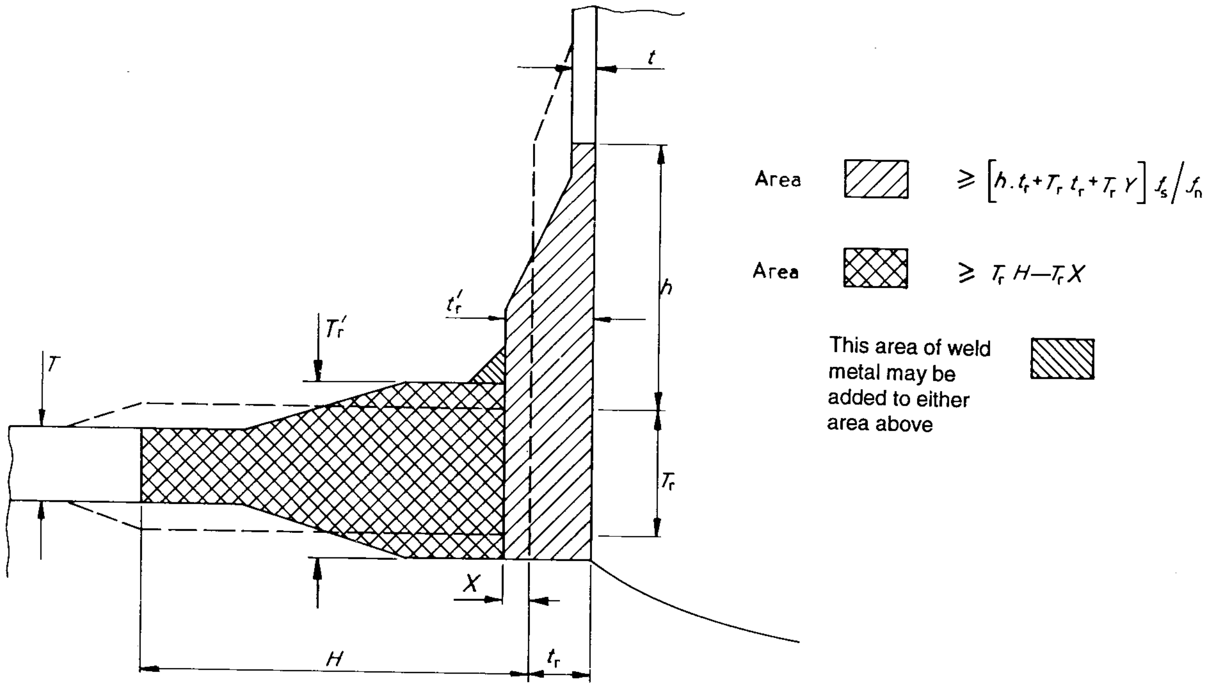
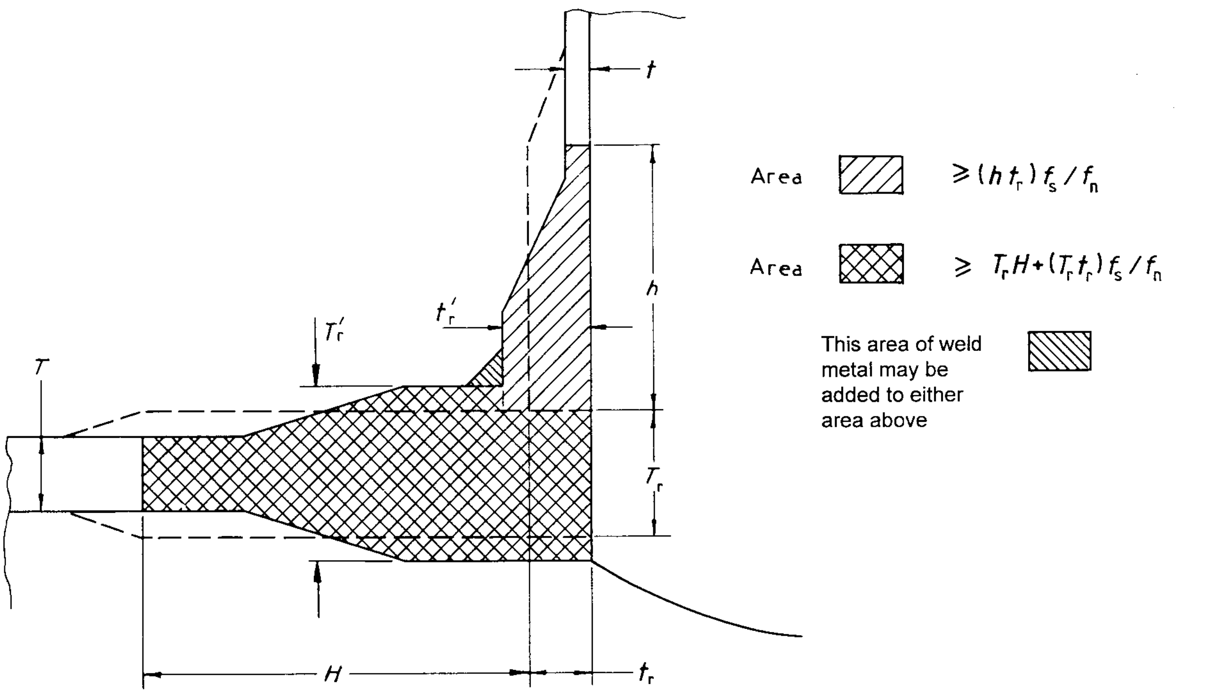


Figure 3.4.4-7 Modified protruding branch compensation



a) Set-in



b) Set-on

Figure 3.4.4-8 Modified flush branch compensation

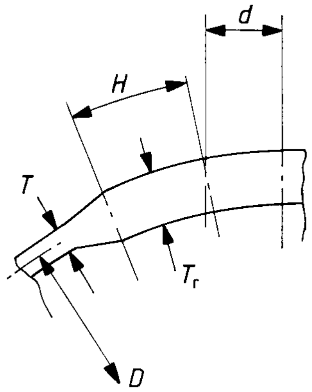


Figure 3.4.4-9 Notation applicable to cylinders

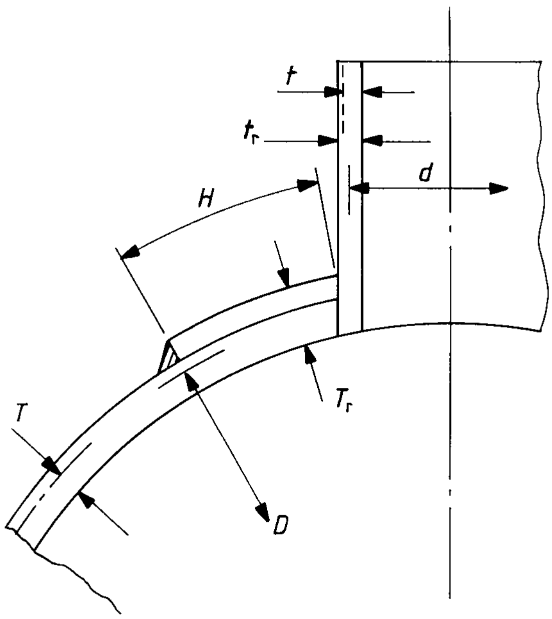
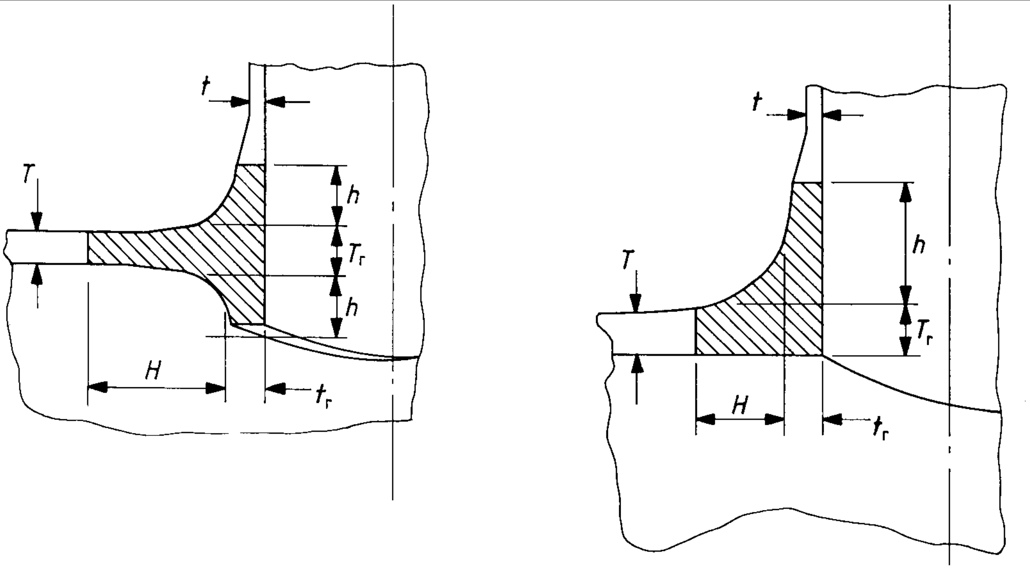


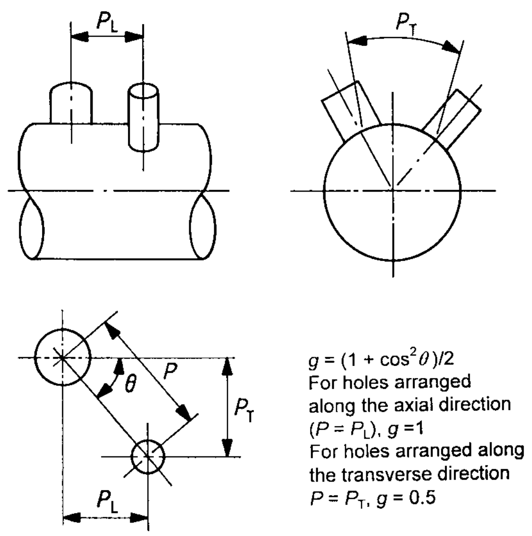
Figure 3.4.4-10 Notation applicable to cylinders



a) Protruding rim b) Flush rim

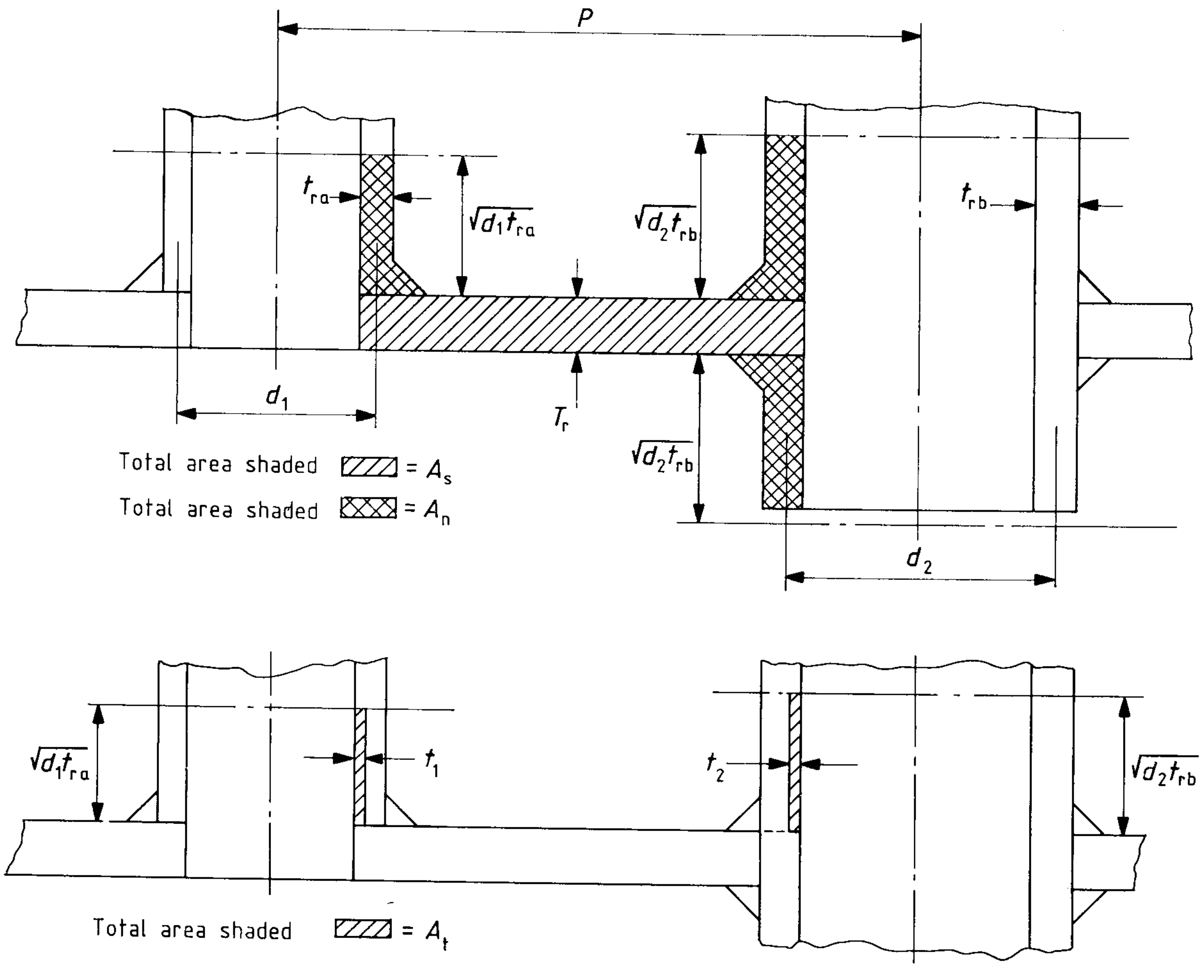
NOTE. The dimensions T_r , H, t_r and h refer to the design of a branch connection using components of constant thickness from which the design of the profiled rim is derived on an area basis.

Figure 3.4.4-11 Rims



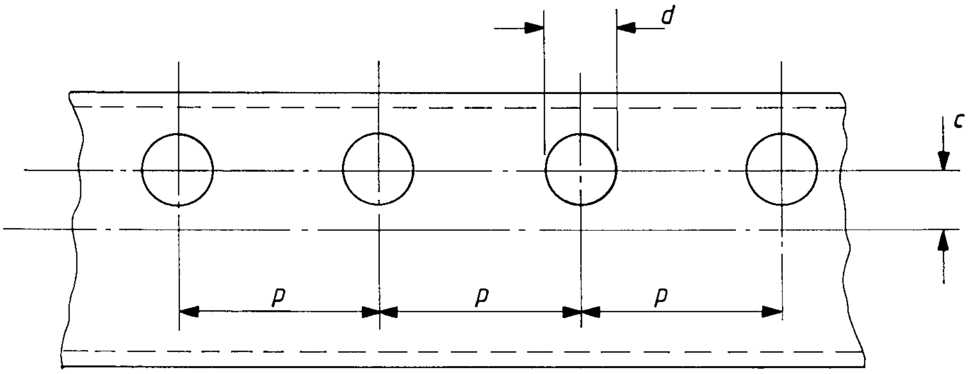
NOTE. For elliptical and oblique nozzles the value of d is the dimension of the opening in the direction of the relevant pitch.

Figure 3.4.5-1 Arrangement factor *g*

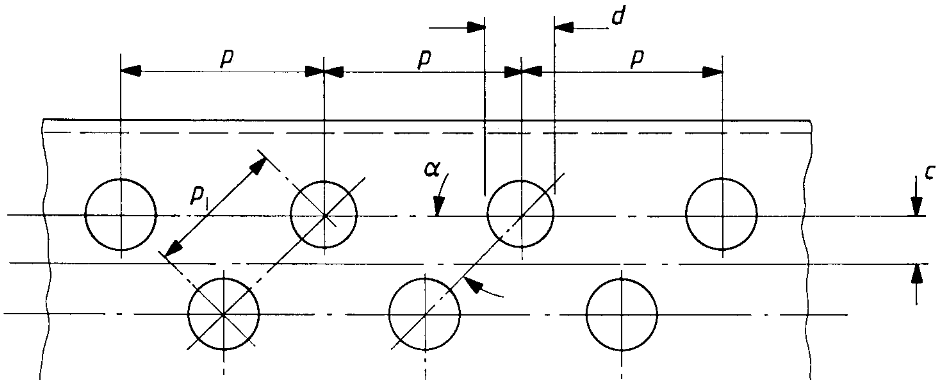


NOTE. For set-in or set-through branch, A_s and A_n should be adjusted accordingly. When branch material is weaker than shell material, A_n and A_t should be reduced in the ratio of the material design stresses.

Figure 3.4.5-2 Branch compensation



a)



b)

Figure 3.5.1-1 Notation for ligaments in rectangular headers

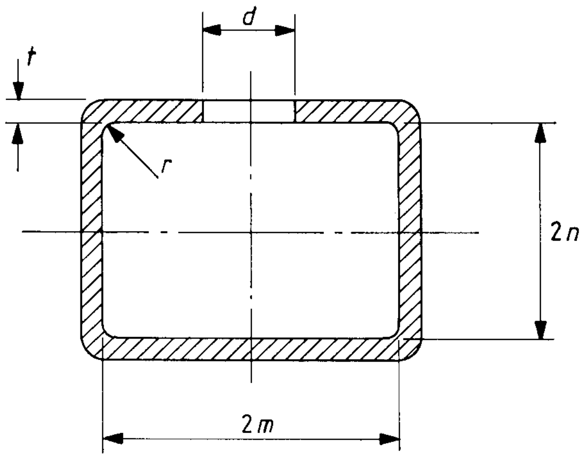
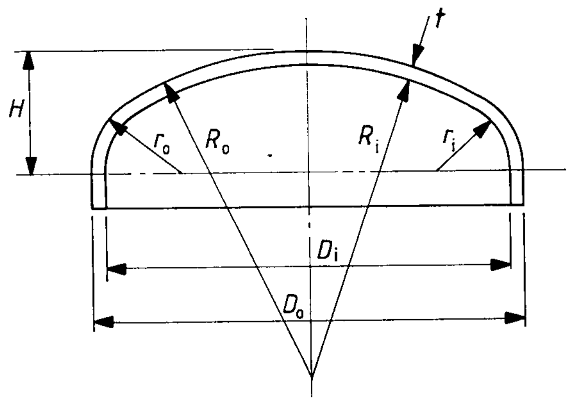
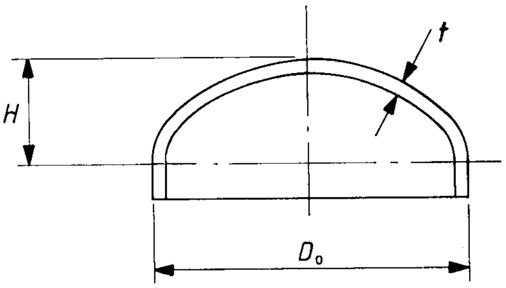


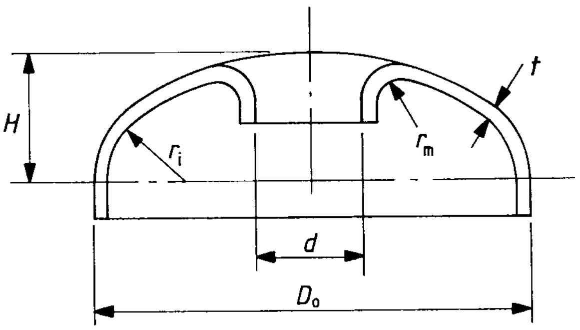
Figure 3.5.1-2 Notation for rectangular headers



a) Torispherical end



b) Semi-ellipsoidal end



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

Figure 3.6.1-1 Typical dished ends

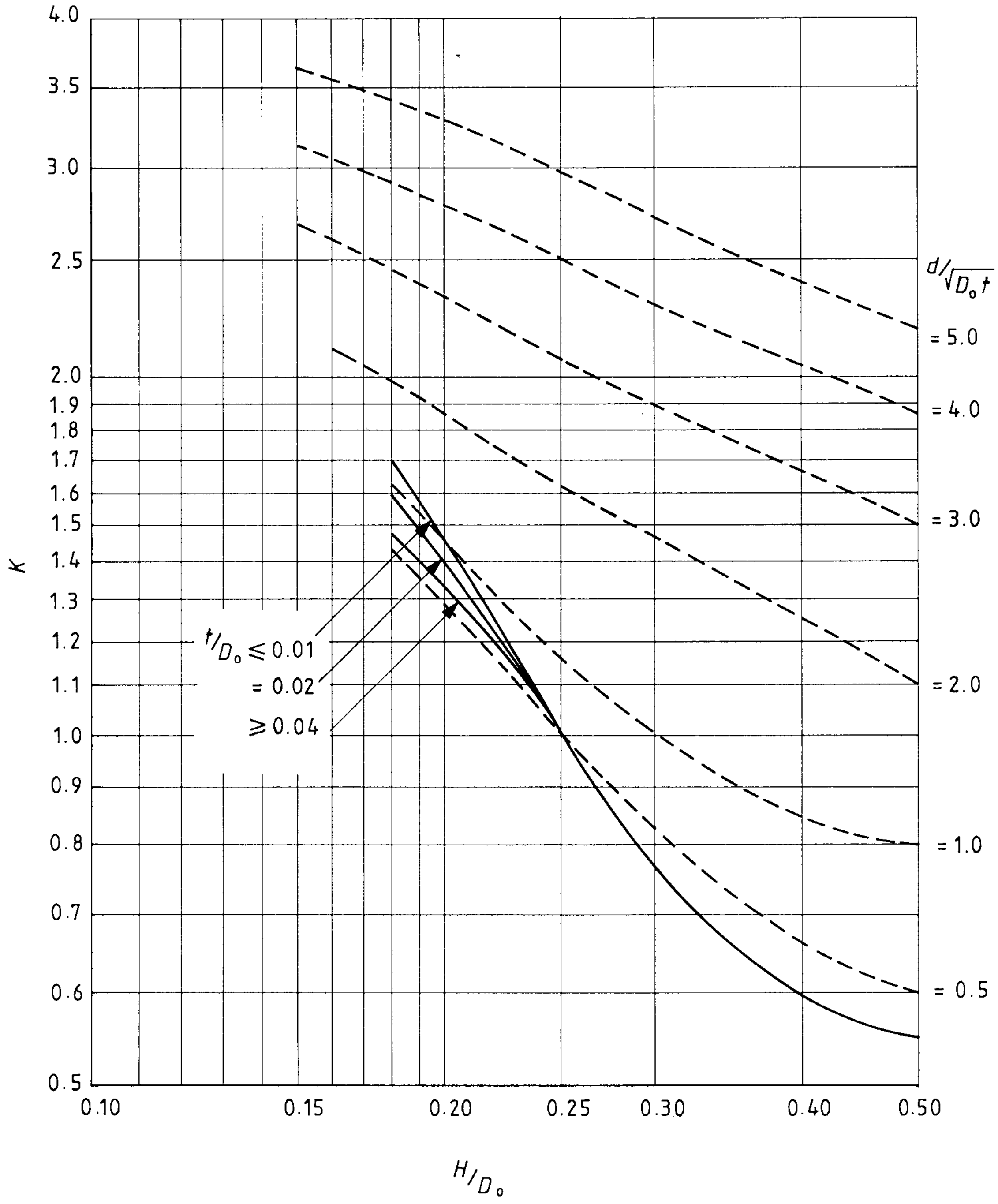


Figure 3.6.1-2 Shape factor ***K***

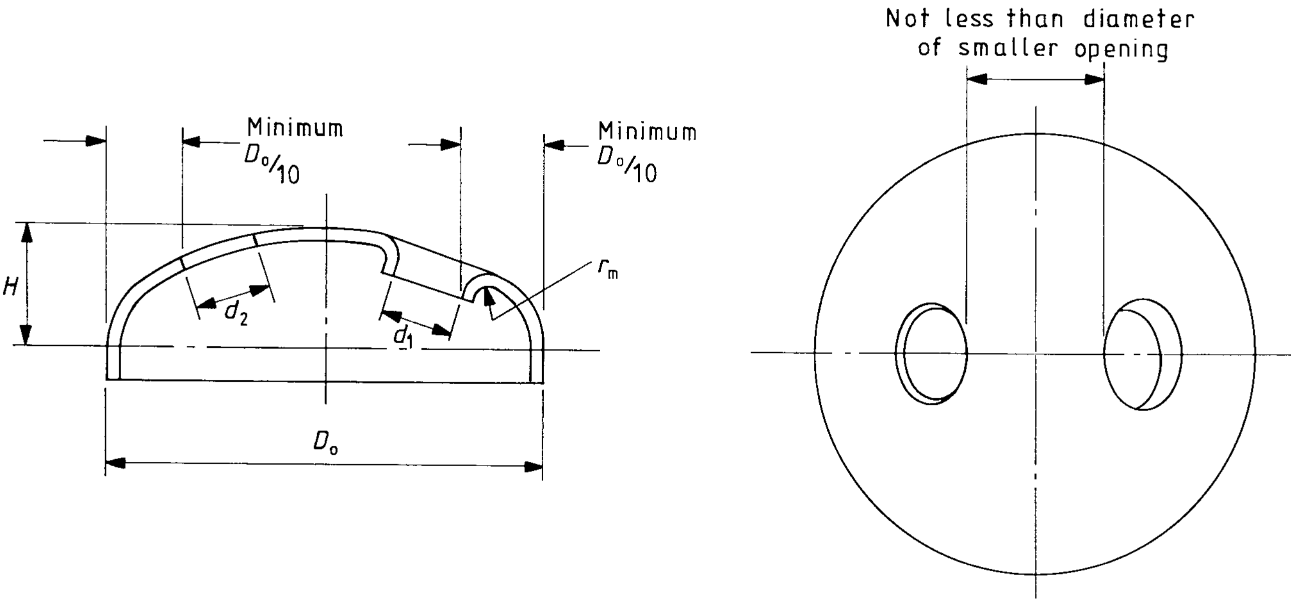
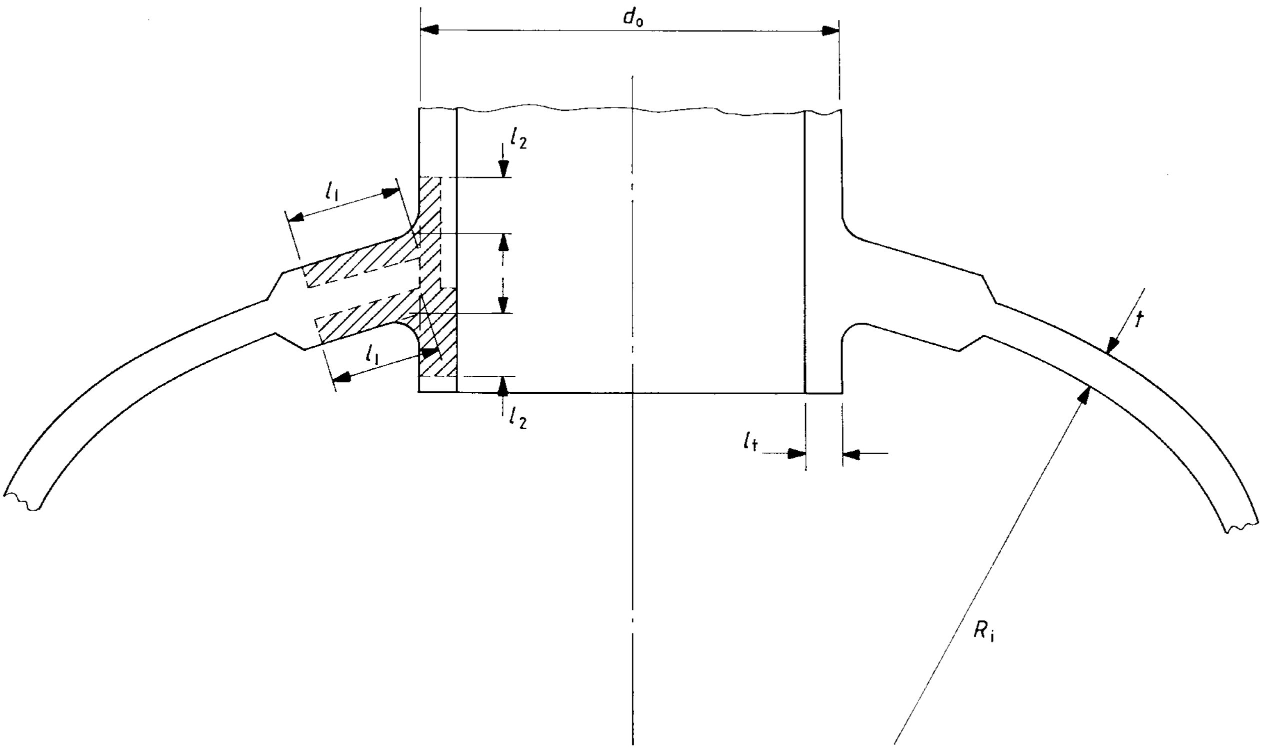


Figure 3.6.1-3 Openings in ends



l_1 $\sqrt{(2R_i t)}$ or $d_o/2$ whichever is the smaller

l_2 $\leq \sqrt{(d_o l_t)}$

Figure 3.6.1-4 Limits of reinforcement

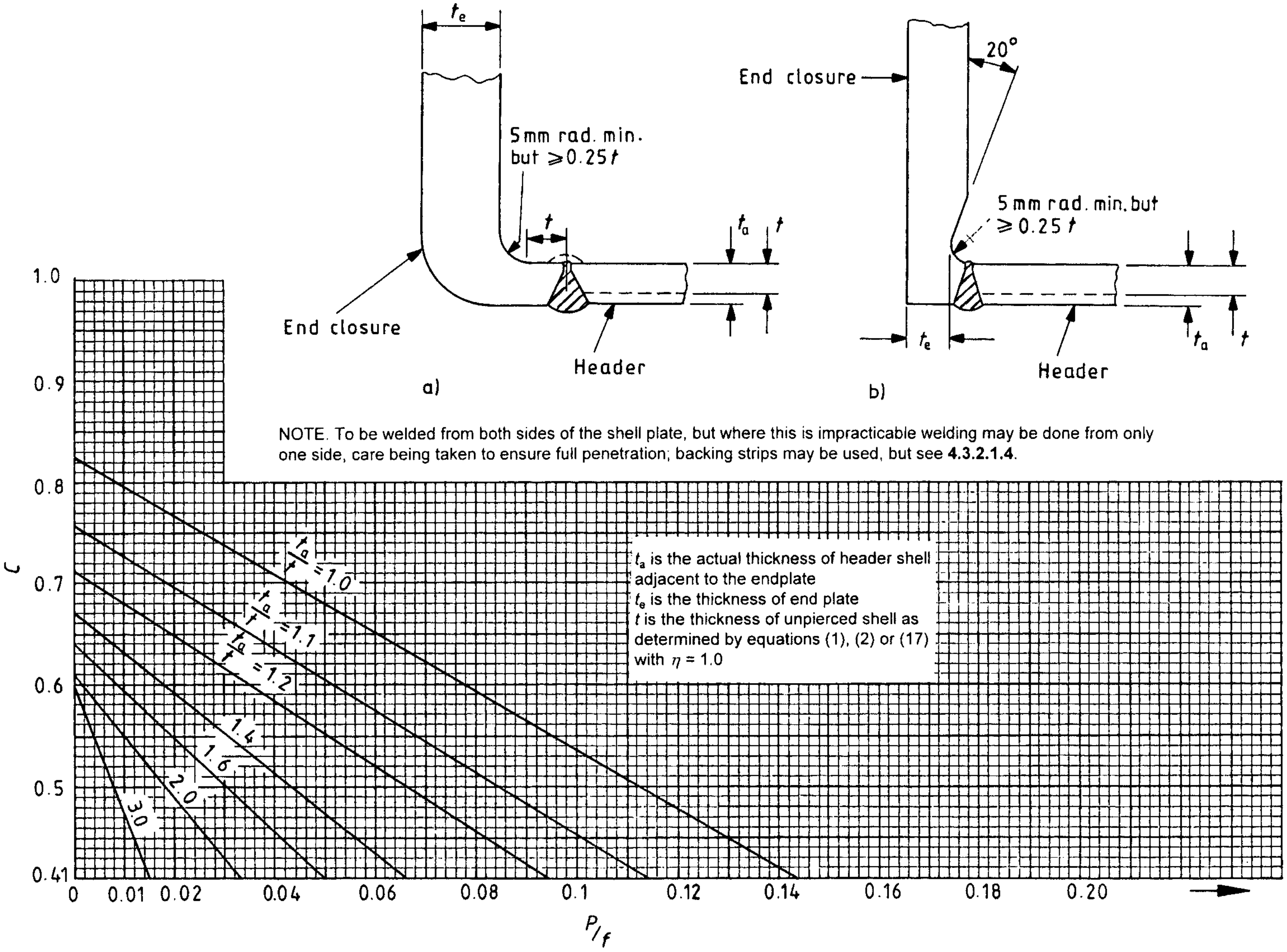


Figure 3.6.2.1-1 Factor C for header ends with butt weld in shell

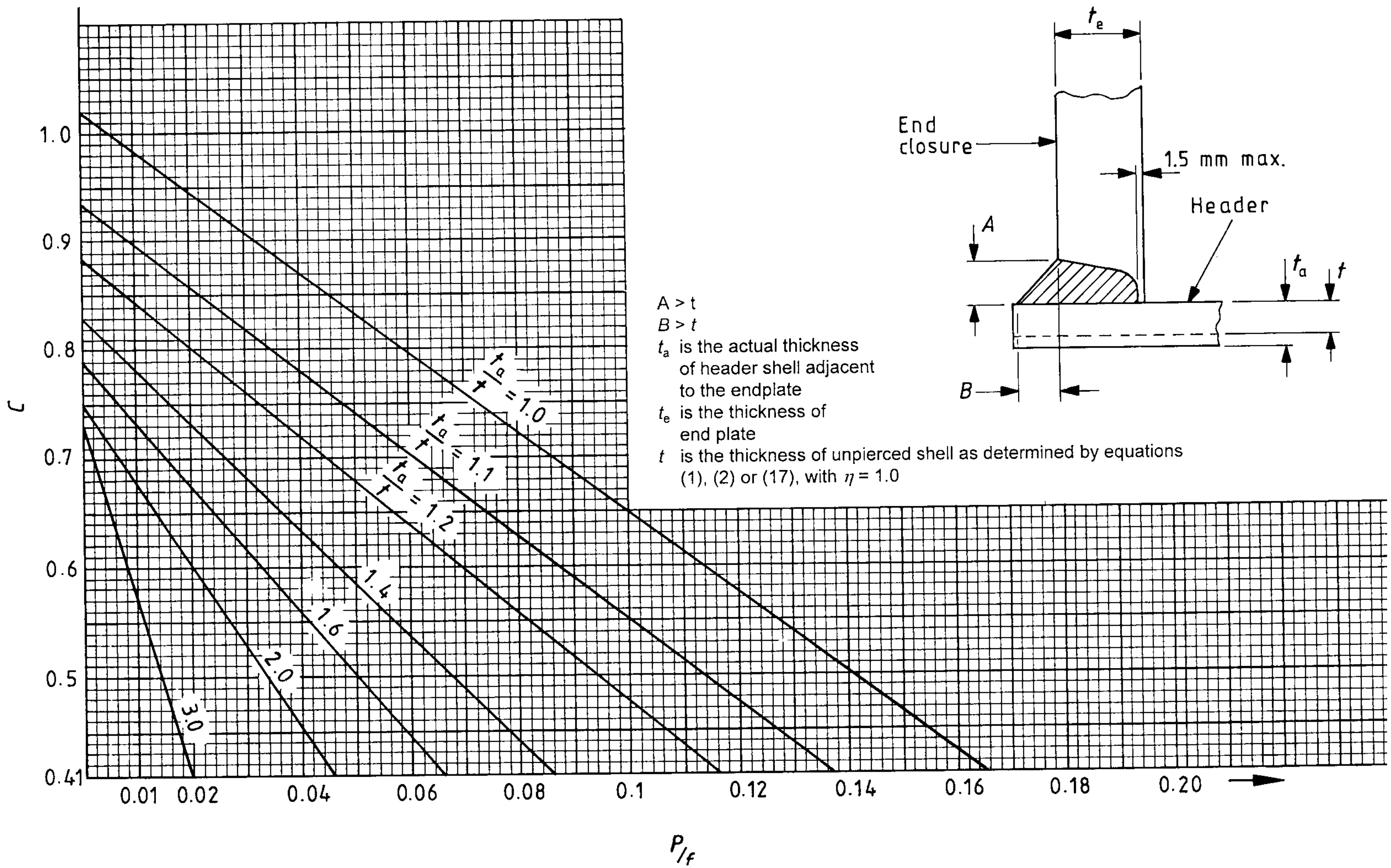


Figure 3.6.2.1-2 Factor *C* for header ends with tee butt weld

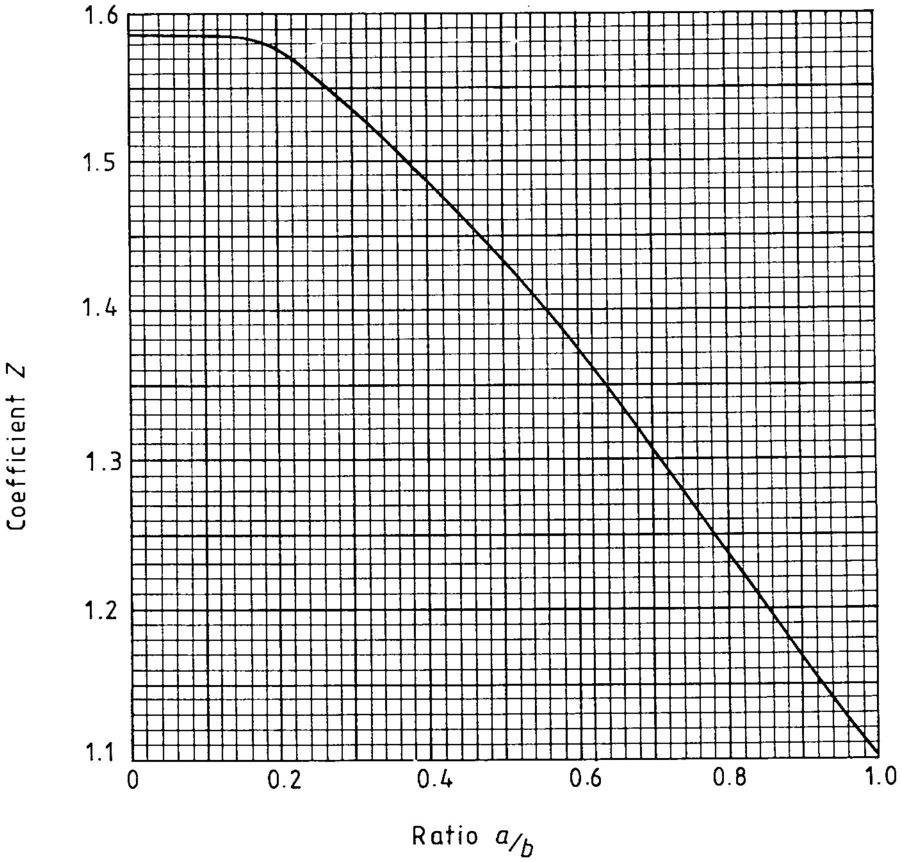
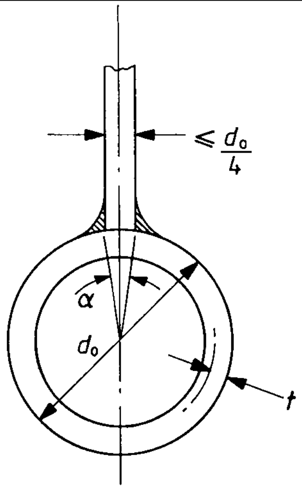
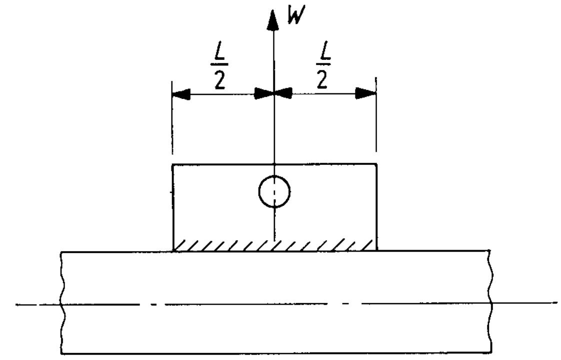


Figure 3.6.2.1-3 Coefficient *Z* for non-circular flat ends

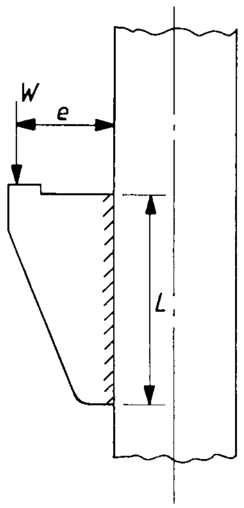


a) Structural attachment welded to tube (section)

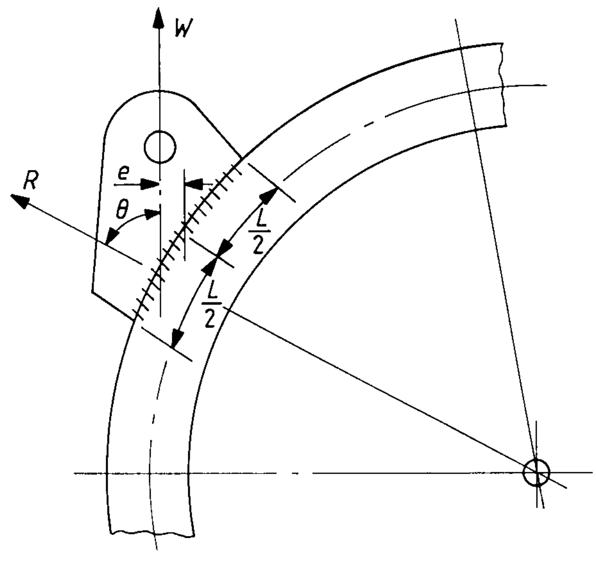


e = o $R = W$

b) Horizontal tube vertical symmetrical support

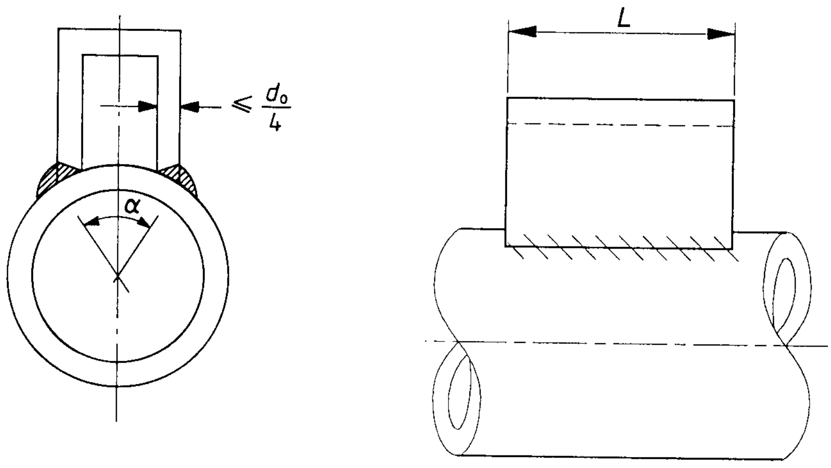


c) Support on vertical tube



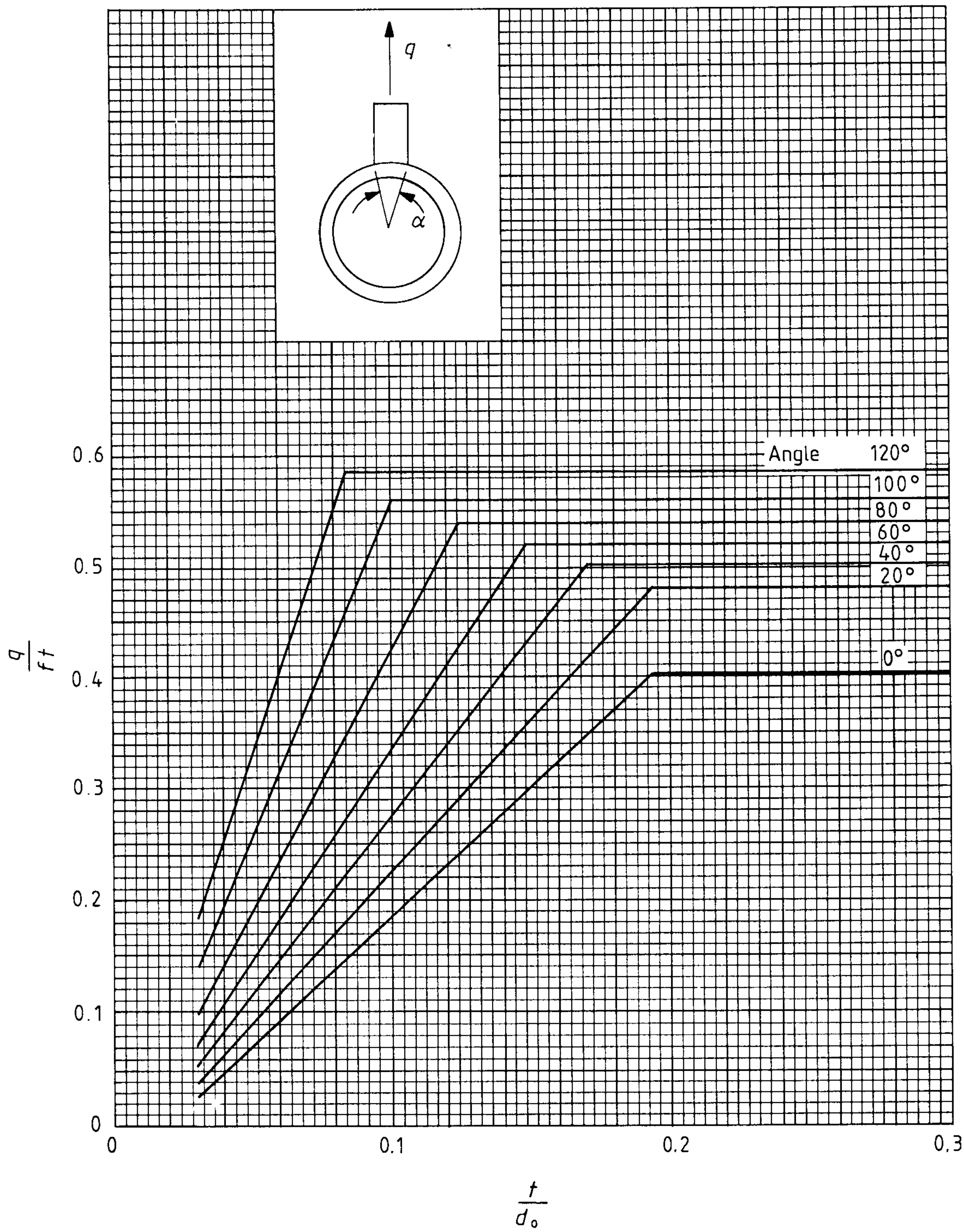
$R = W\cos\theta$

d) Curved tube vertical support



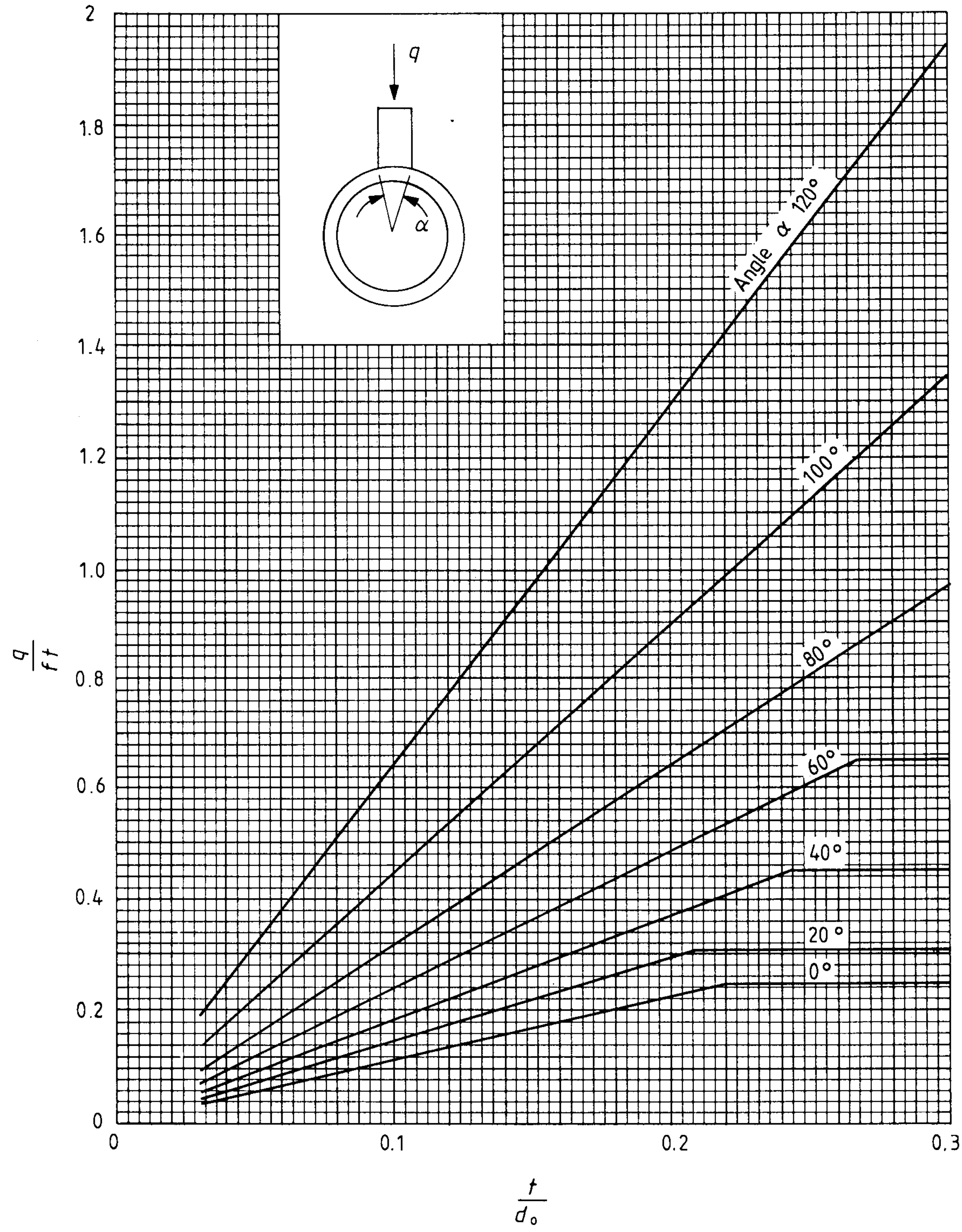
e) Double leg structural attachment

Figure 3.7.5.1 Typical structural attachments to tubes



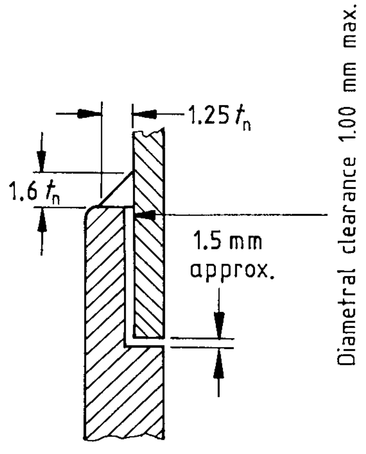
a) Tensile loading

Figure 3.7.5.3 Allowable attachment loading



b) Compressive loading

Figure 3.7.5.3 Allowable attachment loading (*continued*)



Coupling to branch joint

Figure 3.7.7.4 Socket welds

Section 4. Manufacture and workmanship

4.1 Pressure parts

4.1.1 Drums

Drums shall be rolled from plate, solid forged or drawn, fusion welded, or made by a combination of these processes. Each drum shell plate shall be formed to the correct contour up to the extreme edges of the plate. The bending shall be done entirely by machine.

4.1.2 Headers and similar pressure parts

4.1.2.1 Headers and similar pressure parts shall be constructed from forgings, pipes, plates or castings (see section **2**). Headers shall be in a suitably clean condition, both internally and externally, to enable proper visual inspection of the surface to be carried out before drilling of holes for tube stubs, branches, etc. and before welding of any permanent connections.

4.1.2.2 The ends of forged or other seamless steel tube headers shall be closed by any one of the following methods:

a) forging or spinning;

b) securing the ends by welding in accordance with **4.3** and as illustrated in figures 3.6.2.1-1 and 3.6.2.1-2;

c) bolted flanges in accordance with the relevant British Standard.

Bolted flanges in accordance with c) shall not be used where the bolts would be exposed to gases of combustion.

4.1.2.3 Header ends shall be forged or machined from steel of a grade compatible with the bodies of the headers and may be dished, as shown in figure 3.6.1-1, or flat as shown in figures 3.6.2.1-1 or 3.6.2.1-2.

4.1.3 Material identification

The manufacturer shall maintain to the satisfaction of the Inspection Authority a positive system of identification for:

a) drum plates and forgings;

b) drum branches;.

c) drum lifting lugs;

d) header shells and ends;

e) header branches;

f) any other components nominated at the time of purchase by the purchaser (see **1.5.1**c).

The system shall be such that material used in major pressure parts (e.g. drums and header shells) in the completed work can be traced back to its origin.

NOTE. The identification of tubes and pipes may be controlled by a system which permits positive identification of cast, on receipt into the manufacturer's works, and maintains type identification through manufacturing operations, e.g. by tag or by other material identification methods.

4.1.4 Marking

4.1.4.1 Temporary marks for the purpose of identification during manufacture shall be made by any one, or a combination, of the following methods:

a) painting or pen provided they are compatible with the material being marked;

b) vibro etching or other etching tool;

c) metal stamps of the low stress type and only if these marks are made lightly and before any final heat treatment. Temporary marks made by hard stamping direct onto the pressure part shall be removed except for the steels specified in **4.1.4.2**b.

Temporary identification marks shall be subject to visual examination by the Inspecting Authority who can, at their discretion, require them to be removed after inspection.

4.1.4.2 Permanent marks in accordance to section **6** or **4.3.2.1.3** shall be made by any one, or a combination, of the following methods:

a) vibro etching or other etching tool;

b) direct metal stamps. These shall only be used on carbon and carbon manganese steels and steels conforming to BS 1501-271 or -281 and only if the stamps are of the low stress type. Stamping shall take place before final heat treatment. Metal stamps shall not be used directly onto pressure parts of other ferritic alloy or austenitic steels.

c) stamped data plates welded, by an approved weld procedure, directly to the component.

4.1.4.3 Any stamping directly onto steel tubes and pipes shall be on the straight, and at least two outside diameters away from the tangent of any bend.

4.2 Cutting, forming and fabrication tolerances

4.2.1 Cutting of material

4.2.1.1 Weld preparations and openings of the required shapes shall be formed by either of the following methods:

a) machining, chipping or grinding; chipped surfaces which will not be covered with weld metal shall be ground smooth after chipping; or

b) thermal-cutting and gouging.

4.2.1.2 Any material damaged metallurgically in the process of cutting 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 thermally-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 thermally-cut edges on mild steel shall not be regarded as detrimental. If alloy steels are prepared by thermal-cutting, the surface shall be dressed back by grinding or machining for a distance of at least 1.5 mm, unless it has been shown that the material has not been damaged by the cutting process.

NOTE. These requirements for dressing do not apply to surfaces which are prepared for electro-slag welding, where a thermally-cut surface is generally acceptable without further treatment.

After the edges of the material have been prepared for welding, they shall be visually examined for flaws, cracks, laminations, slag inclusions or other defects. When materials are thermally-cut, the edges shall be examined before further work is carried out. Any weld repairs that are required to materials as a result of thermal cutting shall be to an approved welding procedure.

Care shall be taken that the weld preparations are correctly profiled and within the specified tolerances. For recommended preheating temperatures for thermal-cutting of plates, forgings and castings, see **4.5.3**.

4.2.2 Forming of drums, headers and ends

4.2.2.1 ***General***

Drums, headers and ends may be rolled or pressed from plate, solid forged, drawn or extruded, or made by a combination of these processes. Components made by a forging, drawing or extrusion process shall be produced in accordance with the forgemaster's specification as agreed with the boiler manufacturer.

Components formed from ferritic steel plate shall be produced in accordance with the requirements of **4.2.2.2** to **4.2.2.5** inclusive. The heating associated with forming operations and the heat treatment requirements after forming, shall be in accordance with **4.5.2**.

The forming requirements applicable to austenitic steel plate are the subject of development. In the meantime such requirements shall be the subject of agreement between the manufacturer and the Inspecting Authority.

4.2.2.2 ***Hot and cold forming***

For the purposes of this standard, hot and cold forming of drums, headers and ends are defined as follows:

Cold forming of ferritic steels is defined as forming at temperatures below the maximum permissible temperature for post weld heat treatment in accordance with table 4.5.4.

Cold forming for austenitic steels is defined as forming below 300 °C.

Hot forming of ferritic steels is defined as forming at temperatures at or above the maximum permissible temperature for post weld heat treatment in accordance with table 4.5.4.

Hot forming of austenitic steels is defined as forming at or above 300 °C.

4.2.2.3 ***Drum and header shells***

Shell plates shall be formed, either hot or cold, to ensure conformance to the tolerances specified in **4.2.5**. Each shell plate shall be formed to the correct contour up to the extreme edges of the plate. The bending or pressing shall be done entirely by machine.

Local heating and hammering shall not be employed.

4.2.2.4 ***Ends***

Dishing and peripheral flanging, either hot or cold, shall be carried out to ensure conformace to the tolerances specified in **4.2.5**. The operations shall be done by machine. Sectional flanging shall not be employed.

4.2.2.5 ***Plates welded prior to hot or cold forming***

Where practicable, shells and ends shall be rolled or pressed from one piece of plate. Where this is impraticable, butt welding of plate shall be permitted, prior to forming, provided that the welded joints are non-destructively examined after forming in accordance with **5.6** and **5.7** (see **4.3.1.1.3** and **4.3.1.1.4**), and a welding qualification procedure test has been performed in accordance with **5.2** taking into account any heat treatment cycles involved. A production test plate as specified in **5.4** shall be provided.

4.2.2.6 ***Extruded openings in headers***

Extruded openings in headers shall have a fillet with a radius not less than the thickness of the neck of the extrusion as shown in figure C.16a).

4.2.3 Forming of integral piping bends

4.2.3.1 ***General***

Integral piping that is hot or cold bent shall conform to **4.2.3.2** to **4.2.3.5**.

4.2.3.2 ***Thinning in integral pipe bends***

The thickness at any point after bending shall not be less than that calculated by equations (31) and (32) in **3.7.1.1**.

4.2.3.3 ***Departure from circularity of integral pipe bends***

The departure from circularity of integral pipe bends shall not exceed 10 %.

The departure from circularity (in %) shall be calculated from:

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

where

- D_{max} is the maximum outside diameter measured at the pipe bend apex (in mm);
- D_{min} is the minimum outside diameter measured at the same cross-section as D_{max} (in mm);
- D_s is the average outside diameter of the pipe adjacent to the bend (in mm).

4.2.3.4 ***Surface condition of pipe bends***

All bends in integral piping shall be free from surface defects such as cracks, indentations, laps and scabs. Where surface defects are ground out, the pipe thickness shall not be reduced below t as calculated by equations (31) and (32) in **3.7.1.1**.

The surface of the bend shall be such as to permit an effective visual examination. Areas which are ground to remove defects shall be examined by surface flaw detection methods appropriate to the material to ensure complete removal of the defect.

Repairs carried out by welding and subsequent heat treatment shall be by procedures approved by the Inspecting Authority.

4.2.3.5 *Requirement for heat treatment of pipe bends*

With the exception of cold bends of limited deformation as indicated in table 4.2.3, bends in ferritic steel shall be heat treated. The requirement for bends in austenitic steel to be heat treated shall be agreed between the manufacturer and the Inspecting Authority (see **1.5.2.3**j). Where required, heat treatment shall be carried out in accordance with **4.5.2.2**.

4.2.4 Forming and bending of tubes

4.2.4.1 *General*

Tubes up to and including 80 mm outside diameter which are bent hot or cold shall either conform to **4.2.4.2** to **4.2.4.7** and, where appropriate, **4.2.4.8** and **4.2.4.9** or shall be subject to agreement with the Inspecting Authority.

Tubes above 80 mm outside diameter shall either conform to **4.2.3** or shall be subject to agreement with the Inspecting Authority.

4.2.4.2 *Tube bending procedure test*

It shall be demonstrated by means of a tube bending procedure test, in accordance with annex H, that tubes can be satisfactorily bent to the requirements of **4.2.4.1** The tests shall be performed to represent combinations of tube sizes, materials and bend radii which demonstrate the suitability of the bending method chosen. The range and scope of the qualification of tube bends resulting form these procedure tests shall be in accordance with annex H. The results from the bending procedure tests shall be documented and used as a basis for all future tube bends falling within the scope of the combinations tested.

When specific pre-production test bends, conforming to **4.2.4.1**, are manufactured in accordance with table 4.2.3, the resulting documented data shall serve as qualification for subsequent production runs.

NOTE 1. They may also be considered to meet the requirements of annex H.

NOTE 2. Documented evidence of previous satisfactory tube bending procedure tests may be accepted as fulfilling these requirements subject to agreement with the Inspecting Authority.

4.2.4.3 *Tube bending requirements*

Thinning at the bend extrados and departure from circularity (DFC) limits shall be demonstrated by the following dimensional testing during a production run of tube bends.

a) Measure non-destructively 2 % of the production run, including the first bend, for thinning and DFC.

b) Additionally, where $R/D < 1.3$, a sample test bend is required before production commences.

NOTE 1. A sample test bend consists of the sectioning and measuring of a trial bend to establish the maximum thinning and the maximum departure from circularity. The measured values should be checked against e_{ext} and DFC given in **4.2.4.4** and **4.2.4.5** respectively.

NOTE 2. A production run is defined as a series of tubes of the same size and material being bent on a specific machine within the same machine set-up.

NOTE 3. DFC should be measured at the apex of the bend.

NOTE 4. R is the radius of the bend measured to the centre-line of the tube.

NOTE 5. D is the outside diameter of the tube measured on the straight.

NOTE 6. These requirements do not apply to coil type boilers.

Table 4.2.3 Requirement for heat treatment of cold bent ferritic pipes

Material	D (note 1) mm	Design temperature ˚C	R/D (note 1)	Departure from circularity (note 2) %	Heat treatment
Carbon steel including 500 Nb	≥ 76.1	≤ 300	≥ 3.0	≤ 8	Not required
	≥ 76.1	≤ 300	≥ 3.0	> 8 ≤ 10	Required
	≥ 76.1	≤ 300	< 3.0	≤ 10	Required
Carbon steel including 500 Nb	≥ 76.1	> 300	≥ 4.5	≤ 8	Not required
	≥ 76.1	> 300	≥ 4.5	> 8 ≤ 10	Required
	≥ 76.1	> 300	< 4.5	≤ 10	Required
Carbon steel including 500 Nb	< 76.1	No limit	≥ 3.0	≤ 10	Not required
	< 76.1	No limit	< 3.0	≤ 10	Required
Ferritic alloy steels other than 500 Nb	All	No limit	≥ 3.0	≤ 8	Not required
	All	No limit	≥ 3.0	> 8 ≤ 10	Required
	All	No limit	< 3.0	≤ 10	Required

NOTE 1. R is the radius of the bend measured to the centreline of the pipe. D is the outside diameter of the straight pipe.
NOTE 2. The departure from circularity determined in accordance with **4.2.3.3**.

4.2.4.4 ***Tube thinning at the tube bend extrados***

The thickness at any point after bending shall not be less than that given by the equation:

$$e_{ext} = e_{act} \times \frac{2\,R/D + 0.5}{2\,R/D + 1}$$

where

- e_{ext} is the required minimum manufacturing thickness at the extrados (in mm);
- e_{act} is the nominal thickness of the supplied tube minus the supplier's maximum negative thickness tolerance (in mm);
- R is the radius of the bend measured to the centre-line of the tube (in mm);
- D is the nominal outside diameter of the tube (in mm).

NOTE. The required minimum manufactured thickness at the extrados e_{ext} is calculated from the tube ordered thickness and, as such, should always result in a thickness greater than the design thickness. However, in the unlikely event of the thickness of the extrados on the completed tube bend being found, when measured, to be less than e_{ext}, the thickness obtained from **3.7.1.1** equation (31) or (32) may be substituted for e_{act} in the equation above.

The thinning on the extrados of bends formed in two stages i.e. hot formed after initial hot or cold bending, shall not exceed 30 % of the thickness of the straight tube local to the bend as measured during a test procedure.

4.2.4.5 ***Departure from circularity of the tube bends***

The departure from circularity of the tube bend as a percentage of the tube nominal outside diameter shall be calculated from the equation:

$$\text{DFC} = 2 \times \frac{(D_{max} - D_{min})}{(D_{max} + D_{min})} \times 100$$

where

- DFC is the departure from circularity (in %);
- D_{max} is the maximum outside diameter measured at the tube bend apex (in mm);
- D_{min} is the minimum outside diameter measured at the same cross-section as D_{max} (in mm).

The DFC of tube bends, which are bent in a single continuous operation, shall not exceed the limits shown in figure 4.2.4.5a).

The DFC of tube bends which are bend by a double operation, i.e. hot pressed after the primary bending operation, then post-bend heat treated in accordance with **4.2.4.6**, shall not exceed the limits shown in figure 4.2.4.5b).

4.2.4.6 ***Heat treatment of tube bends***

The heat treatment of hot or cold formed bends shall be as follows.

a) All hot formed tube bends and cold formed tube bends requiring heat treatment after bending, including bends hot formed after cold bending, shall be heat treated in accordance with **4.5.2.3** except as follows:

1) Hot formed tube bends in steels 320, 360, 440, 243 and 620 need not receive a post-bend heat treatment if it can be demonstrated that the bending operation was completed within the normalizing range as defined in table 4.5.2.3.

2) Post-bend heat treatment may be waived, by agreement with the Inspecting Authority, if it can be demonstrated by a procedure test approved by the Inspecting Authority, that heat treatment is not required.

b) All cold bent tube bends with thinning greater than 25 % as measured in the procedure test, shall be heat treated in accordance with the requirements of **4.5.2.3**.

c) Where the heat treatment of cold formed tube bends is specified in table 4.2.4.6 it shall be carried out in accordance with the requirements of **4.5.2.3**.

Table 4.2.4.6 Post-bend heat treatment applicable to cold formed tube bends		
Steels	**Bend ratio**	**Heat treatment**
629-590, 91 and 762 only	$R/D < 3.0$	Stress relieve
	$R/D \geq 3.0$	No post-bend test treatment required
all other steels	$R/D \leq 1.3$	Stress relieve
	$R/D > 1.3$	No post-bend heat treatment required

4.2.4.7 ***The surface of tube bends***

The surface of tube bends shall be free of defects such as cracks, indentations, laps and scabs. Surface defects may be removed by grinding, however in such cases the resulting thickness shall not be less than the minimum calculated thickness specified in **3.7.1** or **4.2.4.4**.

The surface of the tube bend shall be such as to permit effective visual examination.

Areas of the tube bend which have been ground to remove defects shall be examined by surface flaw detection methods to ensure that complete removal of the defect has been effected.

Repairs to the tube surface by welding shall not be permitted.

4.2.4.8 ***Gang bending of tube panels***

The tube bends produced by the gang bending method shall conform to the requirements for tubes bent singly, i.e. with **4.2.4.1** to **4.2.4.7** and, where appropriate, **4.2.4.9**.

The gang bending method shall be qualified by a tube bending procedure test in accordance with annex H, which is valid for the specific gang bending machine being utilized. The tube panel used in the test shall consist of at least three tubes which have been welded together prior to gang bending.

The departure from circularity (DFC) shall be measured during production on the two outermost tubes of the panel. The results shall conform to **4.2.4.5**. For practical reasons D_{max} in the equation shall be replaced by the nominal outside diameter of the tube measured in the straight.

4.2.4.9 ***Bending of composite materials tubing***

The bending procedure adopted for metallurgically bonded composite materials tubing shall be in accordance with **4.2.4.1** to **4.2.4.7** and, where appropriate, **4.2.4.9**. Additionally, any special requirements recommended by the tube manufacturer shall be taken into consideration. The inclusion of such additional requirements shall be agreed with the Inspecting Authority.

4.2.4.10 ***Manufacture of welded tubewalls***

NOTE. Welded tubewalls should be manufactured in accordance with annex J.

4.2.5 Fabrication tolerances

4.2.5.1 ***Assembly tolerances for shells and ends to shells***

4.2.5.1.1 *Middle line alignments*

The root faces of the weld preparations shall be aligned within the tolerances permitted by the welding procedure specification and the components shall be aligned as indicated on the drawings within the following tolerances.

a) For longitudinal joints in cyclindrical components, the middle lines of adjacent plates shall be aligned within the following tolerances:

for plate thickness t_a up to and including 10 mm	1 mm;
for plate thickness t_a over 10 mm up to and including 50 mm	$t_a/10$ or 3 mm, whichever is the smaller;
for plate thickness t_a over 50 mm up to and including 200 mm	$t_a/16$ or 10 mm, whichever is the smaller;
for plate thickness t_a over 200 mm	tolerances shall be agreed between the purchaser and the manufacturer (see **1.5.2.3f**).

b) For circumferential joints, the middle lines of adjacent plates shall be in alignment within the following tolerances:

for plate thickness t_a up to and including 10 mm	1 mm;
for plate thickness t_a over 10 mm up to and including 60 mm	10 % of thickness of thinner part plus 1 mm, or 6 mm, whichever is the smaller;
for plate thickness t_a over 60 mm up to and including 200 mm	10 % of the thickness of thinner part;
for plate thickness t_a over 200 mm	tolerances shall be agreed between the purchaser and the manufacturer (see **1.5.2.3f**).

4.2.5.1.2 *Surface alignment*

The alignment at the surface of adjacent plates shall either:

a) not exceed the following maximum tolerances:

1) *longitudinal joints*

up to and including 12 mm	$t_a/4$;
over 12 mm up to and including 50 mm	3 mm;
over 50 mm	$t_a/16$ or 10 mm, whichever is the smaller;

2) *circumferential joints*

up to and including 20 mm	$t_a/4$;
over 20 mm up to and including 40 mm	5 mm;
over 40 mm	$t_a/8$ or 20 mm, whichever is the smaller;

or

b) if the maximum alignment tolerances in a) are exceeded, be reduced by tapering the surface(s) at a slope no steeper than 1 : 4 over a width that includes the width of the welds.

Either of the following methods of tapering shall be used:

i) building up the lower surface with added weld metal to provide the required taper; or

ii) trimming the plate surfaces provided that this does not reduce the plate thickness below the specified minimum for the component and location in question.

4.2.5.2 ***Finished tolerances for shells***

4.2.5.2.1 *Tolerance on diameter*

The maximum internal diameter of a drum shall not exceed the nominal internal diameter by more than 2 %.

4.2.5.2.2 *Circularity (out of roundness)*

The difference between the maximum and minimum internal diameters at any one cross section shall not exceed 1 % of the nominal internal diameter. If the drum is made of plates of unequal thicknesses, the measurements shall be corrected for plate thicknesses, as they may apply, to determine the diameters at the middle line of the plates.

Irregularities in profile, checked using a template embracing an arc of 20 °, shall not exceed 3 mm plus 5 % of the minimum plate thickness. A 25 % increase in the maximum value shall be permitted if the length of the irregularity does not exceed one-quarter of the length of the shell ring with a maximum of 1000 mm.

There shall be no flats at welded seams and any local departure from circular form shall be gradual. Cold rolling of a welded shell to rectify a small departure from circularity shall be permitted but, if this occurs, it shall be done before the non-destructive examination of the seams in accordance with section **5**.

4.2.5.2.3 *Straightness*

The maximum deviation of the complete shell from a straight line shall not exceed 0.15 % of the total cylindrical length. Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

4.2.5.3 ***Finished tolerances for ends***

4.2.5.3.1 *Tolerances on diameter*

See **4.2.5.2.1**.

4.2.5.3.2 *Circularity (out of roundness)*

See **4.2.5.2.2**.

4.2.5.3.3 *Thickness*

The thickness is the thickness of the end after manufacture and is applicable over the whole area of the end. Variations in thickness (thinning) arising during manufacture shall be gradual. In no case shall the thickness of the end be less than the design thickness.

4.2.5.3.4 *Profile*

The depth of dishing, measured from the plane passing through the point where the straight flange joins the knuckle radius, shall in no case be less than the theoretical depth, nor shall this depth be exceeded by a permissible increase in depth of dishing of 1.25 % of diameter, for diameters of ends up to and including 3000 mm. Variations of the profile shall not be abrupt but shall merge gradually in the specified shape. The knuckle radius shall not be less than specified, and shall have common tangents with both the straight flange and the dished profile, at each join.

4.2.5.4 ***Alignment of tube bores***

4.2.5.4.1 *Linear alignment of butt welded tubes*

The welding of tube joints shall include matching, if necessary, of the tube ends at each joint.

Matching of the bores shall be effected by selection, drifting (hot or cold), machining, swaging or by use of a suitable expander. Any machine counter boring required shall not reduce the thickness of the tube wall to below the design thickness. All hot drifted ends shall be heat treated in accordance with requirements of the relevant parts of **4.5**.

The bores of the ends of adjacent tubes should preferably match exactly. Permissible limits for bore difference and bore misalignment are given in table 4.2.5.4.1.

Table 4.2.5.4.1 Alignment tolerances of tube bores

Diameter of tube bore mm	Maximum difference in bore mm	Maximum out of alignment of adjacent tube mm
up to 80	1,0	1,0
80 to 300	1,5	1,5
over 300	2,0	2,0

4.2.5.4.2 *Angular alignment of butt welded tubes*

Any centre line angular misalignment should not normally exceed 3°, i.e. 5 mm in 100 mm, (see figure 4.2.5.4.2), but in any case should be consistent with any specific design requirements.

blank

4.3 Welding

4.3.1 General

4.3.1.1 ***Design and other requirements specific to welding***

4.3.1.1.1 The following requirements relative to welding shall be considered before any manufacturing is commenced.

NOTE. General guidance on the welding of ferritic steels is given in BS EN 1011 which may be used to supplement the welding requirements of this standard.

4.3.1.1.2 Before commencing construction, the manufacturer shall supply to the Inspecting Authority, on request, fully dimensioned sectional drawings showing in full detail the construction of the pressure parts to be welded. Drawings of the proposed weld preparations of the main seams shall be dimensioned and shall be drawn to a scale which clearly shows the relevant details. Sketches shall also show details of the weld preparations for the attachment of standpipes, branches and seatings and their location relative to the longitudinal and circumferential seams and to other openings.

The manufacturer shall also supply, on request, welding procedures in accordance with **5.2**.

NOTE. The welding terms used in this standard are defined in BS 499 : Part 1 and BS EN 22553 : 1995.

4.3.1.1.3 The selection of the materials for the pressure parts, and for any attachments to be made to them, shall be such that any welding operations which are carried out will not render the component unfit for its intended duty.

The selection of welding consumables shall be such as to ensure the cross-weld strength required, by the design, is achieved. The effects of post weld heat treatment on the completed joint, as described in **4.5.4**, shall also be taken into consideration.

4.3.1.1.4 The toes of welds of attachments to main pressure parts should, wherever practicable, not be located closer than 40 mm to main joint welds or branch welds. If this latter condition is not practicable, the attachment weld shall cross the main joint weld completely. In such cases, the surface of the main joint weld shall be ground locally before the attachment weld is made. The attachment welds shall be ground locally after the welding-on of the attachment has been completed.

The portion of the attachment welds which crosses main joint welds shall be treated as “load-carrying” with respect to the non-destructive examination to be applied. Such non-destructive examination shall be carried out in accordance with the requirements of **5.6**.

Openings for branches should, if practicable, be positioned away from the main joint welds of drums and headers. The spacing shall be considered adequate if the distance between the edge of the main joint weld to the edge of the branch or set-on reinforcement, fulfil the following requirements:

Table 4.3.1.1.4 Spacing for welding

Drum or header thickness mm	Spacing Δ mm
$t \leq 25$	$\Delta > 2 \times t$
$t > 25$	$\Delta > 50$

If, for reasons of design, these spacings cannot be achieved, the welds shall be capable of non-destructive examination within the area of influence of the opening and the welds shall be ground to a smooth profile to remove all notches in this area.

Where local grinding of the welds is required, as indicated above, the ground surface shall be 100 % non-destructively examined in accordance with the requirements of **5.6**.

4.3.1.1.5 Where, from design considerations, the dimensions are such that a drum cannot be made from a single plate, it shall be made with a minimum number of seams. Where plates are butt-welded together prior to bending, non-destructive examination shall be carried out subsequent to the bending operation in accordance with section **5**.

4.3.1.1.6 Where any part of the drum is made in two or more courses (strakes) the longitudinal seams shall be completed before commencing the adjoining circumferential seam(s) and, where practicable, the longitudinal seams of adjacent courses shall be staggered.

4.3.1.1.7 Machining of holes through the centre of main seam welds in drums and headers shall be permitted in all materials with the exception of steel grade 762, provided that the seam welds have been subjected to a non-destructive examination in accordance with **5.8.1** or **5.8.2** respectively, over the length of the seam weld to be drilled. This intermediate non-destructive examination may be carried out prior to any specified post-weld heat treatment.

4.3.1.1.8 Where parts other than branches and nozzles are welded to main pressure parts, consideration shall be given at the design stage to the necessity for pre-heating and subsequent heat treatment in conjunction with the dimensions of the welds, the chemical composition of the materials, the section thicknesses involved and the heat input of the welding process to be used.

4.3.1.1.9 Welding of the joints of the component parts of a water tube boiler shall only be undertaken when the following conditions are satisfied:

a) welding procedure specifications have been compiled by the manufacturer in accordance with BS EN 288-2 for each joint or family of joints;

b) the welding procedure specifications selected by the manufacturer are qualified for the field of application;

c) the welders and welding operators are qualified for the work allocated to them and their approvals are valid.

4.3.1.1.10 Where the use of oxy-acetylene welding is proposed the manufacturer shall demonstrate that the location of such welds in the boiler will not result in subsequent problems during operation. The method of procedure qualification shall be in accordance with the requirements of BS EN 288-3 or BS EN 288-8. Welder qualification shall be in accordance with the requirements of BS EN 287.

4.3.1.1.11 Butt welds shall not be permitted within tube bends, except in the special case of coil boilers (see Enquiry Case 1113/7).

4.3.1.1.12 The welding on site of widely differing materials, e.g. austenitic to ferritic materials, should be avoided whenever possible (see also **4.3.2.5.4**).

4.3.1.1.13 During production, a copy of the weld procedure specification shall be available to the welder.

4.3.1.2 ***Welding materials***

Electrodes, filler wires, filler rods, fluxes and fusible inserts shall either:

a) conform to the relevant British Standards, where they exist; or

b) where relevant British Standards do not exist, be agreed between the manufacturer and the purchaser (see **1.5.2.3**g).

The manufacturer shall ensure that the correct consumables, as specified in the welding procedure, are used.

All consumables shall be stored and handled with care, and used in accordance with the conditions specified by the consumable manufacturer.

NOTE. This is particularly important in the case of the requirements for baking and drying when hydrogen controlled consumables are to be used.

Electrodes, filler wires and rods and fluxes that show signs of damage or deterioration, such as cracked or flaked coatings or rusting or dirty electrode wire, shall not be used.

4.3.1.3 ***Approval of fusion welding procedures***

Approval of fusion welding procedures shall be in accordance with **5.2**.

4.3.1.4 ***Welder approval***

Welder approval shall be in accordance with **5.3**.

4.3.1.5 ***Production control test plates for boiler drums***

Production control test plates for boiler drums shall be in accordance with **5.4**.

4.3.1.6 ***Assembly of components for welding***

To maintain during welding the specified alignment (see **4.2.5**) and, where required, the details for the root gap given in the drawings and weld procedures (see **4.3.1.1.1**), the parts to be welded shall be securely held in position by mechanical means, welded bridge pieces or tack welding.

NOTE. The dimensions of the root gap are the dimensions after tack welding.

It is recognized that there may be difficulty in complying strictly with the requirements for the root gap. Slight modification imposed by practical considerations are permitted by agreement between the manufacturer and the Inspecting Authority.

Correction of irregularities in fit-up shall not be carried out by hammering.

The preheating requirements of **4.5.3** shall be applied and maintained during tack welding and welding bridge pieces or other attachments.

Filler materials used for tack welding shall be of a type and class appropriate to the particular weld.

Particular attention shall be paid to the quality of tack welds which shall be deposited by approved welders. Where necessary, the extremities of these tack welds shall be dressed by grinding or chipping to facilitate proper fusion when they are incorporated in the root run. All cracked tack welds shall be completely removed.

All welded bridge pieces shall be removed, and the weld area ground flush and examined by a surface flaw detection method appropriate to the material before stress relief heat treatment.

4.3.1.7 ***Preheating***

Preheating shall be in accordance with table 4.5.3.1-2.

4.3.1.8 ***Post-weld heat treatment***

Post-weld heat treatment shall be in accordance with table 4.5.4.

4.3.1.9 ***Repairs to welds***

4.3.1.9.1 *General*

If it is found necessary to repair a weld, an approved welding procedure shall be employed. The nature and extent of such repairs shall be reported to the Inspecting Authority. When films or other records of non-destructive testing are being examined, the manufacturer shall make available all previous relevant records of the repaired areas. Details of weld repairs shall be made available to non-destructive examination personnel responsible for re-examination.

Defects shall be cut out by an appropriate method. Where welds are partially removed, the portion cut out shall be sufficiently deep and long to remove the whole defect. At the ends of the cavity, there shall be a gradual taper from the base of the cut to the surface of the weld metal. The width and profile of the cut shall be such as to give adequate access for re-welding.

4.3.1.9.2 *Re-welding of main seams of drums*

If, in order to effect a repair, the whole of the weld is removed and the seam re-welded, a new production test plate shall be provided.

When seams have been re-welded, the drum and the test plates (if any) shall be heat treated in accordance with the relevant clauses of this standard and the test plates (if any) shall be tested as in the case of the original weld.

4.3.1.9.3 *Non-destructive examination*

All repaired areas and re-welded seams shall be subjected to non-destructive examination in accordance with section **5** and shall be subject to the same testing and inspection requirements as the original joint.

4.3.1.9.4 *Records*

The manufacturer shall maintain records showing the position, length, width and depth of all repairs carried out on:

a) drum main seam welds and nozzle welds;

b) header main seam welds;

c) integral pipe butt welds over 25 mm thickness or 170 mm outside diameter.

4.3.1.10 ***Welding subsequent to post-weld heat treatment***

Special cases may arise when it is necessary to weld to a pressure part after post-weld heat treatment has been completed, e.g. seal welding of expanded tubes, the welding of minor attachments and effecting minor repairs and this practice shall be permitted on carbon and carbon manganese steels provided that the welding complies with a procedure approved to the requirements of BS 4870 : Part 1, taking into account the following requirements.

a) Minimum preheating shall be in accordance with table 4.5.3.1-2.

b) Either 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.

c) Where practicable, at least two runs of weld metal shall be deposited with the minimum of stop starts.

d) For seal welds, the minimum throat thickness shall not be less than the specified minimum design wall thickness nor greater than 13 mm.

e) The throat thickness of attachment welds shall not exceed 13 mm.

f) The weld metal shall blend smoothly with the component material and shall be dressed if required.

g) After completion of all welding and dressing, as required, the welds shall be examined by magnetic particle methods.

4.3.1.11 ***Miscellaneous welding requirements***

4.3.1.11.1 *Stray arcing*

While arc strikes are to be avoided all accidental arc strikes shall be ground smooth and the parent material examined by a surface flaw detection method appropriate to the material.

4.3.1.11.2 *Protection from weather*

Where necessary, staging and protection from the weather shall be provided to enable the welding operations to be performed under satisfactory conditions.

4.3.1.11.3 *Temporary attachments*

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

Temporary attachments shall be removed prior to the first pressurization unless they have been designed to the same requirements as permanent attachments. The removal technique shall be such as to avoid, as far as practicable, impairing the integrity of the pressure part and shall be by chipping, grinding or thermal cutting followed by chipping or grinding. Any rectification necessary by welding of damaged regions after removal of attachments shall be undertaken by approved welders working to an approved welding procedure. The area from which temporary attachments have been removed shall be dressed smooth and examined by appropriate non-destructive examination methods.

4.3.1.11.4 *Surface condition before welding*

The fusion faces and the adjacent material shall be dry and thoroughly cleaned of grease, oil, lubricants, marking paints, oxide scale or other foreign substances to a clean metal surface for a distance from the welding edges sufficient to prevent contamination of the weld.

4.3.2 Welded joints and connections

4.3.2.1 ***Welds of main seams in drums and headers***

4.3.2.1.1 When multi-run welding is employed, each deposited run shall be free from slag and, when required by the welding procedure, scale shall be removed before succeeding runs of weld are deposited.

4.3.2.1.2 Backing material employed in welding main seams of drums shall be removed after welding.

NOTE. Main seams of drums may be welded from both sides of the plate, or from one side only, with or without the use of backing material.

4.3.2.1.3 The positions of welds in boiler drums shall be permanently marked (see **4.1.4**).

4.3.2.1.4 Permanent backing rings shall not be used for butt welds in headers of the main boiler circulation system which contain water and are subject to heat. Where backing rings are used, they shall conform to BS 2633.

4.3.2.1.5 Fusible inserts shall not be regarded as backing rings. Fusible inserts shall be used only if the material from which they are made is compatible with the parent metal and if they are completely fused into the joint.

4.3.2.1.6 *Butt joints between plates of unequal thickness*

Where a butt welded seam is required between plates of different thicknesses, the thicker plate shall be reduced in thickness by one of the methods shown in figures 4.3.2.1-1 and 4.3.2.1-2. The thicker plate shall be trimmed to a smooth taper for a distance not less than four times the offset including, where necessary, the width of the weld.

NOTE. If necessary the required taper may be obtained by adding additional weld metal beyond the width of what would otherwise be the edge of the weld.

4.3.2.2 ***Welding of header end closures***

4.3.2.2.1 Torispherical, semi ellipsoidal or hemispherical ends shall be secured to the header shell by welding in accordance with **4.3.2.1**.

4.3.2.2.2 Flat ends shall be secured to the header shell by welding as illustrated in figure 3.6.2.1-1 and in accordance with **4.3.2.1** or as illustrated in figure 3.6.2.1-2 and in accordance with **4.3.2.3**.

The extent of non-destructive examination of flat end plate welds as illustrated in figure 3.6.2.1-2 shall be in accordance with **5.8.3.4**.

4.3.2.3 ***Welding of branches, nozzles and stubs to drums and headers***

4.3.2.3.1 *Attachment by welding of pressure parts to drums and headers*

Not less than two runs of metal shall be deposited at each weld. Each run of weld metal shall be clean and free from slag before the next run is deposited.

Permanent backing rings shall not be used for welds in headers of the main boiler circulation system which contain water and are subject to heat. Where backing rings are used, they shall conform to BS 2633.

Fusible inserts shall not be regarded as backing rings. Fusible inserts shall be used only if the material from which they are made is compatible with the parent metal and if they are completely fused into the joint.

Where the use of partial penetration joints is permitted (see figures C.10 and C.11), the depth of penetration shall be specified on the drawing.

The complete weld shall be free from crevices between weld runs and the final finish of all welds shall be such that the change of section between the parts is gradual and free from sharp notches and significant undercutting.

Preheating, where required, shall be carried out in accordance with **4.5.3**.

Attachment welds of branches, nozzles and stubs on drums and headers shall not involve any combination of austenitic and ferritic steels.

4.3.2.3.2 *Attachments, nozzles and fittings*

All pads, reinforcing plates, manhole frames, lugs, brackets, stiffeners, supports and other attachments shall fit closely and the gap at all exposed edges to be welded shall not exceed 2 mm or one-twentieth of the thickness of the attachment at the point of attachment, whichever is greater.

Compensating plates, including access opening frames and reinforcing pads shall be subject to the limits of application specified in **3.4.6**. Where compensating plates or frames are fitted, they shall be provided with tell-tale holes through the outer plate (see figure 4.4.2.4-1).

Frames of the pressed type shall be seamless and shall not be used for design pressures exceeding 4 N/mm^2. They shall bed closely to the surfaces to which they are to be connected and shall be fillet-welded to the inner surface of the drums. The fillet welds shall be of the proportions shown in figure 4.4.2.4-1.

Frames and mouthpieces which are set through the drum plates and welded in accordance with figure 4.4.2.4-2 shall be either formed in one piece without welding, or formed from a suitable rolled section fabricated by fusion welding providing they are stress relieved after welding and before attachment to the drum, unless the whole drum is to be stress relieved on completion. The welds shall also be subjected to non-destructive examination in accordance with **5.7**. Welds in fabricated manhole frames shall be positioned so that they are in a plane at right angles to the longitudinal axis of the drum.

Except where specific dimensions are shown on the drawing, the maximum gap between the outside of any branch or shell and the inside edge of the hole in the shell, flange, reinforcing ring or backing ring shall not exceed 1.5 mm for openings up to 300 mm and 3 mm for openings over 300 mm.

NOTE. To achieve this gap, the outside diameter of the shell or nozzle may be machined over a sufficient length to accommodate the attachment to which it is to be welded.

4.3.2.3.3 *Standpipes, nozzles, branches and connections for mountings*

Standpipes, nozzles, branches and connections for mountings shall be attached using one of the following methods.

a) By welding only. Typical methods of attachment are given in annex C.

b) For other methods of attachment see **4.4.3**.

4.3.2.4 ***Attachment by welding of non-pressure parts to drums and headers***

The attachment of non-pressure parts (e.g. brackets, lugs and flats etc.), including drum internal fittings, to drums and headers by welding shall be permitted.

The welds of attachments designated as load carrying (see 3.1.5f) shall be continuous. This weld shall be a fillet weld around the perimeter of the attachment, a partial penetration weld, a single-sided full penetration weld or a double-sided full penetration weld.

It is permissible for the welds of all other attachments to be made by intermittent fillet welds in accordance with an approved arc welding procedure or by any other proven welding process, e.g. resistance welding.

When multi-run welding is employed, each run of weld metal shall be cleaned to ensure a sound weld before the next run is deposited. Preheating and post-weld heat treatment shall be applied when required by **4.5.3** and **4.5.4** respectively.

Attachment welds which cross main welds shall be designated as load carrying and non-destructively tested accordingly (see **5.8.2.3** and **5.8.3.3**).

NOTE. The site welding of attachments to pressure parts of widely differing materials, e.g. ferritic steel to austenitic steel, should be avoided wherever practicable.

4.3.2.5 ***Welding of pipes and tubes***

4.3.2.5.1 *General*

Except where otherwise specified in this clause, the requirements of BS 2633, BS 1821, BS 4204 or BS 4677, as appropriate, shall be followed.

4.3.2.5.2 *Bends*

Segmental and cut-and-shut bends shall not be used.

4.3.2.5.3 *Backing rings*

Permanent backing rings shall not be used in the boiler tubes of the evaporative circuit.

4.3.2.5.4 *Austenitic to ferritic transition joints*

Welded joints between ferritic and austenitic steels shall be made under shop conditions and shall be located at butt welds.

4.3.2.6 ***Welding of branches, nozzles and stubs to pipes and tubes***

4.3.2.6.1 Not less than two runs of metal shall be deposited at each weld. Each run of weld metal shall be clean and free from slag before the next run is deposited.

Permanent backing rings shall not be used.

Fusible inserts shall not be regarded as backing rings. Fusible inserts shall be used only if the material from which they are made is compatible with the parent metal and if they are completely fused into the joint.

The complete weld shall be free from crevices between weld runs and the final finish of all welds shall be such that the change of section between the parts is gradual and free from sharp notches and undercutting in excess of that permitted by table 5.9.

Preheating, where required, shall be carried out in accordance with BS 2633.

Attachment welds of branches, nozzles and stubs on integral piping and tubes shall not involve any combination of austenitic and ferritic steels.

4.3.2.6.2 Typical methods of attachment of nozzles, branches and connections are given in annex C.

4.3.2.7 ***Attachment by welding of non-pressure parts to pipes and tubes***

The welds of attachments designated as load carrying (see **3.1.5**f) shall be continuous. This weld shall be a fillet weld around the perimeter of the attachment, a partial penetration weld, a single-sided full penetration weld or a double-sided full penetration weld.

It is permissible for the welds of all other attachments to be made by intermittent fillet welds in accordance with an approved arc welding procedure or by any other proven welding process, e.g. resistance welding.

When multi-run welding is employed each run of weld metal shall be cleaned to ensure a sound weld before the next run is deposited. Preheating and post-weld heat treatment shall be applied when required by **4.5.3** and **4.5.4** respectively.

NOTE. The site welding of attachments to pressure parts of widely differing materials, e.g. ferritic steel to austenitic steel, should be avoided wherever practicable.

4.4 Mechanical connections

4.4.1 General

Mechanical connections are those connections which do not involve welding between the connected parts.

4.4.2 Access openings

4.4.2.1 *Scope and restrictions*

In addition to the requirements of **4.4.2.2**, it is permissible to provide openings to facilitate manufacture and maintenance.

Openings in pressure parts with mechanical closures shall be of the internal door type, for calculation pressures exceeding 1.8 MPa. For pressures below this, circular external doors of the blanked flange type shall also be permitted.

Openings in dished ends shall conform to **3.6.1.3**.

4.4.2.2 *Necessity for access*

All drums, headers and other large parts of boilers shall be provided with manholes, handholes, or other inspection openings to permit internal examination and effective cleaning.

NOTE. Access may be gained for this purpose by cutting and re-welding pipes, tubes, or blind nozzles.

4.4.2.3 *Size*

Elliptical manholes shall be not smaller than 400 mm × 300 mm. Circular manholes shall be not less than 400 mm diameter. Handholes shall be not less than 90 mm × 70 mm.

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

The relevant part of Section 30(2) 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 in long and 16 in wide or (if circular) not less than 18 in in diameter.'
>
> The sizes stated above are equivalent to 457.2 mm × 406.4 mm and 457.2 mm diameter respectively.

Section 30 also applies to a 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 conform to 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.

4.4.2.4 *Frames and mouthpieces*

Frames and mouthpieces for access openings shall be of wrought steel in accordance with section **2**. They shall be machined to provide a flat jointing surface for the door. The joint face of the internal manhole frames shall be not less than 18 mm wide. If the calculation pressure exceeds 1.8 MPa, raised circular manhole mouthpieces shall not be fitted.

4.4.2.5 *Internal doors*

Internal doors shall be of wrought steel in accordance with section **2** and constructed in accordance with the following.

a) Doors shall be formed to fit closely to the internal joint surface and shall be fitted with studs, nuts and crossbars.

b) Doors for circular openings larger than 250 mm or elliptical/rectangular openings larger than 250 mm × 175 mm shall have two studs, but for openings of 250 mm × 175 mm or less, only one stud need be fitted. Doors for openings not larger than 123 mm × 90 mm may have the stud forged integrally with the door.

c) 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 fixed in one of the following ways:

   1) screwed through the plate and fillet welded on the inside;

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

   3) 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; or

   4) provided with an integral collar and be riveted or screwed into the door plate and be prevented from turning, in which case the strength of the attachment shall be not less than the strength of the stud.

d) Door spigots, when the door is in a central position, shall have a clearance of approximately 1.5 mm all round and at no point shall the clearance exceed 3 mm. The spigot depth shall be sufficient to trap the gasket.

e) Nuts shall conform to the appropriate British Standard and be faced on the seating surface.

f) Cross bars shall be of wrought steel in accordance with section **2** having a minimum specified tensile strength of not less than 360 MPa. The seating surface shall be faced.

NOTE. Eyebolts with suitable lugs on the door plate, or headed bolts engaging with slotted sections on the door plate, may be used instead of studs.

4.4.2.6 *External doors*

Circular external doors of the blank flange type shall conform to **3.7.7.2**. The design shall incorporate a spigot and recess of sufficient dimensions to completely trap the gasket.

NOTE. Inspection openings may, where necessary, be closed by nozzles with welded caps.

4.4.3 Branches and standpipes

4.4.3.1 ***Scope and restrictions***

The following methods of mechanically connecting branches or standpipes to the main pressure part are permitted.

a) Expanding and belling, for branch outside diameters not exceeding 48.3 mm.

b) Expanding and seal welding, for steel having a carbon content not more than 0.25 % (*m/m*) and branch outside diameters not exceeding 48.3 mm.

c) Screwing and seal welding or screwing directly into the shell, subject to the requirements given in **3.4.9**.

d) Screwing and seal welding or screwing into a socket, subject to the requirements given in **3.4.10**.

e) By studs, subject to the requirements given in **3.4.8**.

Further requirements for these connections are given in **4.4.3.3**. Requirements for the connection between the branch or standpipe and the pipe or mounting it serves are given in **4.4.3.2**.

4.4.3.2 ***Connections to mountings or pipes***

Connections to mountings or pipes shall conform to **3.7.7**.

4.4.3.3 ***Connections to main pressure part***

4.4.3.3.1 *Expanded connections*

The hole in the main pressure part shall provide a belt of parallel seating of not less than 13 mm. It is permitted to seal weld internally or externally. The forming of holes, internal projection and belling shall conform to **4.4.4**.

4.4.3.3.2 *Screwed connections*

Threads of screwed connections shall conform to BS 21, with a taper or vanishing thread. It is permitted to seal weld either internally or externally.

4.4.3.3.3 *Studded connections*

Studs shall be of a design such that high fatigue strength is ensured and shall have a full thread holding in the main pressure part shell or end plate equal to at least one diameter. Studs shall not completely pierce the pressure part, and after allowing suitable clearance at the blind end of the stud, the unpierced material of the pressure part shall amount to not less than one quarter of the stud nominal diameter.

After machining of jointing faces, the final thickness of shells shall not be less than the minimum thickness required by **3.4** and the final thickness of ends not less than that required by **3.6**. Where this cannot be achieved, see **3.4.8**.

Branch or standpipe flanges shall conform to **3.7.7.2**.

4.4.4 Tubes and integral pipes

4.4.4.1 ***Scope and restrictions***

It is permissible to attach tubes and integral pipes to main pressure parts, other than by welding, by propulsive expanding and belling or by expanding and seal welding. It is also permissible to use other methods of expanding, but in such cases it shall be demonstrated that the method provides adequate leak tightness and will prevent tube withdrawal in service, unless documented evidence of satisfactory performance in service is produced.

The outside diameter of tube or pipe connected by expanding shall not exceed 114.3 mm.

When integral pipes are expanded, the material shall meet the flattening and drift expanding test requirements of BS 3059.

It is permissible to join integral pipes together by the mechanical means referred to in **3.7.7**, subject to the restrictions therein.

Mechanical connections between tubes are not permitted.

4.4.4.2 ***Expanding of tubes and pipes***

Tube holes for expanded tubes shall be formed in such a way that the tubes can be effectively tightened in them. The surface finish shall be no coarser than 6.3 μm (see BS 1134). The surface shall exhibit no spiral or longitudinal score marks which could form a leak path. Where the tube ends are not normal to the tube plate, there shall be a neck or belt of parallel seating in the tube hole at right angles to the axis of the tube. The belt shall be at least 10 mm in depth measured in a plane containing the axis of the tube at the hole.

Where pipes or tubes are fitted by propulsive expanding, they shall be belled out from the edge of the tube hole at an angle to the tube axis to resist withdrawal. In no such case shall the projection of the tube through the parallel tube seat be less than 6 mm and the belling shall be not less than given in table 4.4.4.2.

Table 4.4.4.2 Belling dimensions for tubes propulsively expanded

Dimensions in millimetres

Outside diameter of tube	Minimum increase in diameter of belling over diameter of tube holes
Up to and including 51	3
Over 51 up to and including 82.5	4
Over 82.5 up to and including 101.6	5

4.4.5 External or internal non-pressure part attachments

4.4.5.1 *Scope and restrictions*

It is permissible to connect non-pressure parts to pressure parts by mechanical means.

NOTE. Typical instances are for the support or location of the pressure parts, the support and location of drum internals, or the support and location of insulation, casing and cladding.

4.4.5.2 *Chemical requirements*

Materials likely to react chemically with the pressure part shall not be allowed to contact the pressure part. BS 5970 shall be referred to for insulation requirements in this respect.

4.4.5.3 *Mechanical requirements*

Where there is a likelihood of in-service relative movement or fretting between a pressure part and a non-pressure part contacting it, consideration shall be given to wastage of the components. If necessary wear pads shall be welded to the pressure part, or other equivalent means employed.

4.5 Thermal treatment

4.5.1 General

4.5.1.1 *Methods of heat treatment*

Heat treatment shall be effected, by one of the following methods described in **4.5.1.1.1** to **4.5.1.1.5** inclusive.

4.5.1.1.1 *Heating the component as a whole*

Heat the component as a whole in an enclosed furnace.

4.5.1.1.2 *Heat treatment of a shell or drum section*

Heat treat the shell or drum section in an enclosed furnace, ensuring that the overlap of the heated sections of the vessel is at least 1500 mm or $5\sqrt{(Rt)}$, whichever is the greater, (R being the internal radius of curvature and t the thickness of the material).

Where this method is used, the portion outside the furnace shall be shielded so that the longitudinal temperature gradient is such that the distance between the peak and half-peak temperature is not less than $2.5\sqrt{(Rt)}$. Thermocouples shall be provided to measure the longitudinal gradient at the outlet from the furnace.

4.5.1.1.3 *Local heating for P.W.H.T. of drums, headers, tubes and integral pipes*

Locally heat treat drums or headers so that the weld metal and heat-affected zone shall be treated to the heat treatment temperature. The disposition of the heating elements and insulation shall be such as to obtain a temperature profile which is approximately symmetrical about the centreline of the area to be heat treated and circumferentially uniform. The longitudinal temperature gradient shall be such that the temperature at a distance of $2.5\sqrt{(Rt)}$ from the edges of the area being heated shall be not less than one-half of the stress relieving temperature (see figures 4.5.1.1.3-1 and 4.5.1.1.3-2). Thermocouples shall be applied at a sufficient number of locations to measure the peak and half-peak temperatures.

NOTE. Wherever practicable large branches or nozzles should be located so that the toe of the branch attachment weld is not less than $5\sqrt{(Rt)}$ from the nearest edge of a locally heat treated butt weld in the drum or header. Where such a location is not practicable, it is recommended that the branch weld and circumference of the shell at the intersection be heated uniformly when stress relieving the butt weld.

4.5.1.1.4 *Local heating for P.W.H.T. of branch, nozzle and stub butt welds*

For butt welds made to branches heat treat by the following as appropriate.

a) Where pipes, tubes or other fittings are subsequently welded to branches, nozzles or stubs on a shell and post-weld heat treatment is required (see **4.5.4.1**), the disposition of heating elements and insulation around the butt weld shall be such as to produce a temperature profile which is approximately symmetrical about the weld and circumferentially uniform.

Temperatures measured at distances $2.5\sqrt{(rt_1)}$ from the centreline of the weld (r being the branch internal radius local to the vessel and t_1 the thickness of the branch at the butt weld) (see figures 4.5.1.1.3-1 and 4.5.1.1.3-2) shall be not less than one-half of the specified weld temperature measured at the weld.

b) Care shall be taken that during welding and post-weld heat treatment harmful temperature gradients will not occur local to the junction between the shell and the branch, nozzle or stub.

Where branches are of length $L < 5\sqrt{(rt_1)}$ and $L \geq 2.5\sqrt{(rt_1)}$ (see figures 4.5.1.1.3-1 and 4.5.1.1.3-2), the requirements of either c) or d) below shall be met. Where branches are of lengths $L < 2.5\sqrt{(rt_1)}$ the requirements of e) below shall be met. In all cases where acceptable temperature distribution has been demonstrated on the first two of a like system of geometrics, the application of thermocouples shall be permitted only at welds on subsequent branches, providing similar heating and insulation arrangements are used.

c) Temperature differences shall be maintained during heat treatment such that the following conditions are met:

$$KaE\left[\frac{1.4}{l}(T_{0.5} - T_{\text{j}}) + 0.7\,(T_{\text{j}} - T_{\text{o}})\right] \leq R_{\text{p0.2}}$$

where

K is the factor given by

$$K = \frac{(t/t_2)^{2.5}}{2 + (t/t_2)^{2.5}}$$

where

t is the vessel thickness adjacent to the branch (in mm);

t_2 is the branch thickness adjacent to the vessel (in mm);

$R_{p0.2}$ is the minimum specified 0.2 % proof stress at T_j (in N/mm^2);

l is given by:

$L/\sqrt{(r_2 t_2)}$

where

L is the branch length (in mm) (see figure 4.5.1.1.3-1);

r_2 is the branch mean radius local to the vessel (in mm);

a is coefficient of thermal expansion (in mm/mm per ˚C);

E is modulus of elasticity at temperature T_j (in N/mm^2);

$T_{0.5}$ is the measured temperature during heat treatment at the branch mid-length (in ˚C);

T_j is the measured temperature during heat treatment on the shell immediately adjacent to the branch weld fillet (in ˚C);

T_o is the measured temperature during heat treatment on the shell at a distance where the measured temperature is reasonably uniform, i.e. where the temperature gradient has levelled out, and which is not less a distance than t from location T_j (in ˚C).

d) Heating elements and insulation shall be installed both around the butt weld and around the shell symmetrically about the branch intersection. The disposition of heating elements and insulation shall be such as to obtain a temperature profile which is approximately symmetrical about the centreline of the butt weld and circumferentially uniform around the branch. In the shell, the temperature profile shall be approximately symmetrical about the branch intersection and circumferentially uniform. During the heat treatment, precautions shall be taken to ensure that:

1) the temperature of the branch at a distance of $2.5\sqrt{(rt_1)}$ from the centreline of the butt weld is not less than one-half of the heat treatment temperature;

2) the temperature of the pipe or tube at a distance of $2.5\sqrt{(rt_1)}$ from the butt weld is not less than one-half of the heat treatment temperature;

3) the temperature of the shell at a distance of $2.5\sqrt{(Rt)}$ from the outer surface of the branch at its junction with the vessel, is not less than one-half of the temperature measured at the butt weld;

4) thermocouples are applied at sufficient locations in the branch and in the shell in order to measure the temperatures.

e) Where L is less than $2.5\sqrt{(rt_1)}$, the branch and adjacent shell, to a distance not less than $2.5\sqrt{(Rt)}$, shall be uniformly heated.

4.5.1.1.5 *Local heating for normalizing or tempering of components*

Local heating for normalizing or tempering of components shall be by electric heating elements or by partial immersion in a furnace.

4.5.1.2 *Temperature measurement*

An automatic temperature/time record of the heat treatment of each component shall be available for inspection and shall be retained as a record.

Welds attaching thermocouples to components shall be ground flush after heat treatment.

The temperature specified shall be the actual temperature of the component and it shall be determined by thermocouples in effective thermal contact with the component.

NOTE. Where a furnace charge comprises a number of similar components, the thermocoupling may be limited to one component provided it can be demonstrated that the temperature distribution within the furnace is uniform.

A sufficient number of temperatures shall be recorded continuously and automatically to ensure that the whole component being heat treated is within the temperature range specified and that undesirable thermal gradients do not occur.

The manufacturer shall demonstrate that the thermocouples and temperature recording instrumentation are accurate over the temperature range covered by the heat treatment, or such equipment shall be included in a recognized calibration programme.

4.5.2 Heat treatment associated with forming operations

4.5.2.1 *Drums and headers*

4.5.2.1.1 *Heat treatment of drums, headers and ends made from plate*

4.5.2.1.1.1 *General*

Where the plate is bent to an internal radius less than 10 times the plate thickness for carbon and carbon manganese steels and less than 18 times the plate thickness for alloy steels, it shall be heat treated after bending unless, during the last stage of bending it has been heated uniformly throughout to the stress relieving or normalizing temperature, as appropriate.

4.5.2.1.1.2 *Drum ends made from plate*

All plates shall be heat treated after forming, unless previously heated throughout to the normalizing or stress relieving temperature, as appropriate, for the last stage of manufacture.

4.5.2.1.2 *Normalizing other than for tubes and pipes*

4.5.2.1.2.1 Hot formed parts of boilers and electro-slag welds shall be normalized or solution treated, as appropriate. Where the part is heated to normalizing or solution treatment temperature for the hot forming operation, no further heat treatment shall be required unless the material properties are achieved by tempering.

NOTE. Manufacturers should take account of the marked drop in strength and toughness usually encountered after normalizing welds other than those produced by the electro-slag or electro-gas processes.

4.5.2.1.2.2 Where normalizing is undertaken, the parts shall be heated to the normalizing temperature and shall be maintained at that temperature long enough for thorough soaking. They shall then be uniformly cooled, the appropriate rate being generally achieved by cooling freely in still air.

NOTE. Where the geometry of the parts is such that the cooling rate will not be the same throughout, a subsequent stress relieving treatment may be necessary, with particular attention being paid to a slow rate of cooling.

4.5.2.1.2.3 In the case of alloy steels, the range of temperatures, times and cooling rates employed during normalizing shall be such that mechanical properties do not differ from those specified.

4.5.2.2 ***Heat treatment of integral piping bends***

4.5.2.2.1 Requirements for the hot bending of, and the post-bend heat treatment of hot or cold formed bends in, ferritic steel tubes or pipes to BS 3059, BS 3601, BS 3602 or BS 3604 and austenitic steel tubes or pipes to BS 3059 or BS 3605, for integral piping application, shall be as given in **4.5.2.2.2** and **4.5.2.2.3**.

4.5.2.2.2 For ferritic steels hot bending shall be carried out within the temperature range 750 °C to 1100 °C, and post-bend heat treatment of hot or cold formed bends where required by **4.2.3.5** shall be in accordance with table 4.5.2.2.

4.5.2.2.3 For austenitic steels the bending temperature range for hot bending, and the procedures for post-bend heat treatment of hot or cold formed bends, where required by **4.2.3.5**, shall be agreed between the manufacturer and Inspecting Authority (see **1.5.2.3**j).

4.5.2.3 ***Heat treatment of tube bends***

Where heat treatment is required by **4.2.4.6**, bends in tubes supplied in accordance with BS 3059 for parts of boilers, including economizers, furnace walls, superheaters and reheaters shall be heat treated in accordance with table 4.5.2.3.

Table 4.5.2.2 Heat treatment type and temperature ranges for ferritic pipe bends

Material	**Heat treatment type** (note 1)		**Heat treatment temperature** (notes 2, 3 and 4)			
	Cold bends	**Hot bends**	**Stress relieve**	**Normalize**	**Normalize and temper**	
					Normalize	**Temper**
			°C	°C	°C	°C
Carbon steel	SR or N	N (note 5)	550-600	880 to 940		
Steel 500 Nb	SR or N	N	550-600	850 to 960		
1¼NiCuMoNb steel 591 (note 6)	N + T	N + T	—	—	900 to 980	580 to 660
½Cr½Mo¼V steel 660	N + T	N + T	—	—	930 to 980	680 to 720
1Cr½Mo steel 620-440	N + T	N + T	—	—	900 to 960	640 to 720
1¼Cr½Mo steel 621	N + T	N + T	—	—	900 to 960	640 to 720
2¼Cr1Mo steel 622 (N + T)	N + T	N + T	—	—	900 to 960	680 to 750
9Cr1Mo steel 629 (N + T)	N + T	N + T	—	—	900 to 1000	700 to 800
9CrMoVNbN steel 91	N + T	N + T	—	—	1040 to 1080	735 to 780
12CrMoV steel 762	N + T	N + T	—	—	1020 to 1070	730 to 780

NOTE 1. N = normalize
T = temper
SR = stress relieve

NOTE 2. In order to ensure uniform soaking, the temperature for normalizing shall be maintained for a time proportionate to the thickness of the pipe at a rate of not less than 1.2 min/mm of maximum thickness, followed by cooling in still air.
NOTE 3. The temperature specified shall be the actual temperature of the component and shall be determined by thermocouples in effective contact with the component.
NOTE 4. It is recommended that the middle of the above ranges are targeted to ensure future compliance with the proposed European Standard.
NOTE 5. Where the pipe is heated to normalizing temperature for bending, no further normalizing heat treatment is required.
NOTE 6. This steel may also be quenched from the range 880 °C to 930 °C followed by tempering in the range 620 °C to 690 °C.

Table 4.5.2.3 Heat treatment of tube bends

Material grade (BS 3059)	**Cold formed bends** (note 1)	**Hot formed bends** (notes 2 and 3)			**Post bend heat treatment temperature range** (notes 3, 4 and 5)		
		Standard bending temperature range (note 6) °C	**Heat treatment of bends formed within the standard bending temperature range**	**Heat treatment of bends formed so that the minimum temperature is outside the standard range** (note 1)	**Normalize** °C	**Temper** °C	**Solution treatment** °C
320	T or N	1100 to 850	—	N	880 to 940	550-600	
360	T or N	1100 to 850	—	N	880 to 940	550-600	
440	T or N	1100 to 850	—	N	880 to 940	550-600	
243	T or N	1100 to 850	—	N	900 to 960	550-600	
620	T or N	1100 to 850	—	N	900 to 960	620 to 680	
622–490	T or N + T	1100 to 850	T	N + T	900 to 960	650 to 750	
629–590	T or N + T	1100 to 850	N + T	N + T	900 to 1000	700 to 800	
91 (note 7)	T or N + T	1100 to 850	N + T	N + T	1040 to 1080	735 to 780	
762 (note 7)	T or N + T	1100 to 850	N + T	N + T	1020 to 1070	680 to 780	
304S51	ST	1100 to 900	—	ST	—	—	950 to 1100
316S51, S52	ST	1100 to 900	—	ST	—	—	1000 to 1100
321S51 (1010)	ST	1100 to 900	—	ST	—	—	950 to 1070
321S51 (1105)	ST	1100 to 900	ST	ST	—	—	1070 to 1140
347S51	ST	1100 to 900	—	ST	—	—	1000 to 1100
215S15	ST	1100 to 900	—	ST	—	—	1050 to 1150

NOTE 1. N = Normalize
T = Temper
ST = Solution treatment

NOTE 2. Includes bends hot closed after cold bending.

NOTE 3. It is recommended that the middle of the above ranges are targeted to ensure future compliance with the proposed European Standard.

NOTE 4. Minimum soak times are:
N: 0.5 h
T: 0.5 h
ST: 10 min.

NOTE 5. There are no specified heating or cooling rates.

NOTE 6. The standard bending temperature range is defined as the range within which the component is heated before bending and during which the major part of the work is carried out.

NOTE 7. When bends in steel 762 are normalized and tempered, the complete manipulated tube shall be heat treated.

4.5.3 Preheating

4.5.3.1 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 given in BS 6693 : Part 2. Recommendations for preheating temperatures given in tables 4.5.3.1-1 and 4.5.3.1-2 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, 1973[7].

Austenitic stainless steels do not require preheating for welding.

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 5 °C.

4.5.3.2 The manufacturer shall state, in the welding procedure submitted for approval by the Inspecting Authority in accordance with **5.2.1**, 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.

4.5.3.3 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.

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

4.5.3.5 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.

4.5.4 Post-weld heat treatment (for stress relief)

4.5.4.1 *General*

4.5.4.1.1 Post-weld heat treatment, shall be carried out when required by table 4.5.4, after the completion of all welding, but see **4.3.1.10**. Time and temperature records shall be maintained.

Table 4.5.3.1-1 Recommended preheating temperatures for thermal-cutting of plates, forgings, castings, tubes and pipes

Material type	Material thickness mm	Minimum preheating temperature °C
Carbon and carbon manganese steel ≤ 0.25 C	All	Not required
0.3 Mo	≤ 12.5 > 12.5	Not required 100
NiCrMoV and MnCrMoV	≤ 12.5 > 12.5	Not required 100
1Cr½Mo and 1¼Cr½Mo	≤ 12.5 > 12.5	Not required 100
½Cr½Mo¼V	All	150
2¼Cr1Mo	All	150
9CrMoVNbN steel 91	All	200
12CrMoV	All	200

NOTE 1. Additional heat treatment e.g. hydrogen release treatment, may be adopted by the manufacturer to facilitate fabrication. If an intermediate stress relief is carried out the heat treatment temperature used is that given in table 4.5.4.

NOTE 2. Where austenitic stainless steels are solution heat treated, care should be taken if acid pickling is used to remove scale.

NOTE 3. In cases where stress corrosion may occur, see **3.2.3**.

4.5.4.1.2 The post-weld heat treatment, when required by table 4.5.4, shall be either:

a) carried out in accordance with the following:

1) the heat treatment conditions given in table 4.5.4;

or

2) heat treatment conditions other than those given in table 4.5.4 by agreement between the manufacturer and the Inspecting Authority (see **1.5.2.3**h)1)); or

b) waived, by agreement between the purchaser, manufacturer and Inspecting Authority (see **1.5.2.3**h)2)), where it can be proved by documented satisfactory past experience or by tests that the absence of post-weld heat treatment will not adversely affect the service behaviour of the fabricated components.

NOTE. It should be ascertained that in cases where the design stress is time-independent, the properties of parent metals, on which the design of components have been based, will not be affected adversely by post-weld heat treatment, see also **2.2.1.3**.

[7] Available from The Welding Institute, Research Laboratory, Abington Hall, Abington, Cambs CB1 6AL.

Table 4.5.3.1-2 Recommended preheating temperatures for welding of plates, forgings, castings, tubes and pipes

Type	Hydrogen controlled weld metal (note 1)		Non-hydrogen controlled weld metal	
	Material thickness (note 2) mm	Minimum preheating temperature °C	Material thickness (note 2) mm	Minimum preheating temperature °C
Carbon and carbon manganese steel ≤ 0.25 C	≤ 30 > 30	5 100	≤ 20 > 20 ≤ 50 > 50 (note 4)	5 100
0.3 Mo	≤ 12.5 > 12.5	20 100	≤ 38 > 38 (note 4)	150
NiCrMoV and MnCrMoV	≤ 12 > 12	20 100	≤ 38 > 38 (note 4)	150
1 Cr½Mo and 1¼Cr½Mo	≤ 12 > 12	100 150 (note 3)	≤ 12 > 12 ≤ 20 > 20 (note 4)	150 200
½Cr½Mo¼V	≤12 > 12	150 200 (note 3)	(note 4)	
2¼Cr 1 Mo	≤ 12 > 12	150 200 (note 3)	≤ 12 > 12 (note 4)	200
9CrMoVNbN (steel 91)	All	200 (note 3)	(note 4)	
12CrMoV	All	150 (note 3)	(note 4)	

NOTE 1. 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 : Part 2.
NOTE 2. The greatest component thickness at the joint.
NOTE 3. When TIG welding is used, a lower preheating temperature may be applied provided it is proved to be satisfactory by procedure tests.
NOTE 4. It is recommended that only hydrogen controlled weld metal is used.

4.5.4.1.3 The controlling thickness to be used in determining the requirements for post weld heat treatment times shall be as follows:

– butt welds (*W*1): the thickness of the thinner part at the welded joint;

– fillet welds (*W*2): the specified throat thickness of the weld;

– set-on branch (*W*3): the thickness of the branch at the joint;

– set-through branch (*W*4): the thickness of the shell at the joint;

Note. See figure 4.5.4.1.3 for examples of *W*1, *W*2, *W*3 and *W*4.

When the component to be post weld heat treated contains welds with different individual controlling thicknesses, the governing thickness to be used to determine the overall post-weld heat treatment time shall be the greater of the individual controlling thicknesses.

4.5.4.1.4 When weld repairs or modifications have to be made to a component after the final post weld heat treatment stage, except in the case covered by **4.3.1.10**, further heat treatment shall be carried out in accordance with **4.5.4**. The controlling thickness to be used in defining the time required at temperature shall be one of the following:

– the depth of the weld repair (*W*5);

– the thickness of the additional weld runs where reinforcement is added (*W*6);

– where additional welds are added for modification purposes see **4.5.4.1.3**.

NOTE. See figure 4.5.4.1.3 for examples of *W*5 and *W*6.

4.5.4.1.5 Intermediate heat treatment may be implemented at the manfacturer's discretion to facilitate fabrication. The duration of such intermediate heat treatment shall be decided by the manufacturer but the temperatures employed shall not exceed those given in table 4.5.4 (at end of this section).

4.5.4.1.6 Existing welding procedure approvals do not require re-qualification with respect to heat treatment, provided the procedure used for any heat treatment fall within the times and temperatures specified in table 4.5.4 (at end of this section).

4.5.4.2 ***Furnace post-weld heat treatment of components***

The furnace heat treatment of drums, headers, tubes and pipes shall conform to the following.

a) The temperature of the furnace at the time the component is placed in it shall not exceed:

1) for ferritic steels: 400 °C for components of less than 60 mm thickness and not of complex shape, or 300 °C for components of 60 mm thickness or over or of complex shape;

2) for austenitic steels: 300 °C.

b) The rate of heating from the temperature in a) for ferritic steels shall not exceed the following:

1) 220 °C/h for thicknesses not exceeding 25 mm;

2) 5500 °C/h divided by the thickness (in mm) for thicknesses exceeding 25 mm, up to and including 100 mm;

3) 55 °C/h for thicknesses exceeding 100 mm.

c) The rate of heating from 300 °C for austenitic steels shall not exceed:

1) 220 °C/h for thicknesses not exceeding 25 mm;

2) 200 °C/h for thicknesses exceeding 25 mm.

d) For drums and headers, during the heating and cooling periods, variation in temperature shall not exceed 150 °C within 4500 mm and the temperature gradient shall be gradual. Above 500 °C, this variation shall not exceed 100 °C.

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

f) When the component has attained a uniform holding temperature as given in table 4.5.4 the temperature shall be held for the period given in table 4.5.4.

g) Components in ferritic steels shall be cooled in the furnace to temperature not exceeding 400 °C at a rate not exceeding the value for heating in b).

NOTE 1. Below 400 °C the component may be cooled in still air.

h) Components in austenitic steels shall be rapid cooled from the solution treatment temperature.

NOTE 2. Rapid cooled may be in air or quenched. Inter-granular corrosion can occur if the cooling rate is not sufficiently rapid to avoid inter-granular chromium carbide precipitation. The same requirement applies to locally solution-treated welds. In these cases inter-granular corrosion is not necessarily readily visible by inspection.

4.5.4.3 ***Local post-weld heat treatment of components***

The local heat treatment of drums, headers, tubes and pipes shall conform to the following.

a) The rate of heating from the temperature given in **4.5.4.2**a) shall not exceed that stated in **4.5.4.2**b) or c) as appropriate.

b) The rate of cooling down to 400 °C for ferritic materials shall not exceed that stated in **4.5.4.2**g).

NOTE. Below 400 °C lagging may be stripped.

The rate of cooling down for austenitic steels shall be as stated in **4.5.4.2**h).

c) The thermal gradients shall be in accordance with **4.5.1.1.3**.

4.5.4.4 ***Additional requirement for the post-weld heat treatment of joints between dissimilar ferritic steels***

4.5.4.4.1 For ferritic steels included in table 4.5.4, the post-weld heat treatment of welds between dissimilar steels conforming to **2.2.1** shall be permitted provided that:

$T_1' - T_2''$ is not greater than 30 °C for carbon and carbon manganese steels and 20 °C for all other steels

where

T_1' is the lowest soaking temperature acceptable for the steel requiring the higher post-weld treatment temperature range given in table 4.5.4.

T_2'' is the highest soaking temperature acceptable for the steel requiring the lower post-weld heat treatment temperature range given in table 4.5.4.

NOTE 1. The following is an example:

T_1' for 2¼Cr1Mo steel is 690 °C.

T_2'' for 1Cr½Mo steel is 670 °C.

$T_1' - T_2'' = 20$ °C.

hence this combination is permissible.

The post-weld heat treatment temperature for butt welds shall be within the higher of the ranges given in table 4.5.4 appropriate to the two steels being welded.

For branch or attachment welds where the weld is between components of differing importance, i.e. tube to header, the post-weld heat treatment temperature range shall be that given in table 4.5.4 for the major component.

The design shall state which component is of major importance.

NOTE 2. Where post-weld heat treatment is being carried out on welds between dissimilar materials in the lower temperature range, the temperature of the assembly should be held as closely as practicable to the maximum. Similarly, where the post-weld heat treatment is being carried out in the higher temperature range, the temperature should be held as closely as practicable to the minimum.

4.5.4.4.2 Where a major component, of a steel for which no post-weld heat treatment is given in table 4.5.4, is welded to a minor component, of a steel for which post-weld heat treatment is given in table 4.5.4, the weld shall be heat treated within the temperature range given for the minor component for a time appropriate to the thickness of the major component. If the minor component is a tube or pipe, note 5 to table 4.5.4 shall apply.

4.5.4.4.3 Post-weld heat treatment of joints between any combinations of ferritic steels not given in table 4.5.4 shall be permitted, provided that such steels conform to **2.2.1**, by agreement between the manufacturer and the Inspecting Authority (see **1.5.2.3**i).

4.5.4.5 ***Additional requirements for the post-weld heat treatment of joints between ferritic and austenitic steels***

The post-weld heat treatment temperature for butt welds shall be that given in table 4.5.4 for the ferritic steel in the transition joint.

NOTE. Note 5 of table 4.5.4 is not applicable in the case of butt welds between ferritic and austenitic steel components.

4.5.5 Heat treatment of test materials

4.5.5.1 The preheating, interpass temperature, intermediate and post-heat treatments, as applicable, for weld procedure test specimens shall be the same as for production welding, although the preheating temperature used during fabrication may be increased by up to 100 °C without re-approval.

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

4.5.6 Heat treatment of production test plates

Test plates provided in accordance with **5.4.1** shall be subjected to the same heat treatment cycle after welding as that applied to the shell or drum they represent (see also **5.4.4**).

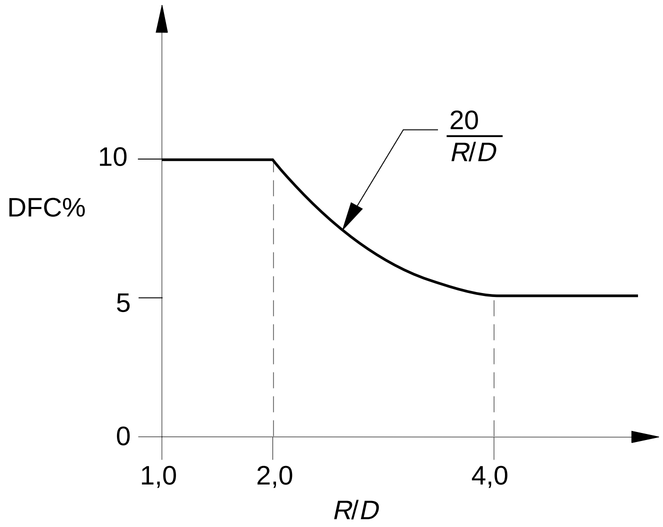
NOTE. Test plates may be heat treated independently, unless otherwise agreed.

4.5.7 Local adjustment of components

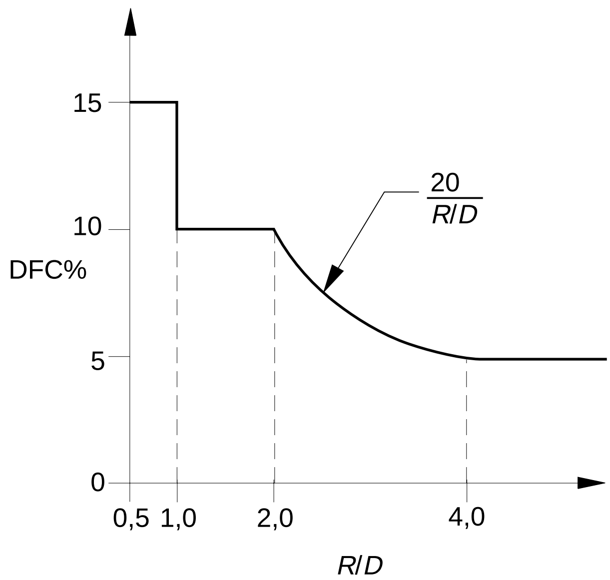
As a result of fabrication operations during the manufacture of headers, tubular assemblies and integral piping, distortion or deformation may occur due to welding shrinkage or inaccuracy in bending operations. The adjustment of such components to acceptable dimensional tolerances, using local heating (including manual gas torches), shall be permitted provided that due recognition is given to the final supply condition of the component.

In addition, for steels 629 and 762, any component which has been subjected to local adjustment at temperatures exceeding 780 °C shall receive a normalizing and tempering treatment which will encompass the entire component.

Local adjustment temperatures shall be monitored by the use of temperature indicating crayons or equivalent means.



a) Limits of departure from circularity for single operation bending



b) Limits of departure from circularity for double operation bending

Figure 4.2.4.5 Limits of departure from circularity

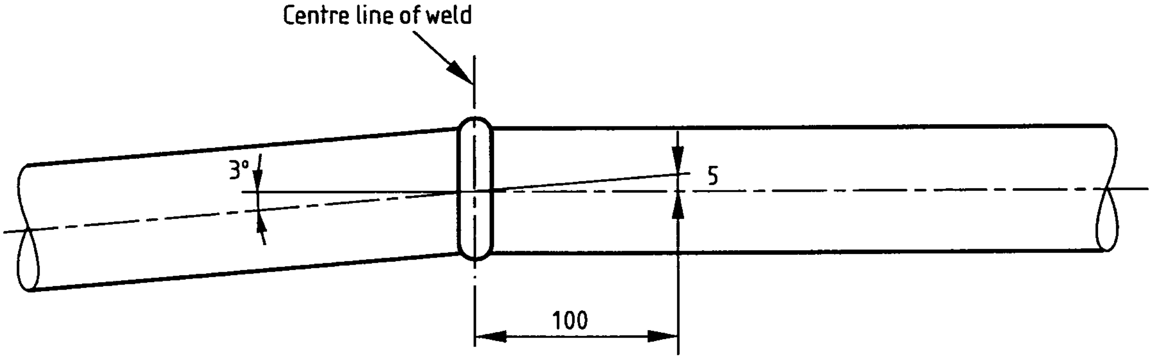
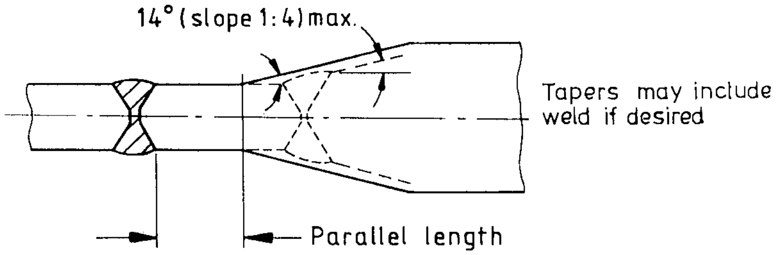
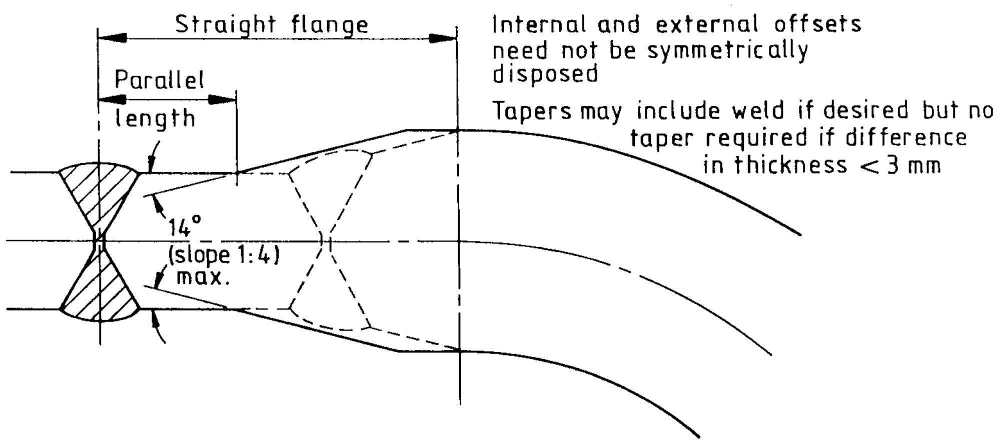


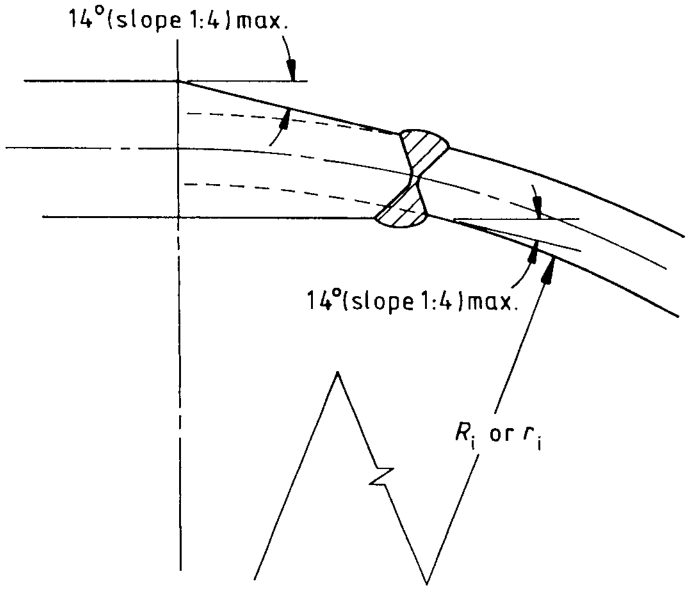
Figure 4.2.5.4.2 Angular alignment of butt welded tubes



a) Internal and external offsets need not be symmetrically disposed



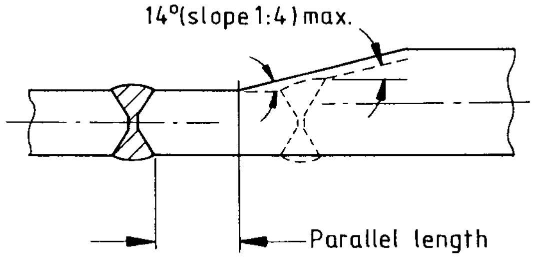
b) End thicker than shell, median plane approx. coincident



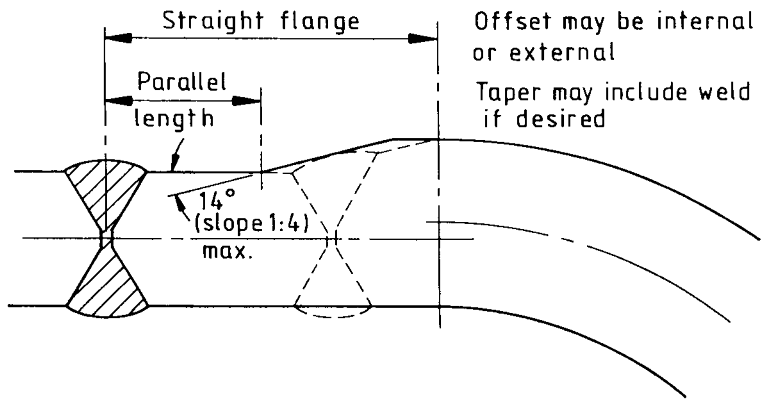
c) End thinner than shell

NOTE. See annex C for details of weld preparation.

Figure 4.3.2.1-1 Butt welds in plates of unequal thickness

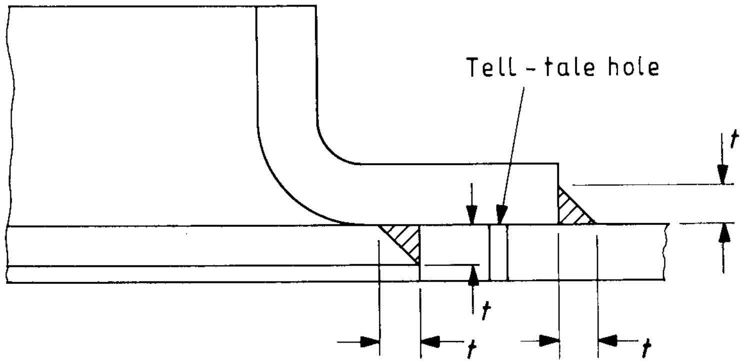


a) Taper may be inside vessel or outside



b) End thicker than shell median plane offset

Figure 4.3.2.1-2 Butt welds with offset of median lines



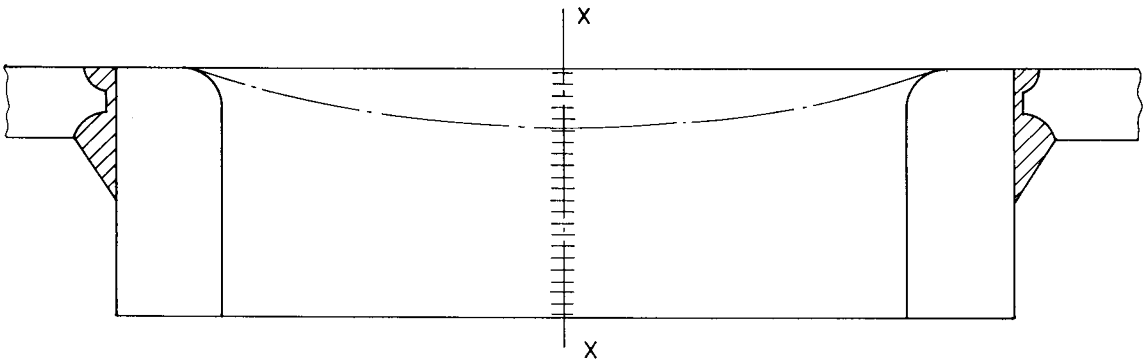
NOTE 1. The use of this type of connection is not permitted where the design pressure exceeds 4 N/mm^2.

NOTE 2. Fillet-welded details are not recommended if the component is subjected to pulsating loads, when preference should be given to the details shown in figures C.12a) and b) and C.16a) and b).

NOTE 3. The leg length, *t*, of the fillet welds should be based on the loads transmitted paying due regard to all fabrication and service requirements but in any case should not be less than 6 mm.

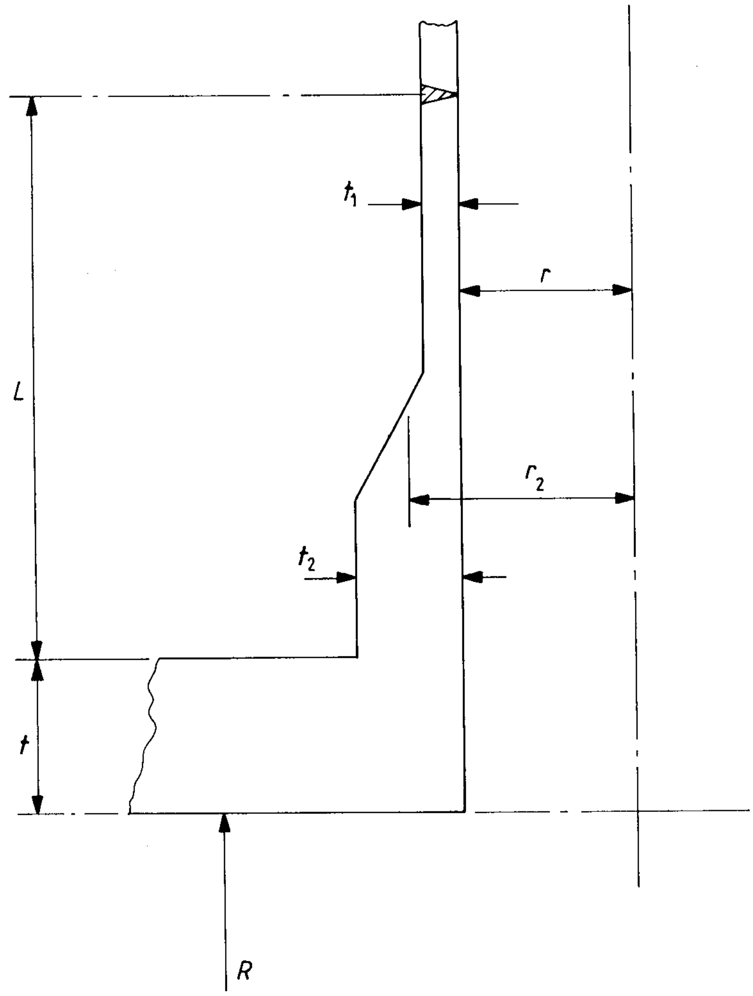
NOTE 4. Avoid use when thermal gradient may cause over-stress in welds.

Figure 4.4.2.4-1 Fillet-welded manhole frame



Alternatively, forging made in halves and fusion-welded along XX.

Figure 4.4.2.4-2 Fusion-welded manhole frame



Key

t_1 is the thickness of branch at butt weld

t is the thickness of shell local to branch

t_2 is the thickness of branch local to shell

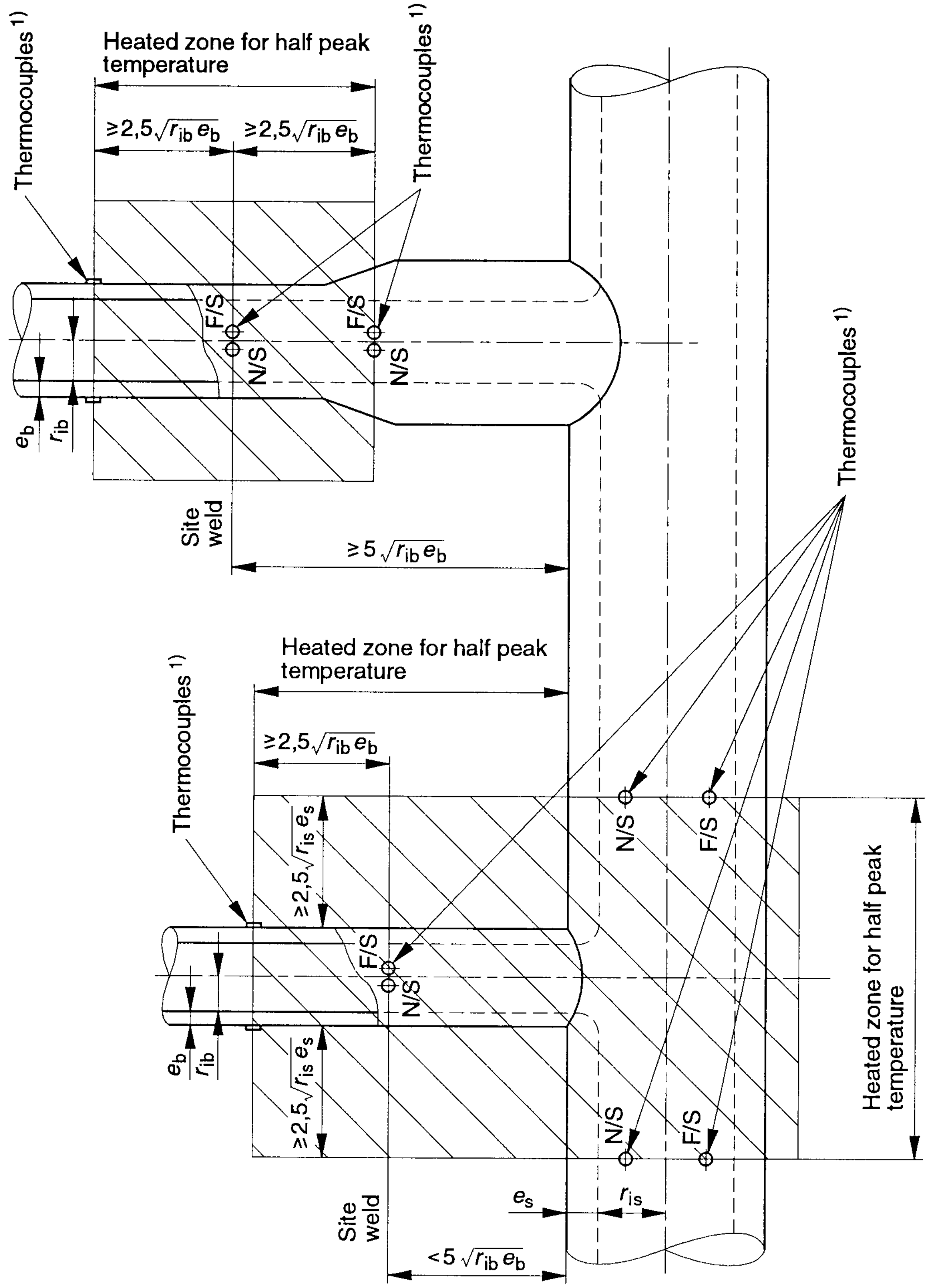
R is the internal radius of shell

r is the internal radius of branch

r_2 is the mean radius of branch local to shell

L is the length from the outside surface of the shell to the butt weld between the branch and the pipe

Figure 4.5.1.1.3-1 Length of branch, nozzle or stub subjected to post-weld heat treatment



[1] Minimum requirements are one near side (N/S) and one far side (F/S) per position as indicated.

Figure 4.5.1.1.3-2 Minimum heated band widths for local heat treatment

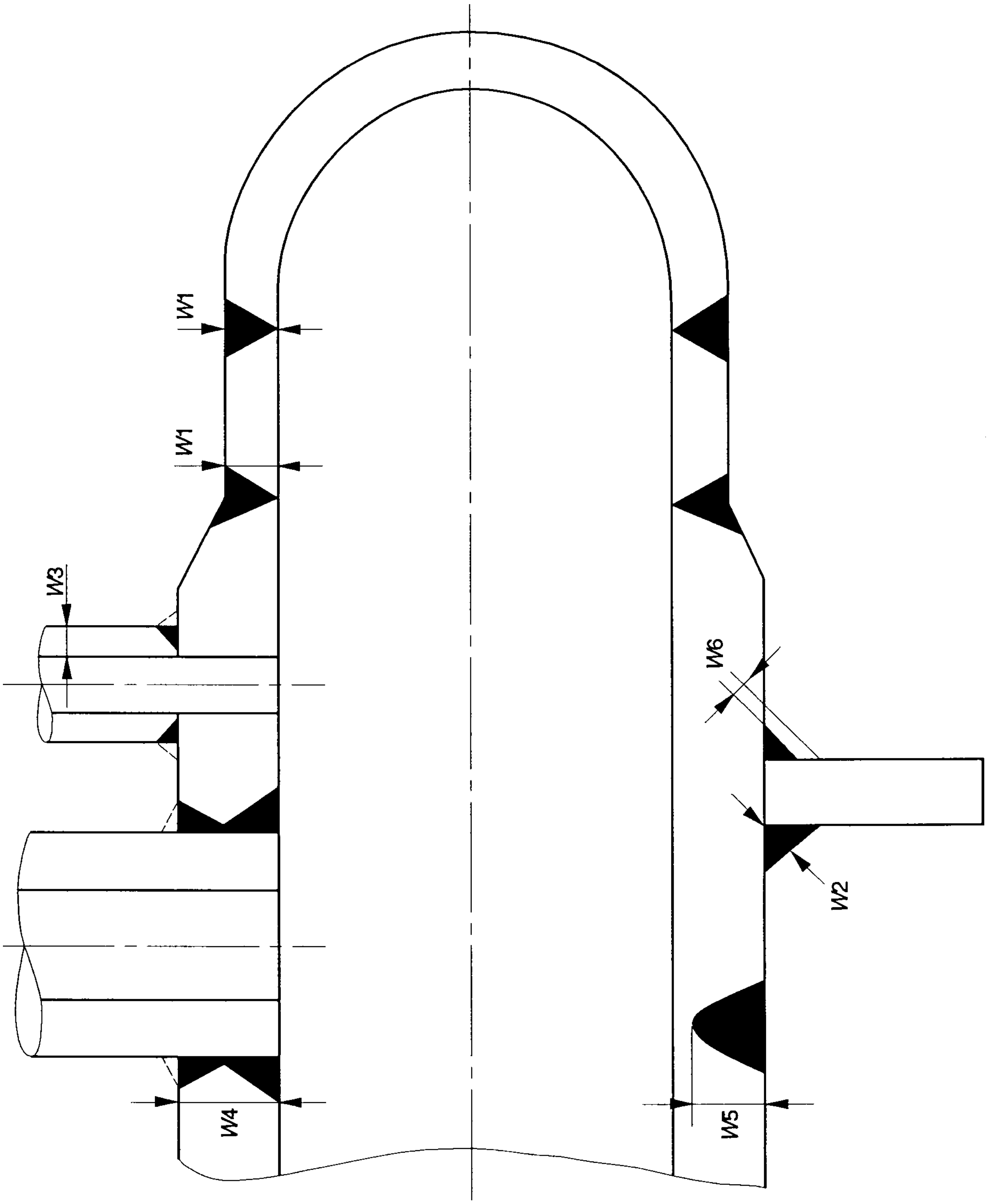


Figure 4.5.4.1.3 Typical examples of controlling thicknesses

Table 4.5.4 Post-weld heat treatment

Figures in parentheses refer to the notes following this table.

Material (1)	**Form**	**British Standard**	**Steel designation**	**Heat treatment temperature** (2) °C	**Minimum time at temperature** (minutes/mm of thickness)
Carbon and carbon manganese steel [0.25 % (*m/m*) maximum carbon] and 0.3 Mo steel – not exceeding 35 mm thickness (3)	Plates	BS 1501 : Part 1 (withdrawn)	All grades	Heat treatment not a requirement, but if applied, should be in the range 550 to 600	2.5
		BS EN 10028-2	P235GH, P265GH, P295GH, P355GH, 16Mo3		
		BS EN 10028-3	P275N, P275NH, P355N, P375NH, P460NH		
	Sections and bars	BS 1502	All grades		
	Forgings	BS 1503	All grades		
		BS EN 10222-4	P285NH, P285QH, P355NH, P355QH, P420NH, P420QH		
			All grades		
	Castings	BS 1504 (withdrawn)	GP 240, GP 280		
		BS EN 10213-2	All grades		
	Tubes	BS 3059 : Parts 1 and 2	All grades		
	Pipes and tubes	BS 3601	All grades		
		BS 3602 : Parts 1 and 2			
Carbon and carbon manganese steel [0.25 % (*m/m*) maximum carbon] and 0.3 Mo steel – exceeding 35 mm thickness (3)	Plates	BS 1501 : Part 1 (withdrawn)	151, 161, 164, 223 224, 225	550 to 600	2.5 but not less than 90 minutes
		BS EN 10028-2	P235GH, P265GH, P295GH, P355GH, 16Mo3		
		BS EN 10028-3	P275N, P275NH, P355N, P375NH, P460NH		
	Sections and bars	BS 1502	151, 161, 211, 221		
	Forgings	BS 1503	161, 221, 223, 224, 225		
		BS EN 10222-4	P285NH, P285QH, P355NH, P355QH, P420NH, P420QH		
	Castings	BS 1504 (withdrawn)	161		
		BS EN 10213-2	GP 240, GP 280		
	Tubes	BS 3059 : Part 2	S1, S2, ERW, CEW, 243		
	Pipes and tubes	BS 3601	S 320, S 360, S 430		
		BS 3602 : Part 1	HFS 360, HFS 430, HFS 500 Nb		
		BS 3602 : Part 2	LAW 430, LAW 490		
MnCrMoV, NiCrMoV	Plates	BS 1501 : Part 2 (withdrawn)	271, 281	630 to 675	2.5
		BS EN 10028-2	(NC) 271, (NC) 281		
	Forgings	BS 1503	271		

Table 4.5.4 Post-weld heat treatment *(continued)*

Figures in parentheses refer to the notes following this table.

Material (1)	**Form**	**British Standard**	**Steel designation**	**Heat treatment temperature** (2) °C	**Minimum time at temperature** (minutes/mm of thickness)
½Cr½Mo¼V	Forgings Castings Pipes and tubes	BS 1503 BS 1504 (withdrawn) BS EN 10213-2 BS 3604 : Part 1	660 660A G12MoCrV5-2 HFS, CFS, 660	680 to 720	2.5 but not less than 180 minutes (4)
1Cr½Mo (5)	Plate Forgings Tubes Pipes and tubes	BS 1501 : Part 2 (withdrawn) BS EN 10028-2 BS 1503 BS 3059 : Part 2 BS 3604 : Part 1	620 13CrMo4-5 NT, NTQ, Q 620 S1, S2, ERW, CEW, 620 HFS, CFS, ERW, CEW 620–440	620 to 680	2.5 but not less than 30 minutes
1¼NiCuMoNb	Pipes and tubes	BS 3604 : Part 1	HFS, CFS, 591	550 to 590 (6)	2.5 but not less than 60 minutes
1¼Cr½Mo (5)	Plate Forgings Castings Pipes and tubes	BS 1501 : Part 2 (withdrawn) BS EN 10028-2 BS 1503 BS 1504 (withdrawn) BS EN 10213-2 BS 3604 : Part 1	621 (NC) 621 621 621A G17CrMo5-5 HFS, CFS, ERW, CEW, 621	630 to 670	2.5 but not less than 30 minutes
2¼Cr1Mo (5)	Plates Forgings Castings Tubes Pipes and tubes	BS 1501 : Part 2 (withdrawn) BS EN 10028-2 BS 1503 BS 1504 (withdrawn) BS EN 10213-2 BS 3059 : Part 2 BS 3604 : Part 1	622 10CrMo9-10, NT, NTQ, Q, 11CrMo9-10, NT, NTQ, Q 622 622A, 622E G17CrMo9-10 S1, S2 622–490 HFS, CFS 622	680 to 730 (7)	2.5 but not less than 60 minutes (4)
9Cr1Mo	Tubes Pipes and tubes	BS 3059 : Part 2 BS 3604 : Part 1	S1, S2 629–590 HFS, CFS 629–590	740 to 780	2.5 but not less than 120 minutes
9CrMoVNbN (9) (steel 91)	Forgings Tubes Pipes and tubes	BS 1503 BS 3059 BS 3604	91 S1, S2, 91 HFS, CFS, 91	735 to 780	2.5 but not less than 60 minutes (4)

Table 4.5.4 Post-weld heat treatment *(continued)*

Figures in parentheses refer to the notes following this table.

Material (1)	**Form**	**British Standard**	**Steel designation**	**Heat treatment temperature** (2) °C	**Minimum time at temperature** (minutes/mm of thickness)
12CrMoV (9)	Forgings Tubes Pipes and tubes	BS 1503 BS 3059 : Part 2 BS 3604 : Part 1	762–690 S1, S2, 762 HFS, CFS, 762	720 to 760	2.5 but not less than 60 minutes
18Cr10Ni (8)	Plate Forgings Pipes and tubes Tubes	BS 1501 : Part 3 BS 1503 BS 3605 BS 3059 : Part 2	304S51 304S51 CFS, HFS, HFM, 304S51 CFS, 304S51	1000 to 1100 Not required	1.0 but not less than 20 minutes (10) Not required
18Cr12NiMo (8)	Plate Forgings Pipes and tubes Tubes	BS 1501 : Part 2 BS 1503 BS 3605 BS 3059 : Part 2	316S51, S53 316S51 CFS, HFS, HFM, 316S51, S52 CFS, 316S51, S52	1000 to 1100 Not required	1.0 but not less than 20 minutes (10) Not required
18Cr12NiTi (8) Solution treated at 950 °C/1070 °C for optimum proof stress properties	Plate Forgings Pipes and tubes Tubes	BS 1501 : Part 3 BS 1503 BS 3605 BS 3059 : Part 2	321S51 321S51 CFS, HFS, HFM, 321S51 (1010) CFS, 321S51 (1010)	950 to 1070 Not required	1.0 but not less than 20 minutes Not required
18Cr12NiTi (8) Solution treated at 1070 °C/1140 °C for optimum creep properties	Plate Forgings Pipes and tubes Tubes	BS 1501 : Part 3 BS 1503 BS 3605 BS 3059 : Part 2	321S51 321S51 CFS, HFS, HFM, 321S51 (1105) CFS, 321S51 (1105)	1070 to 1140 Not required	1.0 but not less than 20 minutes Not required
18Cr12NiNb (8)	Plate Forgings Pipes and tubes Tubes	BS 1501 : Part 3 BS 1503 BS 3605 BS 3059 : Part 2	347S51 347S51 CFS, HFS, HFM, 347S51 CFS, 347S51	1000 to 1100 Not required	1.0 but not less than 20 minutes (10) Not required

Table 4.5.4 Post-weld heat treatment *(continued)*

Figures in parentheses refer to the notes following this table.

Material (1)	**Form**	**British Standard**	**Steel designation**	**Heat treatment temperature** (2) °C	**Minimum time at temperature** (minutes/mm of thickness)
15Cr10Ni6MnNbV (8)	Pipes and tubes	BS 3605	CFS, HFS, HFM, 215S15	1050 to 1150 (11)	1.0 but not less than 20 minutes
	Tubes	BS 3059 : Part 2	CFS, 215S15	Not required	Not required

Notes to table 4.5.4

1) The requirements for the heat treatment of components welded in materials other than those listed in table 4.5.4 are subject to agreement between the manufacturer, the purchaser and Inspecting Authority (see **4.5.4.1.2**a)2)).

2) A normalizing and stress relieving treatment is preferred for certain types of welds such as electro-slag or electro-gas welds and the appropriate treatment should be established when the procedure test is carried out.

3) Where the welded joint connects parts that are of different thickness, the thickness to be considered in applying the limiting thickness of 35 mm for carbon steel, shall be the following nominal thickness including the corrosion allowance.

a) The thinner of two adjacent butt-welded components including shell to end connections providing the requirements of **4.2.5.1.2** to provide a slope to the joint are complied with.

b) The thickness of the shell in connections to flat ends in weld configurations of the type shown in figures 3.6.2.1-1a) and 3.6.2.1-1b) or the flat end in the case of figure 3.6.2.1-2.

c) The thickness of the shell or end in nozzle attachment welds.

d) The thickness of the nozzle at the joint in nozzle 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.

4) For pipes up to and including 127 mm diameter and up to and including 13 mm thick, time may be 30 min minimum.

5) Arc welds in tubes and pipes and attachment welds to tubes and pipes do not require heat treatment provided that the following conditions are complied with (see also **4.5.4.7**):

a) the tube or pipe thickness at the welds does not exceed 13 mm and the outside diameter does not exceed 127 mm;

b) for attachment welds, the weld throat thickness does not exceed 13 mm;

c) the carbon content does not exceed 0.15 % (*m/m*) and the chromium content does not exceed 3.0 % (*m/m*);

d) welding procedure tests have been carried out satisfactorily in accordance with **5.2**.

6) Temperature should be at least 30 °C below the tempering temperature of the original material.

7) For maximum creep resistance.

8) For some austenitic stainless steels which may be prone to cracking due to thickness, complex geometry, material composition (e.g. steel 347) or stress corrosion, etc., consideration should be given to applying post-weld heat treatment which should be agreed between purchaser, manufacturer and Inspecting Authority.

9) For thicknesses over 12.5 mm, after welding but before post-weld heat treatment, ensure that the joint is cooled to a sufficiently low temperature to produce full transformation.

10) For pipes conforming to BS 3605 less than 13 mm thick, post-weld heat treatment is not required, but see also note 8.

11) For austenitic stainless steels solution treated at temperatures between 960 °C and 1140 °C, it is normal practice to rapid cool from solution treatment temperature. The procedure shall be agreed with the Inspecting Authority.

Section 5. Inspection and testing

5.1 Inspection during construction

5.1.1 General

5.1.1.1 Each boiler shall be inspected throughout construction by an Inspecting Authority as defined in **1.3.3**. Without prejudice to the responsibility of the manufacturer, the Inspecting Authority shall be responsible for making sufficient inspections to ensure that the materials, design, construction and testing of the boilers supplied to this standard conform in all respects to this standard (see **1.4.3**).

5.1.1.2 The manufacturer shall provide the Inspecting Authority with all necessary evidence that the design conforms to this standard and shall submit welding procedures for approval (see **5.2.1**) and provide the necessary access to enable the Inspecting Authority to carry out the required examinations.

5.1.1.3 The Inspecting Authority shall make examinations at the stages given in **5.1.2** to **5.1.5** and shall witness the mechanical tests and scrutinize the non-destructive test reports as required in **5.4**. The Inspecting Authority shall advise the manufacturer of the extent of these examinations and any additional examinations and tests which could be required if non-verified material is submitted.

5.1.1.4 Except where explicitly stated otherwise in this standard, inspection activities applicable to a manufacturer's works shall also be applicable to operations carried out on a construction site.

5.1.2 Welded drums and headers

The Inspecting Authority shall approve welding procedure approval tests or records and shall approve welder approval tests or check current welder's certificates and shall carry out examination at the following stages.

a) When plates are ready for identification with plate mill certificates at boiler makers' works and cut to size ready for forming to cylindrical shape.

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

The Inspecting Authority shall identify weld testplate material if production weld tests are required (see **5.4**).

b) When the plates are formed to cylindrical shape with the edges prepared for welding and set up in readiness for commencement of welding.

c) When the welding of the drum or header longitudinal and circumferential seams is completed and the radiographs or ultrasonic test report/records are available for scrutiny.

d) When the end-plates are ready for identification with the mill certificates and cut for the end-shape forming operation.

e) When the end-plates are formed to shape with weld edges prepared and set on to the drum or header in readiness for the agreed circumferential welding operation.

f) When the welding of the end-plates to the drum or header is complete and the radiographs or ultrasonic examination records are available for scrutiny.

g) When each drum or header is prepared to receive any compensation plates and attachments, and when at least 10 % of each type of branch or tube stub is set up ready for welding.

h) When all welding on each drum or header is complete. The Inspecting Authority shall check the record of heat treatment.

i) When the marking-off and preparation of test specimens from the test plates is complete.

j) At the hydraulic test, after which external and internal examinations and marking for certification shall be carried out.

k) After any drum or header machining operations, e.g. tubehole drilling subsequent to the hydraulic test and prior to despatch from the manufacturer's works.

5.1.3 Seamless drums and headers

The Inspecting Authority shall approve welding procedure approval tests or records and shall approve welder approval tests or check current welder's certificates and shall carry out examinations at the following stages.

a) When material is ready for identification with the supplier's test certificates and when each cylinder is prepared for the forming of the ends by forging or for the welding on of separate end closures. The Inspecting Authority shall identify test plate material if production weld tests are required (see **5.4**).

b) When each drum or header is prepared to receive any compensation plates and attachments and when at least 10 % of each type of branch or tube stub is set up ready for welding.

c) When all welding on each drum or header is complete and the radiographs or ultrasonic examination report/records are available. The Inspecting Authority shall check the record of heat treatment.

d) When the marking-off and preparation of test specimens from the test plates is complete.

e) At the hydraulic test, after which external and internal examinations and marking for certification shall be carried out.

f) After any drum or header machining operations, e.g. tube hole drilling, subsequent to the hydraulic test and prior to despatch from the manufacturer's works.

5.1.4 Tubes and integral piping

The Inspecting Authority shall approve welding procedure approval tests or records and shall approve welding approval tests or check current welder's certificates and shall carry out examinations at the following stages.

a) When tubes or pipes are ready for identification with the tube maker's certificate at the boiler maker's works.

b) When at least 10 % of tubes and pipes are set up ready for welding.

c) When all welding of tubes or pipes and their attachments is complete and the non-destructive examination report/records are available for scrutiny.

5.1.5 Completed boiler unit

The Inspecting Authority shall witness the final hydraulic test on site and examine the boiler during the test in accordance with **5.10**.

5.2 Approval of fusion welding procedures

5.2.1 Approval

Fusion welding procedure specifications shall be approved for all welds in components forming the pressure circuit or attached to that circuit.

5.2.2 Performance

All fusion welding shall be performed in accordance with a welding procedure specification (WPS), or other work instruction, prepared in accordance with BS EN 288-2.

5.2.3 Substantiation

Welding procedure specifications shall be substantiated by a welding procedure test carried out in accordance with either BS EN 288-3 or BS EN 288-8, as appropriate. Approval records and welding procedure specifications shall be the subject of approval by the inspecting authority.

5.2.4 Additional tests

The general rules of BS EN 288-3 shall be supplemented for the purpose of this standard by the application of the following additional tests for test specimens representing the longitudinal and circumferential seams of boiler drums. The results of these additional tests shall also be to the satisfaction of the inspecting authority.

5.2.4.1 ***Longitudinal tensile test***

The weld procedure approval test for main seams in drums of thicknesses greater than 20 mm, shall include a longitudinal all weld tensile test. This test shall be performed at not less than the following minimum temperatures:

250 °C for steel group 1;

350 °C for steel groups 2.1, 4 or 5.

The test result shall meet the specified minimum $R_{p0.2}$ value for the parent material at the testing temperature.

5.2.4.2 ***Transverse tensile test***

Depending on the position where the fracture occurs during the test, the test result shall meet the following requirements.

a) When the fracture occurs in the base metal, the test result shall meet the minimum ultimate tensile strength specified for the base material used for the qualification test:

b) When the fracture occurs in the weld, the test result shall meet the minimum ultimate tensile strength specified for the base material used for the qualification test, or for designs based on the $R_{p0.2}$ proof strength, the test result shall meet 90 % of the minimum ultimate tensile strength specified for the base material used for the qualification test.

5.2.4.3 ***Charpy V-notch impact tests***

The test results for the weld deposit in ferritic materials shall meet the following requirements, depending upon the base material and the location of the test pieces in the weldment:

a) The minimum average value produced by the tests shall be the value specified for the base material used for the qualification test at the temperature of the test, i.e. room temperature.

b) One single value may be lower than the value required to achieve the minimum average but this shall not be less than 70 % of the minimum average value.

5.2.4.4 ***Hardness survey***

The results of the hardness survey shall comply with BS EN 288-3, depending on the steel group and whether or not post weld heat treatment is required in accordance with **4.5.4**. For the non heat treated steel group 5, the maximum hardness value shall not exceed 380 HV 10.

Provided that the ductility of the weld metal has been adequately demonstrated by the bend tests specified in BS EN 288-3, and by the impact tests specified in **5.2.4.3**, local deviations in the heat affected zone hardness values shall be acceptable.

5.2.4.5 ***Dissimilar ferritic base material joints***

In the case of weld joints between dissimilar ferritic base materials, the weld metal values shall meet the lower of the minimum values of the parent materials, as required by **5.2.4.1**, **5.2.4.2** and **5.2.4.3**.

5.2.5 Procedures

The manufacturer shall supply to the inspecting authority a list of all the fusion welding procedures required for the fabrication of the water-tube boiler.

5.2.6 Flash butt welding

Flash butt welding procedure tests shall be approved in accordance with BS 4204.

5.2.7 Welded water-wall panels

In addition to the requirements of BS EN 288-8, the procedure qualification test for welded water-wall panels shall comply with the requirements of **J.4**.

5.2.8 Previous approval

Where a manufacturer can furnish proof that he has previously carried out successful welding procedure approval tests in accordance with the requirements of this standard, he shall be deemed exempt from the necessity for re-approval, within the essential variables covered by the previous tests. Demonstration of compliance with BS EN 288-6 clauses **6**a) and **6**b) will be deemed to satisfy this condition.

5.2.9 Additional requirements

The welding procedures for the butt welding of metallurgically bonded composite materials tubing shall be in accordance with the requirements of BS EN 288-8. In addition, any special requirements recommended by the tube manufacturer shall be taken into consideration. The inclusion of any such additional requirements shall be agreed with the inspecting authority. The procedures shall be qualified using composite materials tubing complying with the same specification as the tubing to be used on the boiler.

5.3 Welder and welding operator approval

5.3.1 All welders and welding operators engaged on the welding of pressure parts of boilers fabricated in accordance with this standard, shall pass the specified welder approval tests which are designed to demonstrate their ability to make sound welds of the types on which they are to be employed.

Throughout this standard reference is made to welder approvals in accordance with BS EN 287-1. Where the welds, or parts of the welds in question, may be performed by welding operators, they shall be approved in accordance with the requirements of BS EN 1418, **4.2.1**or **4.2.2**.

5.3.2 Approval testing of welders shall be carried out, recorded and reported in accordance with BS EN 287-1. The essential variables for approval testing of BS EN 287-1, shall be fully applied.

5.3.3 When a welder is approved in accordance with BS EN 287-1 for the welding of butt welds, no additional approval shall be required for the welding of branches, nozzles or attachments, providing that the welding operations are carried out in the range of approval of welder qualifications given in BS EN 287-1.

5.3.4 A list of welders, together with records of their approval tests, shall be retained by the manufacturer who may be required to submit to the inspecting authority evidence of approval of any welder engaged in the fabrication of the boiler.

5.3.5 Welders who have successfully passed the prescribed tests shall be deemed to be approved for the welding on all boilers, within the limits of the procedure, provided that they remain in the employment of the same manufacturer.

5.3.6 A welder who successfully welds all the test pieces required for a welding procedure test to the requirements of **5.2**, shall not normally be required to undertake separate welder approval tests.

5.3.7 If a welder has not been engaged on the fabrication of components using the welding process and equipment appropriate to the welding procedure for a period of more than six months, or if there is any reason to doubt his ability to make satisfactory production welds, the inspecting authority shall be permitted, at its discretion, to require the welder to retake the whole, or part, of the approval test.

5.3.8 Welders involved in the butt welding of metallurgically bonded composite materials tubing shall be qualified in accordance with the requirements of BS EN 287-1. In addition, any special requirements recommended by the tube manufacturer shall be taken into consideration. The inclusion of any such additional requirements shall be agreed with the inspecting authority. The qualification shall have been carried out using composite materials tubing complying with the same specification as the tubing to be used on the boiler.

NOTE. The approval of tests of a welder, when completed to the satisfaction of a recognized inspection authority, should be accepted by other inspection authorities.

5.4 Production control test plates for boiler drums

5.4.1 The number of production control test plates required shall be as follows:

a) *longitudinal welds*: one production control test plate per welding procedure qualification per drum.

b) *circumferential welds*: if the welding procedure qualification is the same as that for the longitudinal seam of the drum, no additional production control test plate is required; if the welding procedure qualification differs from that of the longitudinal seam, then one production control test plate shall be performed per welding procedure qualification per year.

5.4.2 The material used for the test plate shall conform to the same specification as that used in the construction of the boiler drum, and shall be manufactured by the same steelmaking process. The plate shall be of the same nominal thickness as the drum plate. The test plate shall be sufficiently large to allow for the preparation of all the required specimens given in table 5.4.2, and for any additional specimens which might be required. The length of the plate shall in no case be less than 350 mm.

NOTE. The test plate material should be selected from at least one of the casts used in fabricating the drum.

blank

Table 5.4.2 Specimens required for production control test plates for boiler drums

Test specimen	Number of specimens
Macro-examination (see note)	1
Transverse tensile	1
All weld tensile	1
Root bend	
(for all welds made from one side only)	1
Side bend	
(for material at least 10 mm thick)	2
Impact (Charpy V-notch)	
≤ 50 mm thick	3
> 50 mm thick	6

NOTE. If there is any doubt as to the condition of the weld as shown by macro-etching, the area concerned should be examined microscopically to the satisfaction of the Inspecting Authority.

5.4.3 When a boiler drum includes one or more longitudinal seams, the test plates shall, wherever practicable, be attached to the drum plate on one end of one seam, so that the edges to be welded in the test plate are a continuation and duplication of the corresponding edges of the longitudinal seams. The weld metal shall be deposited in the test plate continuously with the welding of the corresponding longitudinal seam so that the welding process, procedure and technique are the same.

The welding consumables shall be from one of the casts and/or batches used in welding the drum.

When it is necessary to weld the test plate separately, e.g. for electro-slag welds and circumferential seams, the test plate shall be welded immediately before or immediately after the welded seam. The procedure used shall be the same as that used in the construction of the drum.

5.4.4 Care shall be taken to minimize distortion of the test plates during welding. If excessive distortion occurs, the test plate shall be straightened before post-weld heat treatment. The preheating, interpass temperature and intermediate and post-weld heat treatment(s) of test plates shall be the same as for production welding of the drum (see also **4.5.6**).

The test plates shall be subjected to the same non-destructive examination methods and acceptance levels as the production weld. If any defects in the weld or the test plate are revealed by non-destructive examination, their positions shall be clearly marked on the plate and test specimens shall be selected with the approval of the Inspecting Authority from other parts of the plate.

5.5 Details of destructive tests for boiler drum production control test plates

5.5.1 General

The test pieces, method of testing, acceptance criteria and requirements for retests shall be in accordance with BS EN 288-3, for destructive tests on weld procedure approval test specimens except where otherwise stated in this clause.

Each production control test plate for boiler drums shall be machined to provide the test pieces given in table 5.4.2. The location and preparation of the test specimens shall be in accordance with BS 709, BS EN 875, BS EN 876, BS EN 895 and BS EN 1321 as appropriate.

5.5.2 Transverse tensile test

5.5.2.1 *General*

The transverse tensile test shall be carried out in accordance with either **5.5.2.2** or **5.5.2.3**.

5.5.2.2 *Design based on room temperature tensile strength (R_m)*

The test shall be conducted, recorded and assessed in accordance with BS EN 288-3 for weld procedure approval transverse tensile tests.

5.5.2.3 *Design not based on room temperature tensile strength (R_m)*

The test shall be conducted, recorded and reported in accordance with BS EN 288-3 for weld procedure approval transverse tensile tests. This test shall be used only to assess the integrity of the weldment. The weld surface and the fracture faces shall be examined to ensure that no defects, metallurgical or physical, are present which could adversely affect the performance of the represented welds in service.

5.5.3 All weld tensile test at elevated temperature

An all weld tensile test shall be carried out on production control test plates of 20 mm thickness and greater.

The yield stress value at 250 °C for carbon and carbon manganese steels, or 350 °C for low alloy steels, shall be not less than the specified minimum yield stress value of the parent material at the corresponding temperature. Where plates are specified to grade 'A', grade 'B' yield stress values shall be assumed for the requirements of this clause. The test shall be carried out in accordance with BS EN 10002-5.

5.5.4 Macro-examination

The specimen shall be prepared for macro-examination. The specimen shall be located in 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 table 5.9.1.

In addition, the sequence of weld deposition in multi-layer welds, shall be examined, and shall show no significant deviations in layer sequence or in weld bead shape, from those defined in the relevant welding procedure specification.

5.5.5 Root bends (for all welds made from one side only)

During testing, the specimen shall not reveal any open imperfections greater than 3 mm in any direction. Slight tearing at the edges of the test specimen shall not constitute failure of the specimen to conform to this requirement.

5.5.6 Side bend test (for plate > 10 mm thickness)

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 edges of the test specimen shall not constitute failure of the specimen to conform to this requirement.

5.5.7 Charpy V-notch impact test

5.5.7.1 The test shall be carried out in accordance with BS EN 10045 : Part 1.

5.5.7.2 The test specimens shall be taken transversely to the weld axis, parallel to the plate surface. The V-notch shall be in the centre of the weld and perpendicular to the plate surface. The number of test specimens shall be dependent on the thickness of the base material as follows:

– 3 specimens for thicknesses ≤50 mm, taken at the middle of the thickness;

– 6 specimens for thicknesses >50 mm, 3 taken at the surface and 3 at the middle of the thickness. The surface specimens shall be taken within 3 mm of the original plate surface.

5.5.7.3 The test results shall be interpreted as follows.

a) The result obtained from each of the Charpy V-notch test specimens shall be at least 40 J, subject to the provision for retests specified in b), when the temperature of the specimens at the time of test does not exceed 37 °C (i.e. not more than 30 °C above the lowest temperature specified in **5.10.4** for hydraulic testing).

b) Provided that no more than one of the specimens tested in accordance with the test temperature requirements of a) produces less than 40 J but not less than 36 J, a retest of three additional specimens shall be made at a test temperature not exceeding 37 °C. If all of these retest specimens conform to the minimum requirement of 40 J, these values shall be accepted.

c) If the tests carried out in accordance with a) or b) have been carried out at a temperature less than 37 °C and the test results do not conform to the minimum specified in a) or b), the test results shall be regarded as void and the manufacturer shall repeat the tests at 37 °C in accordance with a), subject to the provisions for further retests provided by b).

5.5.7.4 In the event of the results of the Charpy V-notch test specimens failing to conform to **5.5.7.3**, the provisions of either a) or b) as follows shall be permitted.

a) The manufacturer shall carry out further heat treatment of the production test plates provided that the same heat treatment cycle is applied to those parts of the boiler drum(s) represented, and provided that no significant adverse effects are caused. After such repeat heat treatment, all the tests given in table 5.4.2 shall be carried out. The tests shall conform to **5.5.1**.

b) Subject to agreement between the manufacturer, the purchaser and the Inspecting Authority (see **1.5.2.3**k), the welds represented by the test specimens having particular Charpy V-notch values less than required by **5.5.7.3** shall be permitted to be accepted as fit for the intended purpose after due consideration of the specific cause and level of impact test results and of the weld quality.

NOTE. There are no requirements in this standard for fracture mechanics tests. Where such tests are carried out, they should be by agreement between the manufacturer, the purchaser and the Inspecting Authority with regard to specimen type, notch location and acceptance criteria. Test methods are given in BS 7448.

5.5.8 Retests of production test plate tensile and bend tests

If any of the tensile and bend test specimens do not conform to **5.5.2.2**, **5.5.3**, **5.5.5** and **5.5.6**, two further test specimens for each failed specimen shall be subjected to the same test. If both retest specimens conform to the requirement(s), the test results shall be deemed to conform to this standard.

If either retest specimen for a tensile test does not conform to the requirement(s) the performance of a computation, using the actual tensile values obtained and the measured minimum thickness of the shell, shall be permitted to demonstrate conformance with section **3**. The acceptance of the computation shall be agreed between the manufacturer and the Inspecting Authority (see **1.5.2.3**l).

If either retest specimen for a bend test does not conform to the requirement(s) the cause shall be investigated and any necessary remedial measures shall be agreed between the manufacturer and the Inspecting Authority (see **1.5.2.3**m).

In the event that there is insufficient material in the test plate for retest specimens, the taking of miniature specimens from the production weld shall be permitted with the approval of the Inspecting Authority. The weld shall be made good to a procedure approved by the Inspecting Authority.

5.6 Non-destructive examination of components

5.6.1 General requirements

5.6.1.1 ***Examination of welds***

The methods, extent and acceptance levels of non-destructive examination shall be in accordance with **5.6** to **5.9** inclusive. Non-destructive examination shall be carried out to written procedures provided by the manufacturer and approved by the Inspecting Authority (see **6.1.3**i).

The requirements for the non-destructive examination of welded tubewalls are contained in Annex J.

5.6.1.2 ***Qualification of personnel***

Personnel responsible for non-destructive examination, including interpretation, evaluation and reporting, shall have qualifications and experience acceptable to the Inspecting Authority.

Other than for visual examination, all personnel responsible for non-destructive examination, including interpretation, evaluation and reporting, shall be certified in accordance with the general rules of BS EN 473.

NOTE. BS EN 473 is not applicable to visual inspection.

Visual examination shall be carried out by suitably trained and experienced personnel that have sufficient knowledge in welding techniques, and a full comprehension of this standard, to be able to identify and interpret imperfections in the welds, or in the heat affected zones of welds, as specified in table 5.9.2.

Radiographs shall be viewed by personnel under the direct supervision of personnel qualified, as a minimum, to level 2 of BS EN 473.

Ultrasonic examination shall be performed under the direct supervision of personnel qualified, as a minimum, to level 2 of BS EN 473.

Magnetic particle and dye penetrant inspections shall be performed, as a minimum, under the direct supervision of personnel qualified to level 2 of BS EN 473.

5.6.1.3 ***Visual examination***

As a minimum requirement, all welds shall be visually examined for profile defects and surface flaws in accordance with BS EN 970 and the requirements of tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3.

5.6.1.4 ***Volumetric examination***

Volumetric examination of welds shall be by ultrasonic techniques, or by radiography, in accordance with the following.

a) **Ultrasonic testing**. Ultrasonic testing shall be carried out in accordance with the requirements of **5.6.2**, to the extent defined in tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3.

b) **Radiography**. Radiographic examination shall be carried out in accordance with the requirements of BS EN 1435, to the extent defined in tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3.

5.6.1.5 ***Surface flaw detection***

Where surface flaw detection is specified in tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3, either magnetic or dye penetrant methods shall be used in accordance with the following.

a) **Magnetic particle inspection** shall be carried out in accordance with BS EN 1290. Where probe contacts are used to induce the magnetic field, two mutually perpendicular directions of magnetization shall be employed. Where the current flow (prod) method is used, arcing at the contact points should be avoided and any resulting marks shall be removed by light grinding.

b) **Dye penetrant inspection** shall be carried out in accordance with BS EN 571-1.

5.6.1.6 ***Percentage inspection of welds***

Where non-destructive examination on a percentage basis of 10 % is specified in tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3, the representative sample of welds for examination shall be agreed with the Inspecting Authority and shall include a sample of each welder's work, for each welding procedure specification on the component concerned. The number of welds to be fully examined shall then be, as a minimum, 10 % of the total number of welds performed by that welder using the same welding procedure specification, on the same component.

Where this standard specifies percentage examination and the examination reveals imperfections which do not comply with the acceptance levels in tables 5.9.2 and 5.9.4, or **5.6.2** in the case of ultrasonic examination, the percentage rate of inspection shall be increased. The basis for the extension shall always be related to each individual component, to each welder involved in the manufacture of that component, and to the same type of welds, i.e. to the same welding procedure specification. The basis for increased examination shall be as follows.

a) When performing the random examination, if one weld, or more than one weld, is/are revealed as not being acceptable, the examination shall be extended to two additional welds of the same type, for each rejected weld.

b) If all the examined welds of that extension, i.e. as called for in a) above, are acceptable then the initial rate of 10 % may be resumed.

c) When one or more of the welds examined during the extension is/are not acceptable, then the examination shall extend to 10 additional welds for each weld rejected during the first extension, or to all the welds in the component if this is less than 10 in number.

d) The extension procedure shall be continued on this principle until all the extension welds are acceptable.

e) If the extension procedure continues to reveal unacceptable welds, the extension procedure shall be increased until a rate of 100 % is achieved.

Where this standard specifies non-destructive examination on a percentage basis of the total number of welds and the manufacturer has demonstrated to the satisfaction of the Inspecting Authority that the welds consistently conform to the standards of acceptance specified in tables 5.9.2 and 5.9.4, or **5.6.2**, a reduction in the percentage rate of examination, to a minimum of 5 % shall be permitted by agreement between the manufacturer and the Inspecting Authority.

5.6.1.7 ***Design requirements***

The designer shall ensure that all non-destructive examination techniques required by this standard can be implemented.

NOTE. Particular care is required in the design of joints subject to ultrasonic examination to ensure that a sufficient length of parent material is available adjacent to welds to permit the required probe movements.

The designer shall nominate on the drawings those attachment welds which are to be considered as load carrying for the purpose of this specification.

5.6.1.8 ***Dressing of welds***

Except where dressing of the welds is specified in this standard, the welds shall be accepted in the undressed condition, unless dressing is necessary to effect satisfactory non-destructive examination.

Dressing in the bore of nozzles and branches of drums, headers, tubes and pipes to remove defects revealed by visual or non-destructive examination shall be permitted. Such dressing shall not exceed 10 % of the through thickness of the weld, but not more than 5 mm, provided that the design thickness of the weld is maintained.

5.6.1.9 ***Timing of NDE***

The specified non-destructive examination shall be carried out after any required final stress relief or heat treatment, except as permitted by **4.3.1.1.7** or by this clause. If no final stress relief is required by **4.5**, non-destructive examination shall be carried out in the as-welded condition.

It shall be permissible to carry out the specified non-destructive examination before any final stress relief or heat treatment in the case of welds in Steel Groups 1, 5.1 and 5.2 only in the following cases:

a) butt welds in tubes and integral pipes;

b) by agreement between the manufacturer and the Inspecting Authority for the following weld types:

i) butt welds in drums and headers;

ii) branch, nozzle and stub welds;

iii) attachments welds.

5.6.1.10 ***Steel groups***

Steels have been grouped together for welding purposes. The groups have been taken from prEN ISO/TR 15608.

5.6.2 Ultrasonic examination

5.6.2.1 ***General requirements***

The assessment of defects for acceptance purposes shall be by evaluation methods 1 or 2 as specified in BS EN 1714, or a combination of these methods.

The evaluation and recording levels shall be in accordance with BS EN 1712, Quality Level B.

NOTE. Characterization of defects in accordance with BS EN 1713 should only be implemented as a contractual requirement and is not an essential feature for conformance to this standard. Defects requiring repair do not require characterization. There are no special requirements for near surface examination.

5.6.2.2 ***Special requirements***

The above ultrasonic standards shall be fully applied to the ultrasonic examinations of welds where specified in tables 5.6.1.3-1, 5.6.1.3-2 and 5.6.1.3-3. However the following special requirements shall be met when options are permitted within those standards.

1) **Austenitic steels**. Ultrasonic examination of fusion welded joints in Steel Group 9 shall be carried out in accordance with written procedures, approved by the Inspecting Authority.

In the event that a satisfactory ultrasonic examination procedure cannot be provided for butt welds, the welds shall, as a minimum, be radiographed. The examination methods to be applied to pressure connection welds shall be by agreement between the manufacturer and the Inspection Authority.

NOTE. It is recognized that ultrasonic techniques for the volumetric examination of austenitic butt, branch, nozzle and stub welds have not been developed to a stage where confidence in the results can be assured. Therefore, before manufacture commences, consideration should be given to the latest state of the art of ultrasonic examination relative to the particular joint configuration and welding process employed. Based on this consideration, agreement should be reached between the manufacturer and the Inspecting Authority regarding the valid use of ultrasonic examination and the assessment of results therefrom.

2) **Partial penetration welds**. Ultrasonic examination of partial penetration welds shall only be carried out in accordance with written procedures, approved by the Inspecting Authority.

3) **Examination levels**. Examination level B shall be used except where the specific test requirements are not defined in BS EN 1714. In such cases examination level D shall be used in accordance with a written procedure approved by the Inspecting Authority, taking into account the general rules of BS EN 1714.

4) **Transverse defects**. Ultrasonic examination for transverse defects shall be performed:

a) on Steel Group 1.2 , where the thickness of the base material is ≥40 mm;

b) on Steel Groups 2, 3, 4 and 5, for all base material thicknesses.

5) **Tandem examination**. The tandem examination technique shall not normally be applied.

6) **Probe frequencies**. Probes with a frequency of between 1.5 MHz and 5 MHz shall be used for normal applications. Specific applications requiring frequencies outside this range shall be subject to agreement between the manufacturer and the Inspecting Authority.

7) **Parent metal examination**. If the edge of the parent metal has not been previously scanned before welding, the parent metal in the scanning zone shall be ultrasonically tested with a normal probe before testing commences with an angle probe.

8) **Preparation of the surface**. Scanning surfaces and surfaces from which the sound beam is reflected shall be assumed to be satisfactory if the surface roughness is not greater than 12.5 μm.

NOTE. Roughness greater than this value may still be acceptable if it can be demonstrated that effective ultrasonic examination can be performed.

9) **Signal to noise ratio**. During the examination of a weld, the noise level, excluding spurious surface indications, shall be at least 12 dB below the required evaluation level.

10) **Measurement of the length of defects**. The length of reflectors, in either the longitudinal or transverse direction, shall normally be determined using the half amplitude method, i.e. the −6 dB technique.

11) **Height measurements**. Where BS EN 1712 is applicable, defect height measurements shall not be necessary. For examinations outside the scope of that standard the examination level, and the acceptance criteria, shall be agreed between the manufacturer and the Inspecting Authority.

12) **Application of ultrasonic examinations to thicknesses of 8 mm or less**. Ultrasonic examination of fusion welded joints in materials ≤8 mm thick shall be conducted in accordance with written procedures approved by the Inspecting Authority.

5.6.3 Non-destructive examination reports

The following information shall be provided, as a minimum, in the examination reports:

– identification of the water tube boiler components concerned;

– identification of the welds examined and any ultrasonic scanning pattern used;

– the examination procedure reference;

– the applicable welding procedure specification;

– the stress relief or post weld heat treatment condition;

– the surface condition prior to the examination, e.g. ground, machined, as welded, etc.;

– details of the procedure, e.g. type of magnetization, consumables used, type of radiographic source or equipment, etc.;

– reference to the applicable acceptance criteria;

– the results of the examination, including details of any repairs;

– in the case of percentage examination, application of any extension zones of examination and their results;

– statement of conformity with the requirements of this standard;

– the date when the examinations were carried out and the date of the report;

– the names, and approvals, of the personnel responsible for the examination, the evaluation and the interpretation of the results.

Table 5.6.1.3-1 Extent of NDE of boiler drums

Types of welds	Surface inspection		Volumetric examination	
	Visual	MPI[1)]	Ultrasonic	Radiographic
Main seams				
Longitudinal and circumferential welds	100 %	100 %	100 %[2)]	100 %[2)]
Pressure connection welds				
Thickness $e \geq 25$ mm	100 %	100 %	100 %	Not permitted
Thickness 15 mm $\leq e < 25$ mm	100 %	100 %	10 %[3)]	Not permitted
All other welds, including seal welds	100 %	10 %	None	None
Attachment welds				
Load carrying	100 %	100 %	None	None
Non load carrying	100 %	10 %	None	None

1) Dye penetrant methods not permitted on drums.
2) Ultrasonic examination is the preferred method for volumetric examination and is mandatory for welds in material Steel Group 4 and ½Cr½Mo¼V steels.
3) No volumetric examination is required if d_o < 170 mm.

Table 5.6.1.3-2 Extent of NDE of headers

Types of welds	Surface inspection		Volumetric examination	
	Visual	MPI[1)]	Ultrasonic	Radiographic
Main seams				
Longitudinal and circumferential welds	100 %	100 %	100 %[2) 3)]	100 %[2) 3)]
Pressure connection welds				
Thickness $e \geq 25$ mm	100 %	100 %	100 %[3)]	Not permitted[3)]
Thickness 15 mm $\leq e < 25$ mm	100 %	100 %	10 %[4)]	Not permitted
All other welds, including seal welds	100 %	10 %	None	None
Attachment welds				
Load carrying	100 %	100 %	None	None
Non load carrying	100 %	10 %	None	None
End plate welds[5)]	100 %	100 %	100 %	Not permitted

1) Dye penetrant methods are permitted for Steel Group 1 and are mandatory for Steel Group 9. They are also permitted for the connecting welds of tube stubs in Steel Groups 2 and 5, where $d_o \leq 80$ mm.
2) Ultrasonic examination is the preferred method for volumetric examination and is mandatory for welds in material Steel Groups 4, 6 and ½Cr½Mo¼V steels.
3) The volumetric examination of welds in Steel Group 9 materials shall be in accordance with the requirements of **5.6.2.2**(1).
4) No volumetric examination is required if d_o < 170 mm.
5) Applies to end plate welds in accordance with figure 3.6.2.1-2.

Table 5.6.1.3-3 Extent of NDE of tubes and pipes

Types of welds	Surface inspection		Volumetric examination[1)2)3)]	
	Visual	MPI[4)]	Ultrasonic	Radiographic
Circumferential welds				
$e \geq 25$ mm or $d_o > 170$ mm	100 %	100 %	100 %	100 %
Other circumferential welds	100 %	None	10 %	10 %
Pressure connection welds				
Thickness $e \geq 25$ mm	100 %	100 %	100 %	Not permitted
Thickness 15 mm $\leq e <$ 25 mm	100 %	10 %	10 %[5)]	Not permitted
All other welds, including seal welds	100 %	10 %	None	None
Attachment welds				
Load carrying	100 %	100 %	None	None
Non load carrying	100 %	10 %	None	None
Welds between tubes and fins (panels)	100 %	None	None	None
Flash butt welds	100 %	[6)]	[6)]	[6)]

[1)] Ultrasonic or radiographic examination methods may be used in all cases except for welds in material Steel Groups 4, 6 and ½Cr½Mo¼V steels where ultrasonic methods are mandatory.
[2)] For Steel Groups 1 and 9 an examination level of 10 % is permitted.
[3)] For the examination methods applicable to Steel Group 9 (austenitic), see **5.6.2.2** (1).
[4)] Dye penetrant methods are permitted for Steel Group 1 and are mandatory Steel Group 9. They are also permitted for the connecting welds of tube stubs and attachment welds in Steel Groups 2 and 5, when $d_o \leq 80$ mm.
[5)] No volumetric examination is required if $d_o < 170$ mm.
[6)] For the NDE requirements applicable to flash butt welds see BS 4204.

blank

5.7 Extent of non-destructive examination and acceptance standards for parent materials

5.7.1 General

When non-destructive examination of parent materials used in the fabrication of boiler components is required, the procedure to be adopted shall be in accordance with the following British Standards, as appropriate.

Castings	BS 6072; BS 6208
Forgings	BS 6072; BS EN 571-1 and BS EN 10228-3
Plate	BS 5996; BS 6072

5.7.2 Examination of, and standards of acceptance for, plates for drums

Plates for drums shall be examined as follows.

a) All drum plates shall be ultrasonically examined in accordance with BS 5996. The minimum acceptable quality grade for this standard shall be B2.

b) A 100 % magnetic particle examination shall be used by the manufacturer to supplement the visual examination of plate edge weld preparations prior to welding, except where electro-slag welding is employed, when visual examination only shall be required.

c) When magnetic particle examination reveals indications exceeding 30 mm in length on the plate edge, the extent of such indications into the plate shall be investigated by ultrasonic methods and the indications cleared by dressing. If the cleared plate edge requires a repair by welding, the method of repair shall be approved by the Inspecting Authority.

5.7.3 Examination of, and standards of acceptance for, forgings for drum courses and drum nozzles

5.7.3.1 *Quality of forgings*

Forgings shall be free from injurious segregations, gross inclusions and external or internal surface cracks.

5.7.3.2 *Volumetric examination*

5.7.3.2.1 *General requirements for ultrasonic examination*

All forgings shall be ultrasonically scanned from at least one major surface according to its geometry in order to aim for 100 % volumetric coverage. A combination of normal (0 °) compression wave and angle beam shear wave probes shall be used and to ensure complete coverage, probes shall be indexed to give at least 10 % overlap on each traverse.

5.7.3.2.2 *Compression wave examination*

A forging shall be unacceptable if the normal (0 °) compression wave examination shows one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to the geometric configuration, which cannot be contained within a square of side 25 mm or one-half of the thickness, whichever is the greater.

NOTE. Complete loss of back reflection is assumed when the back reflection is less than 5 % of full screen height.

5.7.3.2.3 *Shear wave examination*

A forging shall be unacceptable if the angle beam shear wave examination reveals a discontinuity causing an indication that is equal to or greater than the amplitude reference line. To obtain the amplitude reference line the instrument for the angle beam examination shall be calibrated to obtain an indication of 75 % full screen height from a 60 V – notch on the inside diameter in the axial direction and parallel to the axis of the forging.

The inside diameter notch shall be cut to a depth of 3 % of the thickness or 6 mm, whichever is the smaller, with a length of 25 mm, where the thickness is that of the forging to be examined at the time of examination.

At the same instrument setting an indication from a similar outside diameter notch shall be obtained. A line shall be drawn through the peaks of the first indications obtained from the inside diameter and outside diameter notches. This shall be the amplitude reference line.

When practicable the notches shall be in excess metal or test metal. it is permissible to use a separate calibration standard but it shall have the same nominal composition, heat treatment, thickness and outside diameter as the forging it represents. The test surface finish on the calibration standard shall be comparable, but no better than the item to be examined. Where a group of forgings is made it is permissible to use one of these forgings as the calibration standard.

5.7.3.3 *Surface examination*

All surfaces of forgings shall be subject to magnetic particle examination. When magnetic particle examination reveals indications of defects, these indications shall be investigated ultrasonically to determine their extent and acceptability.

Surface indications confirmed as cracks shall be deemed not to conform to this standard. Cracks shall be dressed out where the design minimum thickness can be maintained. Weld repair of surface defects by the forgemaster shall be permitted only with the approval of the Inspecting Authority (see **4.2.2.1**).

5.7.4 Examination of, and standards of acceptance for, headers, pipes and tubes

All headers, pipes and tubes shall be examined in accordance with BS 3059, BS 3601, BS 3602, BS 3604 or BS 3605, as applicable. The test category shall be specified by the designer, but see note 6 to table A.1.

5.7.5 Examination of, and standards of acceptance for, steel castings for pressure purposes.

All steel castings for pressure purposes shall be non-destructively examined in accordance with category I or II of appendix B of BS 1504 : 1976. See **2.2.2**.

For ultrasonic examination, the acceptance level of quality level 1 of table 1 and quality level 1 of table 2 of BS 6208 : 1982 shall be applied.

For radiographic examination, the acceptance levels (i.e. the maximum acceptable severity levels for defects) of paragraph 7-3(a)(1) of appendix 7 of ANSI/ASME BPV-VIII-1[8)], 1980[9)] shall be applied[10)].

For magnetic particle examination, the acceptance levels (i.e. the maximum acceptable severity levels for defects) of paragraph 7-3(a)(3) of appendix 7 of ANSI/ASME BPV-VIII-l[8)] 1980[9)] shall be applied[11)].

Castings found to be defective shall be either rejected or repaired to an approved welding procedure and to the satisfaction of the Inspecting Authority. If repairs by welding are carried out, the castings shall subsequently be given a final stress relief in accordance with BS 4570. Repaired areas of castings shall be re-examined in accordance with BS 1504 and shall be shown to be free from unacceptable defects.

5.8 Extent of non-destructive examination of welds

5.8.1 Boiler drums

Longitudinal and circumferential seams, including any seams in dished ends, branches, nozzles and stub welds, and permanent attachment welds to drums, shall be examined as specified in table 5.6.1.3-1. The inside and outside surfaces of all butt welds, including those made from one side, shall be examined over their full length by magnetic particle examination. All load carrying attachment welds shall be dressed at the toes and examined over their full length by the magnetic particle method.

5.8.2 Headers

All longitudinal and circumferential welds in headers, pressure connection welds and permanent attachment welds to headers shall be examined as specified in table 5.6.1.3-2. Where surface flaw detection is specified, only the outside surface of the welds shall be examined. All load carrying attachment welds shall be dressed at the toes and examined over their full length by surface flaw detection methods appropriate to the material.

5.8.3 Tubes and integral piping

Circumferential welds in tubes and integral piping and any nozzles, branches and stub welds and permanent attachments shall be examined over their full length as specified in table 5.6.1.3-3. Where surface flaw detection is specified, only the outside surface of the welds shall be examined. All load carrying attachment welds shall be dressed at the toes and examined over their full length by surface flaw detection methods appropriate to the material.

---

8) ASME Boiler and pressure vessel code Section VIII. *Rules for construction of pressure vessels Division* 1. Published by The American Society of Mechanical Engineers (ASME) and available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL. Tel. 020 8996 9001.

9) As amended/corrected by subsequent Addenda.

10) The maximum acceptable severity levels specified for defectsdetected by radiographic examination are based on comparisons with the standard reference radiographs in ASTM Specifications SE-446-81, *Standard Reference Radiographs for Steel Castings up to 2 in (51 mm) in Thickness*, and SE-186-81, *Standard Reference Radiographs for Heavy-Walled (2 to 4½ in) (51 to 114 mm) Steel Castings.*

11) The maximum acceptable severity levels specified for defects detected by magnetic particle examination are based on comparisons with the standard reference photographs in ASTM Specification E-125-63 (1980), 'Standard Reference Photographs for Magnetic Particle lndications on Ferrous Castings'.

The ASTM standards are published by The American Society for Testing and Materials (ASTM) and are available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL. Tel. 020 8996 9001.

5.9 Standards of acceptance

5.9.1 General requirements

The standards of acceptance given in tables 5.9.2 and 5.9.4, and **5.6.2** in the case of ultrasonic examination, shall be imposed during fabrication as a means of quality control. Where the joining of different thicknesses is involved *t* shall be taken as the thinner of the thicknesses being joined.

Flaws shall be assessed as follows:

a) Any flaws that do not exceed the levels specified in tables 5.9.2 and 5.9.4, or **5.6.2** in the case of ultrasonic examination, shall be accepted without any further action.

b) For flaws which exceed the levels specified in tables 5.9.2 and 5.9.4, or **5.6.2** in the case of ultrasonic examination, the procedure given in 1) or 2) below shall be followed:

1) The flaws shall be deemed to be defects and the welds either rejected or repaired. Any repairs shall be carried out in accordance with **4.3.1.9**.

2) By agreement between the manufacturer and the Inspecting Authority, the flaws shall be subjected to a fitness for purpose analysis and, if acceptable to the Inspecting Authority on this basis, shall be deemed to conform to this standard.

NOTE. Fitness for purpose may be established by use of suitably documented evidence for a particular application or by calculation, taking into account the material ,stress and environmental factors involved. For this purpose reference may be made to PD 6493.

5.9.2 Visual examination

The welds shall be visually assessed against the acceptance criteria given in table 5.9.2. In the special case of longitudinal fin to tube welds in panel construction, reference shall be made to table J.3.2.3.

5.9.3 Surface flaw detection

Flaws detected by surface flaw detection methods shall be assessed against the acceptance criteria given in table 5.9.2.

5.9.4 Radiographic examination

Internal imperfections detected by radiographic methods shall be assessed against the acceptance criteria given in table 5.9.4.

5.9.5 Ultrasonic examination

Internal imperfections detected by ultrasonic methods shall be assessed against the acceptance criteria given in BS EN 1712, Quality Level B, except in the case of end plate welds in accordance with figure 3.6.2.1-2 where indications classed as planar flaws at the weld root having a through thickness dimension of 2 mm or less shall be disregarded.

Table 5.9.2 Acceptance criteria of weld surface imperfections				
Identification of imperfection				**Maximum permitted**
BS EN ISO 6520-1 group no.	**BS EN ISO 6520-1 reference no.**	**Type of imperfection**	**BS EN 25817 quality level**[1)]	**Definition of maximum permitted**[2)]
1	100X	Cracks (all)	B	Not permitted.
2	201X 202X	Gas cavity (all) Shrinkage cavity (all)	'S'	Permitted when occurring at the surface if: – diameter ≤2 mm; or – depth ≤1 mm; with additional conditions that: – does not occur at a stop or restart; – is not systematic on the same weld for pressure welds or load carrying attachment welds.
3	301X 302X 303X 304X	Slag inclusions (all) Flux inclusions (all) Oxide inclusions Metallic inclusions (all)	'S'	Not permitted when occurring at the surface. Shall be removed, e.g. by grinding.
4	401X	Lack of fusion (all)	B	Not permitted.
	402	Lack of penetration	B	Not permitted if a full penetration weld is required.
5	5011 5012	Undercut	B	Depth ≤0.5 mm (irrespective of length). A smooth transition is required.
	5013	Shrinkage groove	C	Depth ≤1 mm (irrespective of length). A smooth transition is required.
	502	Excess weld metal	C	Depth ≤1 mm + 0.15*b*, maximum 7 mm, where *b* = width of weld, in mm. A smooth transition is required.
	503	Excessive convexity	C	Depth ≤1 mm + 0.15*b*, maximum 4 mm, where *b* = width of weld, in mm. A smooth transition is required.
	504	Excessive penetration	C	Depth ≤1 mm + 0.6*b*, maximum 4 mm, where *b* = width of the penetration, in mm.
	5041	Local protrusion	B	Occasional local excess (see No. 504) is permitted with a maximum that shall be related to the operating conditions.
	506	Overlap	B	Not permitted.
	507	Linear misalignment		See clause **4.2.5**.
	508	Angular misalignment		See clause **4.2.5**.
	509	Sagging	C	Long imperfections (>25 mm) not permitted. Short imperfections (≤25 mm) not permitted if *h* ≥0.10*t*, with a maximum of 1 mm where *h* = depth of sagging, in mm; *t* = thickness of base material, in mm.
	510	Burn through	'S'	Not permitted.
	511	Incompletely filled groove	C	Same as for sagging No. 509.

Table 5.9.2 Acceptance criteria of weld surface imperfections (*continued*)

Identification of imperfection				**Maximum permitted**
BS EN ISO 6520-1 group no.	**BS EN ISO 6520-1 reference no.**	**Type of imperfection**	**BS EN 25817 quality level**[1)]	**Definition of maximum permitted**[2)]
	512	Excessive asymmetry fillet weld	D	$h \leq 2$ mm + 0.2a where h = excess of one leg, in mm; a = throat of weld, in mm.
	515	Root concavity	C	$h \leq 1$ mm (irrespective of length) where h = root concavity, in mm. A smooth transition is required.
	516	Root porosity	'S'	Not permitted.
	517	Poor restart	B	Not permitted.
6	601	Stray flash or arc strike	'S'	Not permitted. Grinding is required, plus DPI or MPI, to ensure that no cracks are present.
	602	Spatter	'S'	Shall normally be removed from all pressure parts and from both load and non load carrying attachment welds. However, isolated, non systematic spatter is permitted on components made from Steel Group 1. NOTE. In the special case of circumferential welded fins which are attached to tubes by a mechanized welding process, spatter should be minimized, but any spatter produced may retain, regardless of the material or heat treatment involved.
	603	Torn surface	'S'	Not permitted. Shall be ground. A smooth transition is required.
	604	Grinding mark	'S'	Not permitted. Shall be flushed by grinding. A smooth transition is required.
	605	Chipping mark	'S'	Not permitted. Shall be flushed by grinding. A smooth transition is required.
	606	Underflushing	'S'	Not permitted. Any local underflushing shall be related to the design requirements, i.e. calculated thickness + corrosion allowance = minimum thickness for base material. Thickness shall be measured by ultrasonic methods in case of doubt.

[1)] The requirements of BS EN 25817 have been modified in certain instances, to suit boiler practice. Where this has been considered necessary a special level of acceptance has been included which is denoted 'S'.
[2)] Where the joining of different thicknesses is involved t shall be taken as the thinner of the thicknesses being joined.

Table 5.9.4 Acceptance criteria for volumetric imperfections in welds found by radiography				
Identification of imperfection				**Maximum permitted**
BS EN ISO 6520-1 group no.	**BS EN ISO 6520-1 reference no.**	**Type of imperfection**	**BS EN 25817 quality level**[1)]	**Definition of maximum permitted**[2)]
1	100X	Cracks (all)	B	Not permitted.
2	2011	Gas pore (isolated or individual in a group)	'S'	$d \leq 0.3t$, maximum 4 mm, for $t \leq 60$ mm and maximum 5 mm, for $t > 60$ mm where d = diameter of a single pore, in mm; t = thickness of base material, in mm.
	2012	Uniformly distributed porosity	'S'	For any individual pore, see gas pore No. 2011.
			C	Not permitted if the total projected surface of porosity exceeds 2 % of the considered projected surface of the weld.
	2013	Localized (clustered) porosity	'S'	For any individual pore, see gas pore No. 2011.
			B	Not permitted if the total projected surface of porosity exceeds 4 % of the considered projected surface of the weld, whichever is the greater of the two following areas: area 1: an envelope surrounding all the pores; area 2: a circle with a diameter corresponding to the weld width.
	2014	Linear porosity	'S'	Same as for uniformly distributed pores No. 2012, but the distance between two pores shall always be greater than twice the diameter of the larger pore, and not be less than 4 mm to ensure that there is no chance of having lack of fusion present.
	2015	Elongated cavities	'S'	$l \leq 0.3t$, maximum 5 mm, and $w \leq 2$ mm where l = length of the projected indication, in mm; t = thickness of base material, in mm; w = width of the projected indication, in mm.
	2016	Worm holes	'S'	Same as for elongated cavity No. 2015.

Table 5.9.4 Acceptance criteria for volumetric imperfections in welds found by radiography (*continued*)

Identification of imperfection				Maximum permitted
BS EN ISO 6520-1 group no.	**BS EN ISO 6520-1 reference no.**	**Type of imperfection**	**BS EN 25817 quality level**[1)]	**Definition of maximum permitted**[2)]
	202	Shrinkage cavities	'S'	$l \leq 0.3t$, maximum 4 mm, and $w \leq 2$ mm where l = length of the projected indication, in mm; t = thickness of base material, in mm; w = width of the projected indication, in mm.
3	301	Slag inclusions	'S'	$w \leq 0.3t$, maximum 3 mm, and depending on the application: elastic range: $l \leq t$, maximum 100 mm creep range: $l \leq 0.5\ t$, maximum 50 mm where w = width of projected indication, in mm; l = length of projected indication, in mm; t = thickness of base material, in mm. NOTE. In the case of multiple linear slag inclusions, with a distance between any two of them less than twice the longest of them, the total length is to be considered as a defect.
	302	Flux inclusion	'S'	Same as for slag inclusion No. 301.
	303	Oxide inclusion	'S'	Same as for slag inclusion No. 301.
	304	Metallic inclusion	'S'	Copper inclusions not permitted. Tungsten inclusions: same as for gas pore No. 2011 – 2012 – 2013.
4	400	Lack of fusion and lack of penetration	B	Not permitted.
	500	Imperfect shape: such defects are normally accepted or rejected by visual examination. Nevertheless, they might occur on surfaces to which there is no access for visual examination, e.g. the internal surface of tubes or pipes. In such cases the visual criteria in table 5.6-4 should be applied to radiographs taken of the defects.		
	5011 5012	Undercut	B	Depth ≤ 0.5 mm (irrespective of length). A smooth tranistion is required.
	5013	Shrinkage groove	C	Depth ≤ 1 mm (irrespective of length). A smooth transition is required.
5	504	Excessive penetration	C	Depth ≤ 1 mm + $0.6b$, maximum 4 mm, where b = width of penetration, in mm.

Table 5.9.4 Acceptance criteria for volumetric imperfections in welds found by radiography (*continued*)

Identification of imperfection				**Maximum permitted**
BS EN ISO 6520-1 group no.	**BS EN ISO 6520-1 reference no.**	**Type of imperfection**	**BS EN 25817 quality level**[1]	**Definition of maximum permitted**[2]
	5041	Local protrusion	B	Occasional local excess (see No. 504) is permitted, with a maximum that shall be related to the operating conditions.
	515	Root concavity	C	$h \leq 1$ mm (irrespective of length), where h = root cavity, in mm. A smooth transition is required.
	516	Root porosity	'S'	Not permitted.
	517	Poor restart	B	Not permitted.

[1] The requirements of BS EN 25817 have been modified in certain instances to suit boiler practice. Where this has been considered necessary a special level of acceptance has been included which is denoted 'S'.
[2] Where the joining of different thicknesses is involved t shall be taken as the thinner of the thicknesses being joined.

5.10 Hydrostatic pressure tests

5.10.1 General

When completely assembled boilers are hydrostatically tested to the test pressure specified in **5.10.2** and individual components are hydrostatically tested in accordance with **5.10.3** there shall be no sign of any weakness or defect.

The hydrostatic tests shall be carried out on welded components or the completed boiler after all welding and heat treatment has been completed, but may be carried out prior to the drilling of holes for expanded tubes.

5.10.2 Hydrostatic test pressure for completely assembled boilers

The test pressure for completed boilers shall be determined at the design stage and shall be at least 1.5 times the maximum permissible working pressure.

5.10.3 Hydrostatic tests on individual components

5.10.3.1 Boiler drums and other cylindrical components with an internal diameter greater than 600 mm designed by the use of non-creep based design stresses, shall be hydrostatically tested at the test pressure specified in **5.10.2** before assembly into the boiler, unless the components are assembled into a boiler and the assembled boiler is tested in the manufacturer's workshop to the test pressure specified in **5.10.2**.

5.10.3.2 All components which are not reasonably accessible for inspection after assembly into the boiler shall be individually hydrostatically tested to the pressure specified in **5.10.2** before assembly into the boiler.

NOTE. Components other than those specified in **5.10.3.1** and **5.10.3.2** can be assembled into the boiler without prior individual testing.

5.10.4 Test procedure

5.10.4.1 The hazards involved in pressure testing shall be considered by the manufacturer and adequate precautions shall be taken.

NOTE 1. Since it is necessary to avoid the risk of repeated over-pressurization, it is recommended that, prior to the hydrostatic test carried out in the presence of the Inspecting Authority, a preliminary examination of the boiler or component should be carried out at the maximum permissible working pressure for the purpose of identifying any significant leaks.

NOTE 2. Care should be taken to ensure that the complete pressure envelope, its supports and its foundations are capable of withstanding the total load that will be imposed upon them during the pressure test.

Water shall be used as the pressurizing agent. The quality of the water used shall be such as to prevent both corrosion and any residue of injurious solids.

The completed boiler, and any components which are required to be hydrostatically tested before assembly into the boiler, shall be tested with water at a temperature at which there is no risk of freezing. The temperature of the water used for the pressure test shall be selected by the manufacturer taking into account the risk of brittle fracture of the pressure parts, and shall not exceed 50 °C.

5.10.4.2 The boiler, or component being tested, and its connections shall be vented, or evacuated; the procedure for dealing with any remaining air pockets shall be subject to previous agreement with the Inspecting Authority, see **3.1.5**h.

5.10.4.3 All temporary tubes, connections and blanking devices shall be designed to withstand the appropriate test pressure.

5.10.4.4 No component undergoing pressure testing shall be subjected to any form of shock loading, e.g. hammer testing, thermal shock, or rapid pressure changes.

5.10.4.5 The full test pressure shall be maintained for 30 min for completed boilers and large components, and for a sufficient length of time to complete examination of smaller components.

5.10.4.6 Prior to close examination, the test pressure shall be reduced to not less than the maximum permissible working pressure.

5.10.5 Repaired components

Pressure parts which have been repaired following the hydrostatic test, shall again be hydrostatically tested in accordance with the provisions of **5.10.1** to **5.10.4** after completion of the repair and any required heat treatment and non-destructive examination, unless otherwise agreed with the Inspecting Authority.

Section 6. Documentation and marking

6.1 Documents

6.1.1 The manufacturer shall allow the Inspecting Authority's inspector full access to all drawings and documents necessary to permit him to check all the dimensions of parts during manufacture.

6.1.2 The manufacturer shall supply the Inspecting Authority with full information, in the form of drawings, documents, or data sheets, concerning the materials of construction, dimensions and design data before commencement of manufacture of each component.

6.1.3 When completed, unless previously supplied during the course of manufacture, the boiler shall be accompanied by a dossier containing, where appropriate, the following documents for the information of the purchaser and/or regulating authority:

a) certificate of conformity with BS 1113:1999 (see **6.2**);

b) record of agreed deviations (see **1.4.2** and j));

c) information supplied by the purchaser (see **1.5.1**);

d) requirements agreed at the contract or order stage (see **1.5.2.2**);

e) pressure part drawings;

f) material test certificates for pressure parts;

g) welding procedures (see **5.2**);

h) non-destructive examination procedures used (see **5.6.1.1**);

i) hydrostatic test certificates;

j) requirements agreed during the manufacturer's operations (see **1.5.2.3** and b));

k) rubbings of drum and header identification marks.

NOTE. The duration for which a manufacturer will retain all records he is required to generate during the design and construction of a boiler is influenced by a number of considerations which are outside the scope of this standard. If a purchaser wishes to retain permanent copies of any such records, other than those listed in this clause, he should state his requirements in the purchase specification.

6.1.4 The manufacturer shall supply to the purchaser and to the Inspecting Authority the dossier referred to in **6.1.3**.

6.2 Certificate of conformity

The certificate shall state that each boiler and separate unit as defined in **1.1.3**a) to e) has been designed, constructed and tested in every respect in accordance with this British Standard (see **1.4.2**), and this certificate shall be countersigned by the Inspecting Authority as evidence that it has been so constructed and tested. Where erection is inspected by a second Inspecting Authority, each Inspecting Authority shall sign the certificate in respect of the work it has supervised.

Where the design, fabrication or erection 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. Each certificate shall be countersigned by the Inspecting Authority.

6.3 Marking

6.3.1 Each boiler and separate type of plant, as described in **1.1.3**a) to e) shall be permanently and legibly marked to show its identity and origin. This marking may be made above the manhole of the main steam and water drum or preferably on a plate permanently attached to a principal pressure part or on the steel structure of the boiler.

The marking shall show the following particulars:

a) the name and domicile of the manufacturer;

b) the manufacturer's serial number;

c) the maximum permissible working pressure;

d) the year of manufacture;

e) the date of hydrostatic test, the test pressure and temperature;

f) the mark of the Inspecting Authority;

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

h) the number of this British Standard, i.e. BS 1113:1999[12)].

6.3.2 Methods of marking shall be in accordance with **4.1.4**.

[12)] Marking BS 1113:1999 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. Such a declaration is not to be confused with third party certification of conformity (see **6.2**).

Section 7. Valves, gauges and fittings

7.1 General

All water-tube steam generating units and associated equipment (see **1.1**) shall be equipped with the valves, gauges and fittings necessary for the safe operation of the plant.

Materials, design, construction, and testing of safety valves shall conform to BS 6759 : Part 1.

Materials, design, construction and testing of valves other than safety valves, of gauges and other fittings shall conform to BS 759 : Part 1.

In the interests of safety parts of this section include requirements for the provision of certain valves and fittings (see **7.3**, **7.7**, **7.8.4** and **7.9**) in piping systems which are separated from the boiler by a shut-off valve. All other requirements of such piping systems are outside the scope of this standard.

7.2 Safety valves

7.2.1 General

7.2.1.1 The minimum bore of the valve seat of any safety valve connected directly to a boiler, superheater, reheater or economiser shall not be less than 20 mm.

7.2.1.2 A water tube boiler, as described in **1.1.3**a, with an evaporation rate of not greater than 3700 kg/h, shall be fitted with a least one safety valve. A water tube boiler, as described in **1.1.3**a, with an evaporation rate greater than 3700 kg/h, shall be fitted with not less than two single safety valves, or one double safety valve.

7.2.1.3 When an integral superheater forms part of a circulating boiler, as described in **1.1.3**a, 1) and 2), the drum shall be fitted with at least one safety valve.

7.2.1.4 Every superheater shall be fitted with at least one single safety valve positioned on the outlet side. For integral superheaters without an intervening stop valve, such valve(s) shall be included as part of the boiler complement required by **7.2.1.2** and **7.2.1.3**.

7.2.1.5 Every reheater shall be fitted with at least two safety valves, at least one of which shall be positioned on the outlet side.

7.2.1.6 Economizers, which may be separated from the boiler by a shut-off valve, shall be fitted with at least one safety valve.

7.2.1.7 To prevent the unnecessary lifting of safety valves, there shall be a margin between the actual pressure at which the boiler generates and delivers steam and the lowest pressure at which any of the safety valves are set to lift.

7.2.2 Discharge capacity

7.2.2.1 The total discharge capacity, calculated in accordance with BS 6759 : Part 1, of all the safety valves mounted on a boiler, including any integral superheater without an intervening stop valve, shall be at least equal to the maximum evaporation rate of the boiler.

7.2.2.2 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 maximum permissible working pressure.

7.2.2.3 Boilers with superheaters shall have the following safety valve capacity.

a) Superheaters shall be fitted with safety valve(s) having a capacity of not less than 20 % of the aggregate maximum evaporation rate of the boiler or boilers supplying steam to them.

b) When integral superheaters form part of circulating type boilers as described in **1.1.3**a, 1) and 2), the safety valves fitted on the boiler drum shall have a capacity of not less than 75 % of the maximum evaporation rate of the boiler.

c) Independently fired superheaters constructed for a maximum permissible working pressure lower than any of the boilers in which the steam they receive is generated, shall be fitted with safety valve(s) having a discharge capacity, calculated in accordance with **7.2.2.1**, of not less than the maximum evaporation rate of the supplying boilers.

7.2.2.4 Reheaters shall be fitted with safety valves having a total discharge capacity, calculated in accordance with **7.2.2.1**, of not less than the maximum steam flow for which the reheater is designed. The safety valve(s) fitted on the outlet side shall have a capacity not less than 20 % of the maximum steam flow for which the reheater is designed.

7.2.3 Installation of safety valves

7.2.3.1 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.

7.2.3.2 The cross-sectional area of the bore of each branch or pad shall at least be 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.

7.2.3.3 The pressure drop in the inlet branch shall not exceed 3 % of the set pressure or one-third of the maximum allowable blowdown permitted by BS 6759 : Part 1, whichever is smaller at certified or rated capacity.

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 of appendix B of BS 6759 : Part 1 : 1984.

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

7.2.4 Drainage and discharge piping

For each safety valve fitted with discharge piping an individual unrestricted drain shall be provided from the drainage connection on the valve. 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 safety valve discharge piping.

7.3 Water level gauges

7.3.1 Each steam boiler, in which a low level, or into which a low flow rate, of water could lead to unsafe conditions, shall have at least two independent and suitable means of indicating the water level or flow. Each indicating device shall be capable of being isolated from the boiler and each device shall be a water level gauge in which the water level can be observed except in the following cases.

a) For once through boilers, suitable water flow or temperature indicators connected to alarms which sound when the flow falls to a predetermined value shall be permitted in place of water level gauges.

b) For boilers with any safety valve set at or above 60 bar *g*, the use of two independent manometric remote water level indicators shall be permitted in place of one of the water level gauges. In such cases these remote water level indicators shall have their own independent connections to the boiler.

c) For boilers of less than 145 kg/h evaporative capacity, one water level gauge is sufficient.

d) The use of alternative devices in place of water level gauges in which the water level can be observed shall be permitted, subject to agreement between the manufacturer and the Inspecting Authority. The design of the devices shall combine appropriate design principles such as fail-safe modes, redundancy, diversity and self-diagnosis in order to provide suitable and reliable indication.

7.3.2 The water level gauge in which the water level can be observed, shall be mounted so that the lowest water level that can be observed is at least 50 mm above the lowest water level at which there will be no danger of overheating any part of the boiler, when in operation at that level. Where this is not practicable, the water level gauges shall be sited by agreement with the Inspecting Authority in positions that have been found by experience to indicate satisfactorily that the water content is sufficient for safety under all service conditions.

7.3.3 At least one water level gauge with its isolating valves or cocks shall be connected directly to the boiler, 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.

7.4 Water level or low water flow alarms

Every steam boiler shall be provided with a low water level or a low water flow audible alarm device.

Water level alarms, whether of low water or high and low water type, shall be so fitted that the alarm is actuated while the water level is still visible or indicated in the water level gauges.

7.5 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 not be 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.

7.6 Pressure gauges

At least one pressure gauge of the bourdon-tube type shall be fitted to each boiler.

7.7 Boiler feedwater valves

7.7.1 Each boiler shall be fitted with:

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

b) a globe stop and check valve.

7.7.2 Further to the requirements of **7.7.1**, 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.

7.8 Boiler blowdown and drain mountings

7.8.1 General

Each boiler shall be fitted with blowdown and drain valves or cocks. Cocks shall not be used for pressures over 1.3 N/mm^2.

NOTE. Suitable means should be provided within the boiler design to enable regular water analysis to be safely undertaken in order to ensure the water quality remains within acceptable limits.

7.8.2 Continuous and automatic blowdown mountings

Valves, cocks and mountings required to control the water conditions in a boiler shall be fitted at appropriate positions.

7.8.3 Drains

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

7.8.4 Safety arrangements

7.8.4.1 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 shall 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.

7.8.4.2 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 shall be permissible.

7.8.4.3 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 lead to separate disposal points, such that inadvertent pressurization of the manual blowdown main cannot occur. All such systems shall either be 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, have a globe stop and check valve, capable of being locked in the closed position.

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.'

7.9 Boiler main stop valves

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, with the following exception.

For unit systems where one boiler is connected to one turbine by means of a unit piping arrangement, the requirement for a stop valve in the direct vicinity of the boiler/superheater outlet, may be waived, however in such cases the unit piping and the turbine stop valve shall be designed to withstand the boiler hydrostatic test pressure.

Where two or more boilers are connected to a common header or steam manifold, the steam connection from each boiler shall be fitted either with one stop valve and one globe stop and check valve capable of being locked in the closed position, or with two stop valves, one of which is capable of being locked in the closed position, and one check valve.

NOTE. Additional isolation is necessary as The Pressure Sytems and Transportable Gas Containers Regulations 1989 require periodic thorough examination of boiler fittings and attachments and this includes the boiler main stop valve. This is not possible unless the boiler under examination can be isolated from a common header or manifold.

Annexes

Annex A
Design stresses for British Standard materials

A.1 General

The British Standard materials included in table A.1, which have been revised during or after 1978, specify minimum elevated temperature yield/proof stress values derived, in most cases, in accordance with the procedures specified in BS 3920.

These values show some difference from the properties specified in previous standards, which were based on individual assessment of the data then available. The BS 3920 procedure is essentially empirical and properties derived by it are regarded as characteristic values (to be used for quality control purposes as prescribed in the relevant material standards) rather than as critical properties in the design context. Nevertheless, it is reasonable and convenient to base permissible design stresses directly on these characteristic yield/proof stress values unless this would result in design stresses for which there is no justification in terms of previous experience and current understanding of structural behaviour. This has been done except in a few cases, which are indentified in table A.1, where design stresses based on the simple relationships specified in **2.2.3** and **2.2.4** would have resulted in an unwarranted reduction or increase in the stress levels which have previously been established for the materials in question.

The time-independent design stress criteria may be applied to materials not included in table A.1 provided they conform to **2.1.2.2**. Values of $R_{e(T)}$ for such materials should be verified by tests in accordance with BS EN 10002-5 at the appropriate temperature, unless the values were derived in accordance with BS 3920.

Table A.1 Design stress values (N/mm²)
Plates

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of *f* for design temperature (°C) not exceeding													Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	h	
BS 1501 : Part 1 Carbon steel (semi- or fully-killed)																		
151–, 161–360	360	205	3 to 16	100	86	81		78		77	76	*69*	*60*	*52*	*44*	*36*	100 000	13
(A and B)		195	40	96							*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		185	63	95							*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		175	100	91							*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		170	150	88														
151–, 161–400	400	225	3 to 16	117	97	92		89	88	87	*79*	*69*	*60*	*52*	*44*	*36*	100 000	13
(A and B)		215	40	110					88	*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		205	63	108					88	*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		200	100	105					*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		195	150	102														
151–, 161–430	430	250	3 to 16	128	107	102	100	99	*98*	*88*	*79*	*69*	*60*	*52*	*44*	*36*	100 000	13
(A and B)		240	40	121				99	*93*	*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		230	63	119				99	*90*	*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		220	100	115				*97*	*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		210	150	110														

Table A.1 Design stress values (N/mm^2) *(continued)*

Plates

Type-grade and method of manufacture	R_m N/mm^2	R_e N/mm^2	Thickness mm	Values of *f* for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 1501 : Part 1 Carbon steel (fully-killed aluminium treated)																		
164–360A	360	255	3 to 16	97	86	79		73	73	72	71	*69*	*60*	*52*	*44*	*36*	100 000	10
		235	40								71	*65*	*56*	*48*	*40*	*32*	150 000	
		220	63								*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		202	100								*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		180	150															
164–360B	360	255	3 to 16	107	95	87		83	82	81	*79*	*69*	*60*	*52*	*44*	*36*	100 000	10
		235	40							81	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		220	63							*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		202	100							*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		180	150															
164–400A	400	275	3 to 16	111	98	91		86	85	84	*79*	*69*	*60*	*52*	*44*	*36*	100 000	10
		265	40							*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		245	63							*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		225	100							*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		201	150															
164–400B	400	275	3 to 16	121	108	101		95	94	*88*	*79*	*69*	*60*	*52*	*44*	*36*	100 000	10
		265	40						*93*	*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
		245	63						*90*	*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
		225	100						*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
		201	150															

Table A.1 Design stress values (N/mm^2) *(continued)*

Plates

Type–grade and method of manufacture	R_m N/mm^2	R_e N/mm^2	Thickness mm	Values of *f* for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 1501 : Part 1 Carbon manganese steel (fully-killed niobium treated)																		
223–460A	460	340	3 to 16	143	130	124	117	115	114	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		330	40					115	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		320	63					115	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		294	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		262	150															
223–460B	460	340	3 to 16	158	139	131	125	124	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		330	40					124	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		320	63					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		294	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		262	150															
223–490A	490	355	3 to 16	158	139	131	125	124	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		345	40					124	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		340	63					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		313	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		279	150															
223–490B	490	355	3 to 16	168	147	137	133	132	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		345	40					*128*	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		340	63					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		313	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		279	150															

Table A.1 Design stress values (N/mm^2) *(continued)*

Plates

Type–grade and method of manufacture	R_m N/mm^2	R_e N/mm^2	Thickness mm	Values of f for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 1501 : Part 1 Carbon manganese steel (fully-killed aluminium treated)																		
224–400A	400	275	3 to 16	111	98	91		86	85	84	83	*77*	*65*	*56*	*48*	*42*	100 000	10
		265	40							84	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		245	63							84	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		225	100							*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		201	150															
224–400B	400	275	3 to 16	121	108	101		95	94	93	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		265	40							93	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		245	63							*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		225	100							*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		201	150															
224–430A	430	305	3 to 16	121	108	101		95	94	93	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		285	40							93	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		275	63							*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		253	100							*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		225	150															
224–430B	430	305	3 to 16	132	117	111		105	104	103	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		285	40						104	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		275	63						*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		253	100						*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		225	150															
224–460A	460	325	3 to 16	132	117	111		105	104	103	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		315	40						104	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		305	63						*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		281	100						*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		250	150															

Table A.1 Design stress values (N/mm^2) *(continued)*

Plates

Type–grade and method of manufacture	R_m N/mm^2	R_e N/mm^2	Thickness mm	Values of f for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 1501 : Part 1 Carbon manganese steel (fully-killed aluminium treated)																		
224–460B	460	325	3 to 16	142	128	121	116	115	114	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		315	40					115	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		305	63					115	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		281	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		250	150															
224–490 (A and B)	490	325	3 to 16	142	128	121	116	115	114	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		315	40					115	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		305	63					115	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		281	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		250	150															
BS 1501 : Part 1 Carbon manganese steel (fully-killed niobium and aluminium treated)																		
225–490A	490	355	3 to 16	158	139	131	125	124	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		345	40					124	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		340	63					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		313	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		279	150															
225–490B	490	355	3 to 16	168	147	137	133	132	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	10
		345	40					*128*	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		340	63					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
		313	100					*115*	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
		279	150															

Table A.1 Design stress values (N/mm²) *(continued)*
Plates

Type–grade and method of manufacture	R_m N/mm²	R_e N/mm²	Thickness mm	250	300	350	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	Design lifetime h	Notes
BS 1501 : Part 2 Low alloy steel																								
271 MnCrMoV	640	500	Up to 25	237	237	237	234					231	209	181	155	129	107	87	69	54	41	30	100 000	13
												229	202	173	145	118	95	76	60	44	32	23	150 000	
												221	192	160	132	108	87	68	51	38	26	18	200 000	
												216	188	157	129	105	83	65	48	35	23	14	250 000	
	610	460	75	226	226	226	221					219	209	181	155	129	107	87	69	54	41	30	100 000	13
												219	202	173	145	118	95	76	60	44	32	23	150 000	
												219	192	160	132	108	87	68	51	38	26	18	200 000	
												216	188	157	129	105	83	65	48	35	23	14	250 000	
	590	420	150	219	207	201	195					193	190	181	155	129	107	87	69	54	41	30	100 000	13
													190	173	145	118	95	76	60	44	32	23	150 000	
													190	160	132	108	87	68	51	38	26	18	200 000	
													188	157	129	105	83	65	48	35	23	14	250 000	
281 NiCrMoV	640	500	Up to 25	237	237	237	234	233	233	226	209	188	168	145	124	103	85	69	55	44	33	24	100 000	13
								233	232	218	202	182	158	135	112	93	77	62	47	35	26		150 000	
								233	226	213	196	177	152	128	105	87	69	55	40	31	22		200 000	
								232	222	207	191	172	147	123	98	82	65	50	35	27			250 000	
	610	460	75	226	226	226	221			220	209	188	168	145	124	103	85	69	55	44	33	24	100 000	13
										218	202	182	158	135	112	93	77	62	47	35	26		150 000	
										213	196	177	152	128	105	87	69	55	40	31	22		200 000	
										207	191	172	147	123	98	82	65	50	35	27			250 000	
	590	430	150	219	207	201	195				193	188	168	145	124	103	85	69	55	44	33	24	100 000	13
											193	182	158	135	112	93	77	62	47	35	26		150 000	
											193	177	152	128	105	87	69	55	40	31	22		200 000	
											191	172	147	123	98	82	65	50	35	27			250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Plates

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of *f* for design temperature (°C) not exceeding																	Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**400**	**450**	**460**	**470**	**480**	**490**	**500**	**510**	**520**	**530**	**540**	**550**	**560**	**570**	h	
BS 1501 : Part 2 Low alloy steel																						
620 A 1Cr½Mo	480	340	Up to 75	154	143	134	132	129		127												10
	450	280	100	136	121	113	110	108			106											
	430	255	150	125	108	99	96	94				92										
620 B 1Cr½Mo	480	340	Up to 75	165	152	143	141	137		136	135	134	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	10
											135	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
											135	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
											131	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	
	450	280	100	145	129	121	117	115			113	112	111	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	10
												112	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
												112	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
												107	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	
	430	255	150	133	115	105	103	100				98	97	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	10
													97	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
													94	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
													88	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	
621 A 1¼Cr½Mo	515	340	Up to 75	175	166	159	157	153	152													13
	500	320	100	166	156	149	146	143		141												
	490	310	150	160	149	142	139	136		134												
621 B 1¼Cr½Mo	515	340	Up to 75	187	177	170	167	163	162	161	160	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	13
										161	*149*	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
										161	*138*	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
										155	*131*	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	
	500	320	100	177	167	159	156	152		150	149	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	13
											149	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
											138	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
											131	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	
	490	310	150	171	159	151	148	145		142	142	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*	100 000	13
											142	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*	150 000	
											138	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*	200 000	
											131	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Plates

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of *f* for design temperature (°C) not exceeding																							Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**360**	**370**	**380**	**390**	**400**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	**510**	**520**	**530**	**540**	**550**	**560**	**570**	**580**	h	
BS 1501 : Part 2 Low alloy steel																												
622-515 A	515	310	Up to 100	166	163	158					153	146																10
2¼Cr1Mo	500	285	150	155	151	147					143		134															
622-515 B	515	310	Up to 100	177	173	168					163	156	154	152	*143*	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*	100 000	2, 4, 10
2¼Cr1Mo													154	*148*	*135*	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*	150 000	
													154	*143*	*130*	*117*	*104*	*92*	*79*	*68*	*69*	*52*	*45*	*38*	*33*	*28*	200 000	
													152	*139*	*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*	250 000	
	500	285	Up to 150	165	161	157					153		143	141	139	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*	100 000	10
														141	*135*	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*	150 000	
														141	*130*	*117*	*104*	*92*	*79*	*68*	*69*	*52*	*45*	*38*	*33*	*28*	200 000	
														139	*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*	250 000	
622-690 A 2¼Cr1Mo	690	555	Up to 50	256	256	256	256																					10
622-690 B	690	555	Up to 50	256	256	256	256	256	256	*248*	*235*		*170*	*157*	*143*	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*	100 000	4, 10
2¼Cr1Mo								256	*251*	*238*	*225*		*161*	*148*	*135*	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*	150 000	
								256	*247*	*234*	*221*		*156*	*143*	*130*	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*	200 000	
								255	*242*	*229*	*216*		*152*	*139*	*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Plates

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of f for design temperature (°C) not exceeding																					Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**400**	**450**	**500**	**520**	**540**	**550**	**560**	**580**	**600**	**620**	**640**	**650**	**660**	**680**	**700**	**720**	**740**	**750**	h	
BS 1501 : Part 3 Austenitic stainless steel																										
304S51	490	230	Up to and including 100	103	98	93	89	87	85			83	82	82	*76*	*65*	*55*	*50*	*45*	*38*	*33*	*28*			100 000	
														82	*72*	*61*	*51*	*46*	*42*	*36*	*31*				150 000	
														81	*69*	*58*	*48*	*44*	*40*	*34*	*30*				200 000	
														78	*66*	*55*	*46*	*42*	*38*	*33*	*29*				250 000	
321S31	510	235	Up to and including 100	121	117	113	110	107	104	103	103	102	102	*86*	*71*	*57*	*42*	*36*	*31*						100 000	8
											103	*101*	*93*	*78*	*64*	*49*	*36*	*32*	*27*						150 000	
											103	*97*	*89*	*74*	*58*	*45*	*33*	*28*	*25*						200 000	
											100	*93*	*85*	*71*	*55*	*42*	*31*	*26*	*22*						250 000	
321S51	490	210	Up to and including 100	104	99	96	93	90	87			86	86	85	*82*	*68*	*55*	*49*	*44*	*34*	*26*				100 000	
														85	*76*	*62*	*50*	*44*	*38*	*29*					150 000	
														85	*72*	*58*	*46*	*41*	*35*	*27*					200 000	
														84	*68*	*55*	*44*	*38*	*33*	*25*					250 000	
347SS1	510	240	Up to and including 100	127	123	120	118	116	115		114	113	113	*99*	*82*	*66*	*53*	*47*	*41*	*31*	*23*				100 000	
												113	*112*	*93*	*75*	*61*	*48*	*42*	*37*	*28*	*22*				150 000	
												113	*106*	*88*	*72*	*58*	*45*	*39*	*34*	*25*	*19*				200 000	
												112	*102*	*85*	*68*	*55*	*42*	*37*	*32*	*24*	*19*				250 000	
316S51, S53	510	240	Up to and including 100	111	106	101	99	96	93			90		89	88	*74*	*58*	*53*	*46*	*35*	*28*	*23*			100 000	4
															85	*66*	*52*	*46*	*41*	*32*	*25*	*19*			150 000	
															79	*62*	*48*	*43*	*38*	*29*	*22*	*18*			200 000	
															75	*58*	*45*	*40*	*35*	*27*	*22*	*18*			250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Sections and bars

Type–grade	R_m	R_e	Nominal diameter/thickness (values in parenthesis apply to sections and flat bars)		Values of *f* for design temperature (°C) not exceeding														Design lifetime	Notes
			Over	Up to and including	250	300	350	400	410	420	430	440	450	460	470	480	490	500		
	N/mm²	N/mm²	mm	mm															h	
BS 1502 Carbon steel (semi- or fully-killed)																				
151, 161	430	250	—	25 (16)	128	107	102	99	*98*	*88*	*79*	*69*	*60*	*52*	*44*	*36*	*28*		100 000	
		240	25 (16)	63 (40)	121			99	*93*	*83*	*74*	*65*	*56*	*48*	*40*	*32*	*22*		150 000	
		230	63 (40)	100 (63)	119			99	*90*	*80*	*71*	*62*	*53*	*45*	*37*	*28*	*18*		200 000	
		220	100 (63)	160 (100)	115			*97*	*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*			250 000	
BS 1502 Carbon manganese steel (semi- or fully-killed)																				
211, 221	430	250	—	25 (16)	128	107	102	99	98	97	*90*	*77*	*65*	*56*	*48*	*42*	*36*	*32*	100 000	
		240	25 (16)	63 (40)	121					*95*	*81*	*68*	*58*	*50*	*43*	*38*	*32*	*26*	150 000	
		230	63 (40)	100 (63)	119					*88*	*75*	*63*	*54*	*46*	*40*	*34*	*28*		200 000	
		220	100 (63)	160 (100)	115					*83*	*70*	*59*	*51*	*43*	*37*	*32*	*25*		250 000	
BS 1502 Carbon manganese steel (fully-killed aluminium treated)																				
224–430	430	275	—	25 (16)	121	108	101	95	94	93	*90*	*77*	*65*	*56*	*48*	*42*	*36*	*32*	100 000	
		265	25 (16)	63 (40)						93	*81*	*68*	*58*	*50*	*43*	*38*	*32*	*26*	150 000	
		245	63 (40)	100 (63)						*88*	*75*	*63*	*54*	*46*	*40*	*34*	*28*		200 000	
		240	100 (63)	160 (100)						*83*	*70*	*59*	*51*	*43*	*37*	*32*	*25*		250 000	
224–490	490	325	—	25 (16)	142	128	121	115	114	*105*	*90*	*77*	*65*	*56*	*48*	*42*	*36*	*32*	100 000	
		315	25 (16)	63 (40)					*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	*32*	*26*	150 000	
		305	63 (40)	100 (63)					*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	*28*		200 000	
		300	100 (63)	160 (100)					*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	*25*		250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Sections and bars

Type–grade	R_m N/mm^2	R_e N/mm^2	Limiting ruling section mm	Values of f for design temperature (°C) not exceeding 250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	Design lifetime h	Notes
BS 1502 Low alloy steel																										
271	560	370	160	208	204	199	192		188	186	*181*	*155*	*129*	*107*	*87*	*69*	*54*	*41*	*30*						100 000	7
											173	*145*	*118*	*95*	*76*	*60*	*44*	*32*	*23*						150 000	
											160	*132*	*108*	*87*	*68*	*51*	*38*	*26*	*18*						200 000	
											157	*129*	*105*	*83*	*65*	*48*	*35*	*23*	*14*						250 000	
620–440	440	265	160	139	123	113	109		107				105	104	*93*	*76*	*62*	*52*	*42*	*33*	*27*				100 000	7
														102	*83*	*67*	*55*	*44*	*35*	*29*	*24*				150 000	
														94	*76*	*61*	*49*	*40*	*32*	*26*	*22*				200 000	
														88	*70*	*57*	*45*	*37*	*30*	*25*	*20*				250 000	
620–470	470	300	160	159	144	136	133		130			128	127	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*				100 000	7
													124	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*				150 000	
													114	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*				200 000	
													107	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*				250 000	
620–540	540	375	160	200	196	189	186		182	181	180	*162*	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*				100 000	7
										181	*174*	*149*	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*				150 000	
										181	*162*	*138*	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*				200 000	
										179	*155*	*131*	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*				250 000	
622	490	275	160	157	153	149	145		137	135	132	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*	*29*	*26*	100 000	2, 4, 7
											132	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*	*27*	*23*	150 000	
											130	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*	*25*	*22*	200 000	
											126	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*	*23*	*20*	250 000	
629–590	590	400	160	219	217	215	211	208	207	*195*	*176*	*159*	*144*	*129*	*115*	*103*	*91*	*80*	*68*	*58*	*48*	*38*	*31*	*26*	100 000	
									207	*188*	*169*	*152*	*137*	*123*	*110*	*97*	*85*	*74*	*62*	*52*	*42*	*34*	*28*	*23*	150 000	
									204	*183*	*165*	*148*	*132*	*118*	*105*	*93*	*81*	*69*	*58*	*48*	*38*	*31*	*25*	*22*	200 000	
									199	*179*	*161*	*144*	*129*	*115*	*102*	*89*	*78*	*66*	*55*	*45*	*35*	*28*	*24*	*21*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Sections and bars

Type–grade	R_m	R_e	Limiting ruling section	Values of *f* for design temperature (°C) not exceeding																						Design lifetime	Notes
				250	**300**	**350**	**400**	**450**	**500**	**540**	**550**	**560**	**570**	**580**	**590**	**600**	**620**	**640**	**650**	**660**	**680**	**700**	**720**	**740**	**750**		
	N/mm²	N/mm²	mm																							h	
BS 1502 Austenitic stainless steel																											
304S51	490	230	160	103	98	93	89	87	85		83		82	82	81	*76*	*65*	*55*	*50*	*45*	*38*	*33*	*28*			100 000	
														82	*78*	*72*	*61*	*51*	*46*	*42*	*36*	*31*				150 000	
														81	*75*	*69*	*58*	*48*	*44*	*40*	*34*	*30*				200 000	
														78	*72*	*66*	*55*	*46*	*42*	*38*	*33*	*29*				250 000	
316S51	510	240	160	111	106	101	99	96	93		90			89	88	88	*74*	*58*	*53*	*46*	*35*	*28*	*23*	*19*	*18*	100 000	4
															88	*85*	*66*	*52*	*46*	*41*	*32*	*25*	*19*	*16*		150 000	
															88	*79*	*62*	*48*	*43*	*38*	*29*	*22*	*18*	*15*		200 000	
															85	*75*	*58*	*45*	*40*	*35*	*27*	*22*	*18*	*15*		250 000	
321S51–490	490	190	160	93	87	84	81	79	78		77				76	76	*68*	*55*	*49*	*44*	*34*	*26*				100 000	
																76	*62*	*50*	*44*	*38*	*29*					150 000	
																72	*58*	*46*	*41*	*35*	*27*					200 000	
																68	*55*	*44*	*38*	*33*	*25*					250 000	
321S51–510	510	235	160	121	117	113	110	107	104	103	102	102	*95*	*86*	*78*	*71*	*57*	*42*	*36*	*31*	*24*	*18*				100 000	
										103	*101*	*93*	*86*	*78*	*72*	*64*	*49*	*36*	*32*	*27*						150 000	
										103	*97*	*89*	*82*	*74*	*66*	*58*	*45*	*33*	*28*	*25*						200 000	
										100	*93*	*85*	*78*	*71*	*62*	*55*	*42*	*31*	*26*	*22*						250 000	
347S51	510	240	160	127	123	120	118	116	115	114	113	113	*109*	*99*	*91*	*82*	*66*	*53*	*47*	*41*	*31*	*23*	*17*			100 000	
											113	*112*	*102*	*93*	*84*	*75*	*61*	*48*	*42*	*37*	*28*	*22*				150 000	
											113	*106*	*98*	*88*	*79*	*72*	*58*	*45*	*39*	*34*	*25*	*19*				200 000	
											112	*102*	*94*	*85*	*76*	*68*	*55*	*42*	*37*	*32*	*24*	*19*				250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Forgings

Type–grade and method of manufacture	R_m	R_e	Ruling section (see note d))	Values of *f* for design temperature (°C) not exceeding													Design lifetime	Notes
	N/mm^2	N/mm^2	mm	250	300	350	390	400	410	420	430	440	450	460	470	480	h	
BS 1503 Carbon manganese steel (fully-killed)																		
164	490	305	≤ 100	142	128	121	116	115	114	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		280	> 100 ≤ 150	137					*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									104	*98*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
221–410	410	215	≤ 100	112	100	95		92		92	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		205	> 100	108						92	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
										88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
										83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
221–430	430	225	≤ 100	119	107	102		99	99	98	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		215	> 100	115					99	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									99	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
221–460	460	245	≤ 100	129	117	112		108	108	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		235	> 100	125					108	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									104	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
221–490	490	265	≤ 100	140	128	122	119	118	118	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		255	> 100	135				118	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								118	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
221–510	510	285	≤ 100	147	135	129	125	124	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
								124	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Forgings

Type–grade and method of manufacture	R_m	R_e	Ruling section (see note d))	Values of f for design temperature (°C) not exceeding													Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	h	
BS 1503 Carbon manganese steel (fully-killed)																		
223–410	410	245	≤ 100	120	106	99		92		91	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		230	> 100	115						91	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
										88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
										83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
223–430	430	260	≤ 100	128	114	107		100	99	98	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		245	> 100	123						*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
										88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
										83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
223–460	460	290	≤ 100	140	127	119		111	110	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		270	> 100	135					110	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									104	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
223–490	490	320	≤ 100	152	139	131	125	123	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		295	> 100	146				123	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
223–510	510	340	≤ 100	159	147	138	132	131	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
								128	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
224–410	410	235	≤ 100	114	101	94		89	88	88	88	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		220	> 100	109						88	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
										88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
										83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Forgings

Type–grade and method of manufacture	R_m	R_e	Ruling section (see note d))	Values of *f* for design temperature (°C) not exceeding													Design lifetime	Notes
	N/mm²	N/mm²	mm	250	300	350	390	400	410	420	430	440	450	460	470	480	h	
BS 1503 Carbon manganese steel (fully-killed)																		
224–430	430	250	≤ 100	121	108	101		96	95	95	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		235	> 100	117						*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
										88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
										83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
224–460	460	275	≤ 100	132	118	111		105	105	104	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		255	> 100	127					105	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									104	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
224–490	490	305	≤ 100	142	128	121	116	115	115	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		280	> 100	137				115	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								115	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
224–510	510	315	≤ 100	149	135	128	124	122	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
								122	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
225–490	490	340	≤ 100	160	147	137	131	130	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	1a), 7
		300	> 100	154	145			*128*	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
								121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Forgings

Type–grade and method of manufacture	R_m	R_e	Ruling section (see note d))	Values of *f* for design temperature (°C) not exceeding																										Design lifetime	Notes
				250	300	350	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620		
	N/mm²	N/mm²	mm																											h	
BS 1503 Ferritic alloy steel																															
620–440 1Cr½Mo	440	275		131	123	113	108					105				101	101	*93*	*76*	*62*	*52*	*42*	*33*	*27*						100 000	1a), 7
																	101	*83*	*67*	*55*	*44*	*35*	*29*	*24*						150 000	
																	94	*76*	*61*	*49*	*40*	*32*	*26*	*22*						200 000	
																	88	*70*	*57*	*45*	*37*	*30*	*25*	*20*						250 000	
620–540 1Cr½Mo	540	375	≤ 200	200	196	189	186					182	181	180	*162*	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*						100 000	1a), 7
													181	*174*	*149*	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*						150 000	
													181	*162*	*138*	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*						200 000	
													179	*155*	*131*	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*						250 000	
621–460 1¼Cr½Mo	460	275		145	137	127	122					117			115	114	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*						100 000	1a), 7
																114	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*						150 000	
																114	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*						200 000	
																107	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*						250 000	
660–460 CrMoV	460	300		161	150	144	139					135				134	133	*131*	*115*	*100*	*87*	*76*	*66*	*56*						100 000	1a), 7
																	133	*122*	*106*	*92*	*80*	*69*	*59*	*47*						150 000	
																	132	*115*	*100*	*87*	*75*	*65*	*55*							200 000	
																	128	*111*	*96*	*83*	*72*	*62*	*50*							250 000	
271–560 MnCrMoV	560	370		208	204	199	192					188	186	*181*	*155*	*129*	*107*	*87*	*69*	*54*	*41*	*30*								100 000	1a), 7
														173	*145*	*118*	*95*	*76*	*60*	*44*	*32*	*23*								150 000	
														160	*132*	*108*	*87*	*68*	*51*	*38*	*26*	*18*								200 000	
														157	*129*	*105*	*83*	*65*	*48*	*35*	*23*	*14*								250 000	
622–490 2¼Cr1Mo	490	275		157	153	149	145					137	135	132	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*					100 000	1a), 4, 7
														132	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*					150 000	
														130	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*					200 000	
														126	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*					250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Forgings

Type–grade and method of manufacture	R_m	R_e	**Ruling section (see note d))**	**Values of *f* for design temperature (°C) not exceeding**																										**Design lifetime**	**Notes**
	N/mm^2	N/mm^2	mm	**250**	**300**	**350**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	**510**	**520**	**530**	**540**	**550**	**560**	**570**	**580**	**590**	**600**	**610**	**620**	h	
BS 1503 Ferritic alloy steel																															
622–560 2¼Cr1Mo	560	370		207	207	201	197	196	195	194	*183*	*170*	*157*	*143*	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*					100 000	1a), 4, 7
									195	*186*	*173*	*161*	*148*	*135*	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*					150 000	
									195	*182*	*169*	*156*	*143*	*130*	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*					200 000	
									190	*178*	*165*	*152*	*139*	*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*					250 000	
91 9CrMoVNbN S1, S2	630	450		233	233	229	221					207	204	201	198	194	*190*	*176*	*163*	*149*	*137*	*125*	*112*	*102*	*91*	*81*	*72*	*64*	*57*	100 000	
																194	*185*	*171*	*158*	*145*	*132*	*119*	*108*	*97*	*86*	*77*	*68*	*60*	*53*	150 000	
																194	*182*	*168*	*154*	*141*	*128*	*110*	*105*	*93*	*83*	*74*	*65*	*58*	*52*	200 000	
																192	*178*	*165*	*152*	*138*	*125*	*113*	*102*	*91*	*81*	*72*	*64*	*56*	*49*	250 000	
762–690 12Cr1Mo 0.3Va	690	480	≤ 250	240	233	227	219					*206*				190	187	*173*	*155*	*138*	*122*	*107*	*93*	*80*	*68*	*58*	*48*	*40*	*33*	100 000	1a), 7
																	184	*168*	*152*	*135*	*115*	*98*	*85*	*72*	*62*	*52*	*44*	*37*	*30*	150 000	
																	180	*164*	*146*	*128*	*110*	*94*	*80*	*68*	*58*	*40*	*41*	*34*	*28*	200 000	
																	176	*160*	*142*	*124*	*105*	*90*	*77*	*65*	*55*	*46*	*38*	*32*	*25*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Forgings

Type–grade and method of manufacture	R_m N/mm²	R_e N/mm²	Ruling section (see note d)) mm	Values of *f* for design temperature (°C) not exceeding 250	300	350	400	450	500	520	540	550	560	580	590	600	620	640	650	660	680	700	720	740	Design lifetime h	Notes
BS 1503 Austenitic stainless steel																										
304S51	490	230		103	98	93	89	87	85			83	82	82	81	*76*	*65*	*55*	*50*	*45*	*38*	*33*	*28*		100 000	1a)
														82	*78*	*72*	*61*	*51*	*46*	*42*	*36*	*31*			150 000	
														81	*75*	*69*	*58*	*48*	*44*	*40*	*34*	*30*			200 000	
														78	*72*	*66*	*55*	*46*	*42*	*38*	*33*	*29*			250 000	
316S51	510	240		111	106	101	99	96	93			90		89	88	88	*74*	*58*	*53*	*46*	*35*	*28*	*23*		100 000	1a), 4
															88	*85*	*66*	*52*	*46*	*41*	*32*	*25*	*19*		150 000	
															88	*79*	*62*	*48*	*43*	*38*	*29*	*22*	*18*		200 000	
															85	*75*	*58*	*45*	*40*	*35*	*27*	*22*	*18*		250 000	
321S51–490	490	190		93	87	84	81	79	78			77		76	76	76	*68*	*55*	*49*	*44*	*34*	*26*			100 000	1a)
															76	76	*62*	*50*	*44*	*38*	*29*				150 000	
															76	*72*	*58*	*46*	*41*	*35*	*27*				200 000	
															76	*68*	*55*	*44*	*38*	*33*	*25*				250 000	
321S51–510	510	235		121	117	113	110	107	104		103	102	102	*86*		*71*	*57*	*42*	*36*	*31*					100 000	1a)
											103	*101*	*93*	*78*		*64*	*49*	*36*	*32*	*27*					150 000	
											103	*97*	*89*	*74*		*58*	*45*	*33*	*28*	*25*					200 000	
											100	*93*	*85*	*71*		*55*	*42*	*31*	*26*	*22*					250 000	
347S51	510	240		127	123	120	118	116	115		114	113	113	*99*		*82*	*66*	*53*	*47*	*41*	*31*	*23*			100 000	1a)
												113	*112*	*93*		*75*	*62*	*48*	*42*	*37*	*28*	*22*			150 000	
												113	*106*	*88*		*72*	*58*	*45*	*39*	*34*	*25*	*19*			200 000	
												112	*102*	*85*		*68*	*55*	*42*	*37*	*32*	*24*	*19*			250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Castings

Type–grade and method of manufacture	R_m N/mm^2	R_e N/mm^2	Thickness mm	Values of f for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 1504 Carbon steel																		
161–430A	430	230		115	104	95		87										1b), 1c)
161–430E	430	230		115	104	95		93	93	92	*84*	*71*	*60*	*51*	*44*	*37*	100 000	1b)
									93	*89*	*75*	*63*	*54*	*46*	*38*	*30*	150 000	
									92	*82*	*69*	*58*	*49*	*42*	*34*		200 000	
									88	*78*	*65*	*54*	*46*	*38*			250 000	
161–480A	480	245		128	115	105	101											1b), 1c)
161–480E	480	245		128	115	109	107	107	106	*99*	*84*	*71*	*60*	*51*	*44*	*37*	100 000	1b)
								107	*100*	*89*	*75*	*63*	*54*	*46*	*38*	*30*	150 000	
								103	*92*	*82*	*69*	*58*	*49*	*42*	*34*		200 000	
								99	*88*	*78*	*65*	*54*	*46*	*38*			250 000	
161–540A	540	280		144	130	119		109										1b), 1c)

Table A.1 Design stress values (N/mm^2) *(continued)*
Castings

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of *f* for design temperature (°C) not exceeding																			Design lifetime	Notes
				250	**300**	**350**	**400**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	**510**	**520**	**530**	**540**	**550**	**560**	**570**	**590**		
	N/mm^2	N/mm^2	mm																				h	
BS 1504 Low alloy steel																								
245E ½Mo	460	260		140	121	116	113		110		109	108	*95*	*78*	*62*	*51*	*41*	*32*					100 000	1b)
												107	*88*	*70*	*57*	*46*	*37*	*30*					150 000	
												100	*81*	*65*	*53*	*42*	*35*	*28*					200 000	
												95	*77*	*62*	*50*	*40*	*32*	*25*					250 000	
621A 1¼CrMo	480	280		141	136	123	114		108															1b), 1c)
660A CrMoV	510	295		145	137	128	118		112					106										1b), 1c)
622E 2¼CrMo	540	325		197	193	187	182	174	*170*	*153*	*137*	*120*	*107*	*95*	*85*	*76*	*65*	*61*	*53*	*45*	*39*	*34*	100 000	1b), 4
								174	*161*	*144*	*129*	*112*	*98*	*88*	*77*	*68*	*63*	*56*	*48*	*41*	*36*	*31*	150 000	
								172	*156*	*139*	*124*	*107*	*94*	*83*	*71*	*63*	*59*	*52*	*45*	*38*	*33*	*28*	200 000	
								170	*152*	*135*	*119*	*103*	*91*	*79*	*68*	*60*	*57*	*49*	*42*	*36*	*32*	*27*	250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Castings

Type-grade and method of manufacture	R_m	R_e	Thickness	Values of f for design temperature (°C) not exceeding																					Design lifetime	Notes
	N/mm^2	N/mm^2	mm	**250**	**300**	**350**	**400**	**450**	**500**	**520**	**540**	**550**	**560**	**580**	**600**	**620**	**640**	**650**	**660**	**680**	**700**	**720**	**740**	**750**	h	
BS 1504 High alloy steel																										
629A 9Cr1Mo	620	420		184	176	157	144	123	87			55			21											1b)
BS 1504 Austenitic stainless steel																										
304C15A	480	240		108	104	101	99	95	92	90	81	75	68	57	47	38	31	27	23	18					100 000	1b), 8
										90	76	68	62	52	42	33	26	23	20	15					150 000	
										85	72	65	58	48	38	31	24	21	18						200 000	
										82	68	61	56	45	36	28	22	19	17						250 000	
347C17A	480	240		132	128	126	122	119	116	114	113	109	99	82	66	53	41	35	31	22					100 000	1b), 8
											112	102	93	75	61	48	37	32	28	22					150 000	
											106	98	88	72	58	45	34	29	25	19					200 000	
											102	94	85	68	55	42	32	28	24	19					250 000	
316C71	510	260		122	116	110	106	102	96			93	92	91	74	58	46	41	35	28	23				100 000	1b), 8
														85	66	52	41	36	32	25	19				150 000	
														79	62	48	38	33	29	22	18				200 000	
														75	58	45	35	31	27	22	18				250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Steel boiler and superheater tubes

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of f for design temperature (°C) not exceeding													Design lifetime	Notes
	N/mm²	N/mm²	mm	**250**	**300**	**350**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	h	
BS 3059 : Part 1 Carbon steel																		
320 HFS, CFS, ERW and CEW	320	195		86	77	71		68										
BS 3059 : Part 2 Carbon and carbon manganese steel																		
360 S1, S2 ERW and CEW	360	235		111	97	87		78		77	76	*69*	*60*	*52*	*44*	*36*	100 000	
											74	*65*	*56*	*48*	*40*	*32*	150 000	
											71	*62*	*53*	*45*	*37*	*28*	200 000	
											68	*59*	*51*	*42*	*35*	*26*	250 000	
440 S1, S2 ERW and CEW	440	245		134	119	106		101	101	100	*90*	*77*	*65*	*56*	*48*	*42*	100 000	
									101	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
									101	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
									98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Steel boiler and superheater tubes

Type–grade and method of manufacture	R_m N/mm²	R_e N/mm²	Thickness mm	Values of *f* for design temperature (°C) not exceeding: 250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620	630	640	650	660	Design lifetime h	Notes
BS 3059 : Part 2 Alloy steel																																
243 0.3 Mo S1, S2, ERW and CEW	480	275		149	128	120	117		115		113	112	*95*	*78*	*62*	*51*	*41*	*32*													100 000	
												107	*88*	*70*	*57*	*46*	*37*	*30*													150 000	
												100	*81*	*65*	*53*	*42*	*35*	*28*													200 000	
												95	*77*	*62*	*50*	*40*	*32*	*25*													250 000	
620 1Cr½Mo S1, S2, ERW and CEW	460	180		129	129	129	120		116			114	113	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*										100 000	
													113	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*										150 000	
													113	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*										200 000	
													107	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*										250 000	
622–490 2¼Cr1Mo S1, S2	490	275		157	153	149	145		137	135	133	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*	*29*	*26*							100 000	2, 4
											133	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*	*27*	*23*							150 000	
											130	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*	*25*	*22*							200 000	
											126	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*	*23*	*20*							250 000	
629–590 9Cr1Mo S1, S2	590	400		219	217	215	211	208	207	*195*	*176*	*159*	*144*	*129*	*115*	*103*	*91*	*80*	*68*	*58*	*48*	*38*	*31*	*26*							100 000	
									207	*188*	*169*	*152*	*137*	*123*	*110*	*97*	*85*	*74*	*62*	*52*	*42*	*34*	*28*	*23*							150 000	
									204	*183*	*165*	*148*	*132*	*118*	*105*	*93*	*81*	*69*	*58*	*48*	*38*	*31*	*25*	*22*							200 000	
									199	*179*	*161*	*144*	*129*	*115*	*102*	*89*	*78*	*66*	*55*	*45*	*35*	*28*	*24*	*21*							250 000	
91 9CrMoVNbN S1, S2	630	450		233	233	229	221		207	204	201	198	194	*190*	*176*	*163*	*149*	*137*	*125*	*112*	*102*	*91*	*81*	*72*	*64*	*57*	*50*	*44*	*38*	*32*	100 000	
													194	*185*	*171*	*158*	*145*	*132*	*119*	*108*	*97*	*86*	*77*	*68*	*60*	*53*	*47*	*42*	*35*	*28*	150 000	
													194	*182*	*168*	*154*	*141*	*128*	*116*	*105*	*93*	*83*	*74*	*65*	*58*	*52*	*45*	*39*	*33*		200 000	
													192	*178*	*165*	*152*	*138*	*125*	*113*	*102*	*91*	*81*	*72*	*64*	*56*	*49*	*43*	*38*	*32*		250 000	
762 12CrMoV S1, S2	720	470		241	234	230	225		215			205	*201*	*191*	*173*	*155*	*138*	*122*	*107*	*93*	*80*	*68*	*58*	*48*	*40*	*33*					100 000	
													200	*184*	*168*	*152*	*135*	*115*	*98*	*85*	*72*	*62*	*52*	*44*	*37*	*30*					150 000	
													197	*180*	*164*	*146*	*128*	*110*	*94*	*80*	*68*	*58*	*49*	*41*	*34*	*28*					200 000	
													192	*176*	*160*	*142*	*124*	*105*	*90*	*77*	*65*	*55*	*46*	*38*	*32*	*25*					250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Steel boiler and superheater tubes

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of f for design temperature (°C) not exceeding																					Design lifetime	Notes
	N/mm²	N/mm²	mm	250	300	350	400	450	500	540	550	560	570	580	590	600	610	620	630	640	650	660	680	700	h	
BS 3059 : Part 2 Austenitic stainless steel																										
304S51	490	230		101	97	94	91	88	86		83		82	82	81	76	71	65	60	55	50	45	38	33	100 000	
CFS														82	78	72	66	61	55	51	46	42	36	31	150 000	
														81	75	69	63	58	53	48	44	40	34	30	200 000	
														78	72	66	61	55	51	46	42	38	33	29	250 000	
316S51, S52	510	240		111	106	102	98	96	93		90			89	88	88	82	74	66	58	53	46	35	28	100 000	
CFS															88	85	75	66	58	52	46	41	32	25	150 000	4
															88	79	70	62	55	48	43	38	29	22	200 000	
															85	75	66	58	52	45	40	35	27	22	250 000	
321S51 (1010)	510	235		121	117	112	110	107	104	102	102	101	95	86	78	71	63	57	49	42	36				100 000	
CFS											101	93	86	78	72	64	56	49	42	36	32				150 000	
											97	89	82	74	66	58	52	45	38	33	28				200 000	
											93	85	78	71	62	55	48	42	35	31	26				250 000	
321S51 (1105)	490	190		93	87	84	82	79	77		76				75	75	75	68	60	55	49	44	34		100 000	
CFS																75	68	62	56	50	44	38	29		150 000	
																72	65	58	52	46	41	35	27		200 000	
																68	62	55	49	44	38	33	25		250 000	
347S51	510	240		135	130	124	122	119	119	117	117	116	109	99	91	82	74	66	59	53	47	41	31	23	100 000	
CFS											117	112	102	93	84	75	68	61	55	48	42	37	28	22	150 000	
											116	106	98	88	79	72	64	58	51	45	39	34	25	19	200 000	
											112	102	94	85	76	68	61	55	48	42	37	32	24	19	250 000	
215S15	540	270		141	139	136	135	133	132		130					126	125	124	123	107	87	71	52	40	100 000	
CFS																		124	114	93	75	62	46	35	150 000	
																		124	104	83	67	56	42	32	200 000	
																		118	96	76	62	52	40		250 000	

Table A.1 Design stress values (N/mm²) *(continued)*
Steel pipes and tubes for pressure purposes

Type–grade and method of manufacture	R_m N/mm²	R_e N/mm²	Thickness mm	Values of f for design temperature (°C) not exceeding 250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
BS 3601 Seamless and electric resistance or induction welded carbon and carbon manganese steel																		
320																		
ERW	320	195		86	77	71		68										
360																		
S, ERW	360	235	≤ 16															
S		225	> 16 ≤ 40	96	86	79		75										
S		215	> 40 ≤ 65															
430																		
S, ERW	430	275	≤ 16															
S		265	> 16 ≤ 40	115	103	95		89										
S		255	> 40 ≤ 65															
BS 3602 : Part 1 Seamless and electric resistance welded, including induction welded, carbon and carbon manganese steel																		
360																		
HFS, CFS, ERW, CEW	360	235	≤ 16	111	97	87		78		77	76	*69*	*60*	*52*	*44*	*36*	100 000	
											74	*65*	*56*	*48*	*40*	*32*	150 000	
HFS, CFS,		225	> 16 ≤ 40								*71*	*62*	*53*	*45*	*37*	*28*	200 000	
HFS, CFS		215	> 40 ≤ 65								*68*	*59*	*51*	*42*	*35*	*26*	250 000	
430																		
HFS, CFS, ERW, CEW	430	275	≤ 16	120	109	101		95	95	*98*	*79*	*69*	*60*	*52*	*44*	*36*	100 000	
									93	*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
HFS, CFS		265	> 16 ≤ 40						*90*	*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
HFS, CFS		255	> 40 ≤ 65						*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
500-Nb	500	355	≤ 16	163	148	135	127	125	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	
HFS, CFS		345	> 16 ≤ 40					125	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
		325	> 40 ≤ 65					*121*	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
								115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
BS 3602 : Part 2 Longitudinally arc welded carbon and carbon manganese steel																		
430																		
LAW	430	250	≤ 16	120	109	101												6
		240	> 16 ≤ 40															
490																		
LAW	490	325	≤ 16	143	131	121												6
		315	> 16 ≤ 40															

Table A.1 Design stress values (N/mm²) *(continued)*
Steel pipes and tubes for pressure purposes

Type–grade and method of manufacture	R_m N/mm²	R_e N/mm²	Thickness mm	Values of f for design temperature (°C) not exceeding: 250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620	630	640	650	660	Design lifetime h	Notes
BS 3604 : Part 1 Seamless and electric resistance welded alloy steel																																
591 1¼NiCuMoNb HFS, CFS	610	440		226	226	226	226																									9
620–440	440	290		157	128	121	116		112			112	111	111	93	76	62	52	42	33	27										100 000	
1Cr½Mo													111	102	83	67	55	44	35	29	24										150 000	
HFS, CFS													111	94	76	61	49	40	32	26	22										200 000	
ERW and CEW													107	88	70	57	45	37	30	25	20										250 000	
621	420	275		145	116	110	105		101				100	100	93	76	62	52	42	33	27										100 000	
1¼Cr½Mo														100	83	67	55	44	35	29	24										150 000	
HFS, CFS														94	76	61	49	40	32	26	22										200 000	
ERW and CEW														88	70	57	45	37	30	25	20										250 000	
660	460	300		161	150	144	139		135				134	133	131	115	100	87	76	66	56										100 000	
½CrMoV														133	122	106	92	80	69	59	47										150 000	
HFS, CFS														132	115	100	87	75	65	55											200 000	
														128	111	96	83	72	62	50											250 000	
622	490	275		157	153	149	145		137	135	133	131	118	105	94	82	72	61	53	45	39	34	29	26							100 000	2, 4
2¼Cr1Mo											133	122	108	97	85	73	63	56	48	42	36	31	27	23							150 000	
HFS, CFS											130	117	104	92	79	68	59	52	45	38	33	28	25	22							200 000	
											126	113	100	87	75	65	57	49	42	36	32	27	23	20							250 000	
629–590	590	400		219	217	215	211	208	207	195	176	159	144	129	115	103	91	80	68	58	48	38	31	26							100 000	
9Cr1Mo									207	188	169	152	137	123	110	97	85	74	62	52	42	34	28	23							150 000	
HFS, CFS									204	183	165	148	132	118	105	93	81	69	58	48	38	31	25	22							200 000	
									199	179	161	144	129	115	102	89	78	66	55	45	35	28	24	21							250 000	
91	630	450		233	233	229	221		207	204	201	198	194	190	176	163	149	137	125	112	102	91	81	72	64	57	50	44	38	32	100 000	
9CrMoVNbN													194	185	171	158	145	132	119	108	97	86	77	68	60	53	47	42	35	28	150 000	
HFS, CFS													194	182	168	154	141	128	116	105	93	83	74	65	58	52	45	39	33		200 000	
													192	178	165	152	138	125	113	102	91	81	72	64	56	49	43	38	32		250 000	
762	690	490		240	232	227	217		206				191	187	173	155	138	122	107	93	80	68	58	48	40	33					100 000	
12CrMoV														184	168	152	135	115	98	85	72	62	52	44	37	30					150 000	
HFS, CFS														180	164	146	128	110	94	80	68	58	49	41	34	28					200 000	
														176	160	142	124	105	90	77	65	55	46	38	32	25					250 000	

Table A.1 Design stress values (N/mm^2) *(continued)*
Steel pipes and tubes for pressure purposes

Type–grade and method of manufacture	R_m	R_e	Thickness	Values of *f* for design temperature (°C) not exceeding																						Design lifetime	Notes
	N/mm^2	N/mm^2	mm	250	300	350	400	450	500	520	540	550	560	580	600	620	630	640	650	660	680	700	720	740	750	h	
BS 3605 Seamless and austenitic stainless steel																											
304S51	490	230		101	97	94	91	88	86			83	82	82	*76*	*65*	*60*	*55*	*50*	*45*	*38*	*33*	*28*			100 000	
HFS, CFS,														82	*72*	*61*	*55*	*51*	*46*	*42*	*36*	*31*				150 000	
HFM														*81*	*69*	*58*	*53*	*48*	*44*	*40*	*34*	*30*				200 000	
														78	*66*	*55*	*51*	*46*	*42*	*38*	*33*	*29*				250 000	
316S51, S52	510	240		111	106	102	98	96	93			90		89	88	*74*	*66*	*58*	*53*	*46*	*35*	*28*	*23*			100 000	4
HFS, CFS,															*85*	*66*	*58*	*52*	*46*	*41*	*32*	*25*	*19*			150 000	
HFM															*79*	*62*	*55*	*48*	*43*	*38*	*29*	*22*	*18*			200 000	
															75	*58*	*52*	*45*	*40*	*35*	*27*	*22*	*18*			250 000	
321S51 (1010)	510	235		121	117	112	110	107	104		102	102	101	*86*	*71*	*57*	*49*	*42*	*36*	*31*						100 000	
HFS, CFS,											102	*101*	*93*	*78*	*64*	*49*	*42*	*36*	*32*	*27*						150 000	
HFM											102	*97*	*89*	*74*	*58*	*45*	*38*	*33*	*28*	*25*						200 000	
											100	*93*	*85*	*71*	*55*	*42*	*35*	*31*	*26*	*22*						250 000	
321S51(1105)	490	190		93	87	84	82	79	77			76		76	75	*68*	*60*	*55*	*49*	*44*	*34*	*26*				100 000	
HFS, CFS,															75	*62*	*56*	*50*	*44*	*38*	*29*					150 000	
HFM															*72*	*58*	*52*	*46*	*41*	*35*	*27*					200 000	
															68	*55*	*49*	*44*	*38*	*33*	*25*					250 000	
347S51	510	240		135	130	124	122	119	118		117	117	116	*99*	*82*	*66*	*59*	*53*	*47*	*41*	*31*	*23*				100 000	
HFS, CFS,												117	*112*	*93*	*75*	*61*	*54*	*48*	*42*	*37*	*28*	*22*				150 000	
HFM												*116*	*106*	*88*	*72*	*58*	*51*	*45*	*39*	*34*	*25*	*19*				200 000	
												112	*102*	*85*	*68*	*55*	*48*	*42*	*37*	*32*	*24*	*19*				250 000	
215S15	540	270		141	139	136	135	133	132			130			126	124	123	*107*	*87*	*71*	*52*	*40*				100 000	
HFS, CFS,																124	*114*	*93*	*75*	*62*	*46*	*35*				150 000	
HFM																124	*104*	*83*	*67*	*56*	*42*	*32*				200 000	
																118	*96*	*76*	*62*	*52*	*40*					250 000	

Notes to table A.1

General notes

a) Table 2.1.2 gives the nominal design stress values, *f*, of various British Standard materials for design temperatures, ˚C, not exceeding those stated at the head of each column. Time-dependent values which are given for design lifetimes of 100 000, 150 000, 200 000 and 250 000 h are italicized. Values at intermediate temperatures and intermediate times shall be obtained by linear interpolation; values obtained by linear interpolation involving only one italicized value may be regarded as time-independent.
Interpolated values shall be rounded to two decimal places in accordance with BS 1957.
For design temperatures below 250 ˚C the design stress values for 250 ˚C shall be used.
b) The design temperature as specified in **2.2.7** should not exceed the upper temperature for which a value of *f* is given except where note 1c) applies; where extrapolation of the values given is required, this shall be on the basis agreed between the manufacturer and the purchaser (see **1.5.2.2**d).
c) If required for stress analysis purposes, the transition from linear elastic to linear plastic behaviour for all materials except austenitic steels may be assumed to occur at a stress for 1.5 × *f* unless *f* is time-dependent; for austenitic steels, the corresponding stress may be taken as 1.35 × *f*.
d) Overall thickness limits are as defined in the relevant material specification. In the case of forgings, the term ‘ruling section’ shall be interpreted in accordance with BS 5046.
e) For values between the thicknesses stated, design stresses shall be obtained by linear interpolation.
Notes applicable to individual materials
1a). The values for forgings may be increased up to (but not more than) the values permitted for plate in the equivalent material grade and equivalent ruling section on provision by the forgemaster of appropriate supporting data showing that the minimum acceptance criteria for equivalent plate are satisfied.
1b). An appropriate casting quality factor, as specified in **2.2.6**, should be applied to these values.
1c). Design stress values at higher temperatures are subject to agreement (see **1.5.2.2**d).
2. At temperatures at or above 580 ˚C the effect of scaling becomes significant and due allowance should be made for this.
3. This material is available only in a limited range of thickness and in the normalized condition. It has a restricted carbon content to obviate the necessity for stress relief subsequent to fabrication. A nominal design stress of 129 N/mm^2 may be assumed at temperatures below 350 ˚C.
4. Subject to continued fitness for service reviews being instituted at two-thirds of the design lifetime indicated (see **2.2.5**) and by agreement between the manufacturer and the purchaser (see **1.5.2.2**b), time-dependent values may be increased by up to 10 %, providing the resulting value does not exceed the lowest time-independent stress given.
5. (*Deleted*)
6. Use of LAW tubing is conditional on its being subjected to the same non-destructive examination requirements as those laid down for longitudinal seams in drums; see **5.7.4**.
7. Material will (or may be) supplied in the quenched and tempered condition, in which case time-dependent properties may be susceptible to degradation as a result of subsequent fabrication processes (see **2.2.1**).
8. Time-dependent design stress values apply only if the minimum carbon content equals or exceeds 0.04 %.
9. The use of steel 591 shall be limited to applications at design temperatures not exceeding 400 ˚C.
10. The British Standard covering these materials was withdrawn on 15 February 1993 in favour of BS EN 10028 : Parts 1, 2 and 3. These materials are regarded as obsolescent but their use may be continued under the provisions of **2.1.2.2.8** using the design stress values given in this table.
11. (*Deleted*)
12. (*Deleted*)
13. The British Standard covering these materials was withdrawn on 15 February 1993 in favour of BS EN 10028 : Parts 1, 2 and 3. These materials are now included in the national annex NC of BS EN 10028 : Part 2 to which reference should be made for the technical details and limitations applicable to the steels. For design purposes the design stress values given in this table should continue to be used.

Annex B
Example of the design of a boiler drum

B.1 Data

Boiler drum calculation pressure	= 3.65 N/mm^2 (gauge)
Internal diameter of drum	= 1220 mm
Length between supports (arranged near drum ends)	= 9150 mm
Mean effective diameter of tube holes	= 85 mm
Longitudinal pitch	= 158 mm
Externally applied loads including the self-weight of the drum and its contents under working conditions	W = 2150 kN
Drum swept by gases of combustion in first pass	
Proportion S of second moment of area I_c of the second drum included in I_A (see equation (12), **3.3.4.3.3**)	= 6.115 × 10^9 mm^4

The drum is connected to a lower second drum by a bank of tubes forming substantial struts (see **3.3.4.3.3**).

Steel BS 1501-161 grade 430B.

No corrosion allowance is included in this calculation.

B.2 Thickness required based on circumferential stress (see 3.3)

Saturated steam temperature corresponding to 3.65 N/mm^2 gauge	= 247 °C
Mean wall working metal temperature T = 247 °C + 25 °C	= 272 °C
Minimum design strength f (for plates over 40 mm thick up to and including 63 mm thick)	= 113.72 N/mm^2

Longitudinal ligament efficiency (see equation (6))

$$= \frac{158 - 85}{158} = 0.462$$

Then thickness t (see equation (1))

$$= \frac{3.65 \times 1220}{2 \times 113.7 \times 0.462 + 3.65}$$

= 43.9 mm. Use 44 mm thickness.

The design stress, f, at this thickness is 114.65 N/mm^2.

Circumferential ligament efficiency between parallel rows of tube holes (see **3.3.3.7**) is calculated as follows:

Angle from centre line of drum =10°36′.

Mean circumferential pitch between rows of holes

$$= \frac{10.6}{360} \times 2\,\pi \times 632 = 116.9\text{ mm}$$

Circumferential ligament efficiency

$$= \frac{116.9 - 85}{116.9} = 0.273$$

This is more than half of the efficiency of the longitudinal ligaments.

Equivalent longitudinal ligament efficiency forthe staggered tube holes, rows B, C and D, (see **3.3.3.5.2**) is calculated as follows:

Angle from centre line of drum = 9°30′

Mean circumferential pitch between rows of holes

$$= \frac{9.5}{360} \times 2\,\pi \times 632 = 104.3\text{ mm}$$

Using figure 3.3.3.5-5

$$\frac{S_c}{S_l} = \frac{209.6}{158} = 1.326$$

$$\frac{S_l - d}{S_l} = \frac{158 - 85}{158} = 0.462$$

Equivalent longitudinal efficiency for the staggered holes from figure 3.3.3.5-5 = 0.462.

This is equal to the efficiency of the longitudinal ligaments.

NOTE. If bending stresses due to weight were negligible then a thickness of 44 mm would be satisfactory. However, in this case the bending stresses cannot be ignored and the stresses on the ligaments have to be calculated (see **3.3.4**).

B.3 Combined stresses (see 3.3.4)

Calculate stresses based on a shell thickness of 44 mm.

The net cross-sectional area of the drum taken through the tube holes in a plane at right angles to the drum axis (the tube hole C does not occur in the same vertical section as the other tube holes)

= 126 100 mm^2.

For properties of the cross-section see table B.3.

For arrangement of tube holes in drum see figure B.3.

Table B.3 Properties of the cross-section

Hole	Angle from vertical θ	r cos θ mm	K mm	ΣAK	K^2 mm^2	ΣAK^2
A	30°	632 × 0.86	−547.3		299 537	
B	61°24′	632 × 0.4787	+302.5		91 506	
D	42°24′	632 × 0.7385	+466.7		217 809	
E	31°48′	632 × 0.8499	+537.1		288 476	
F	21°12′	632 × 0.9323	+589.2		347 157	
G	10°36′	632 × 0.9829	+621.2	$= 85 \times 44 \times \Sigma K$	385 889	$= 85 \times 44 \times \Sigma K^2$
H	0°	632 × 1.0	+632.0	$\Sigma AK = 85 \times 44 \times 5404$	399 424	$\Sigma AK^2 = 85 \times 44 \times 3.432 \times 10^6$
K	10°36′	632 × 0.9829	+621.2	$= 20.21 \times 10^6$	385 889	$= 12.84 \times 10^9$
L	23°12′	632 × 0.9191	+580.9		337 445	
M	33°48′	632 × 0.8310	+525.2		275 835	
N	44°24′	632 × 0.7145	+451.6		203 943	
O	55°	632 × 0.5736	+362.5		131 406	
P	65°36′	632 × 0.4131	+261.1		68 173	
Σ			+5404	20.21×10^6	3.432×10^6	12.84×10^9

NOTE. The second moment of area I_A of 13 tube holes should be added to ΣAK^2 but this is so small in this case that it may be ignored.

For headers with comparatively large holes it should be calculated, taking into account the angularity of the holes, and then added to ΣAK^2.

Eccentricity of net cross-section, i.e. height of neutral axis above centreline of drum:

$$e = \frac{\Sigma AK}{\text{Net area}} = \frac{20.21 \times 10^6}{126\ 100} = 160.3 \text{ mm}$$

Second moment of area of undrilled shell:

$$= \frac{\pi}{64}(1308^4 - 1220^4) = 34.94 \times 10^9 \text{ mm}^4$$

Net second moment of area of drilled shell about horizontal centreline:

$$= (34.94 - 12.84) \times 10^9$$
$$= 22.10 \times 10^9 \text{ mm}^4$$

Second moment of area of section about neutral axis:

$$I_b = 22.10 \times 10^9 - (160.3^2 \times 126\ 100)$$
$$= 18.86 \times 10^9 \text{ mm}^4$$

Proportion S of second moment of area of second drum included (see equation 12)):

$$= S \times I_c = 6.115 \times 10^9 \text{ mm}^4$$

Total effective second moment of area (see **3.3.4.3.2**):

$$I_A = (18.86 + 6.115) \times 10^9 = 24.98 \times 10^9 \text{ mm}^4$$

Maximum direct longitudinal stress (see equation (8)):

$$f_d = \frac{3.65 \times 1220^2}{1.273 \times 126\ 000} = 33.84 \text{ N/mm}^2$$

Bending moment due to eccentricity (see equation (10)):

$$M_E = \frac{3.65 \times 1220^2 \times 160.3}{1.273} = 684.1 \text{ MN·mm}$$

Bending moment due to externally applied loads:

$$M_W = \frac{WL}{8} = \frac{2.150 \times 10^6 \times 9150}{8} = 2459 \text{ MN·mm}$$

Resultant bending moment (see equation (9)):

$$M_R = M_E + M_W = 3143 \text{ MN·mm.}$$

Distance from neutral axis of net cross-section to the extreme centreline of the drum shell plate:

$$Y = 610 + 22 + 160.3 = 792.3 \text{ mm.}$$

Stress due to bending (see equation (11)):

$$f_b = \frac{3143 \times 10^6 \times 792.3}{24.98 \times 10^9} = 99.69 \text{ N/mm}^2$$

Resultant longitudinal stress:

$$= f_d + f_b = 33.84 + 99.69 = \underline{133.53 \text{ N/mm}^2}$$

This is the longitudinal stress on the circumferential ligaments between parallel rows of holes at the bottom of the drum and is in excess of the design strength, f, (114.65 N/mm^2). The drum thickness will therefore need to be increased.

Take for example a drum 54 mm thick. This thickness has f = 114.16 N/mm^2. It is found that the change in drum thickness alters the total weight W to 2190 kN.

Net cross-section area	= 156 500 mm^2
Eccentricity of net cross-section e	= 159.5 mm
Second moment of area of section about neutral axis I_b	= 23.96 × 10^9 mm^4
Proportion S of second moment of area of second drum which may be included	= 6.115 × 10^9 mm^4
Total effective second moment of area I_A	= 30.08 × 10^9 mm^4
Maximum direct longitudinal stress f_d	= 27.27 N/mm^2
Bending moment due to eccentricity M_E	= 680.7 MN·mm
Bending moment due to externally applied loads M_W	= 2505 MN·mm
Resultant bending moment M_R	= 3186 MN· mm
Distance from neutral axis of the net cross-section to the extreme centreline of the drum shell plate Y	= 796.5 mm
Stress due to bending f_b	= 84.35 N/mm^2
Resultant longitudinal stress	= 111.62 N/mm^2

NOTE. This is the longitudinal stress on the circumferential ligaments between parallel rows of holes at the bottom of the drum and is less than the design strength f (114.16 N/mm^2).

If there were no staggered tube holes, then the drum thickness of 54 mm would be satisfactory but in this case the stress on the diagonal ligaments of the staggered holes also has to be calculated.

B.4 Stress on diagonal ligaments

Stress on diagonal ligaments between rows C and D (see **3.3.4.4**) for 54 mm thick drum is calculated as follows:

$$\sigma_1 = \frac{3.65\ (610 + 0.5 \times 54)}{54}$$

$$= 43.06\ \text{N/mm}^2$$

Longitudinal stress on gross area of circumferential section:

$$\sigma_2 = \eta_2\ (f_a + f_b)$$

where f_a is the stress due to end load = 27.27 N/mm^2.

Distance from neutral axis to mid point of inclined ligament:

$$Y = (637 \times \sin 42^\circ 51') + 159.5$$

$$= 592.7\ \text{mm}$$

Bending stress at mid point of inclined ligament:

$$f_b = \frac{3186 \times 10^6 \times 592.7}{30.08 \times 10^9}$$

$$= 62.78\ \text{N/mm}^2$$

The ligament efficiency (η_2) on circumferential section at point where fd and fb act is determined in the following manner.

Circumferential pitch on mean of plate between rows B and D:

$$= \frac{19}{360} \times 2\ \pi \times 637\ \text{mm}$$

$$= 211.2\ \text{mm}$$

$$\eta_2 = \frac{211.2 - 85}{211.2} = 0.5976$$

Thus σ_2 = 0.5976 (27.27 + 62.78) = 53.81 N/mm^2.

Actual ligament efficiency on diagonal line (η_3) is calculated as follows:

$$\tan \alpha = \frac{105.6}{79} = 1.3367$$

$$\alpha = 53.20^\circ;\ \cos \alpha = 0.5900$$

$$\eta_3 = 1 - \frac{85 \times 0.5990}{79} = 0.3565$$

Average direct stress on ligament:

$$A_1 = \frac{1}{0.3555} \left\{ \frac{43.06 + 53.81}{12} + \frac{(43.06 - 53.81) \times (-0.2823)}{2} \right\} = 140.51\ \text{N/mm}^2$$

Average transverse stress on ligament:

$$B_1 = 0.3555 \left\{ \frac{43.06 + 53.81}{2} - \frac{(43.06 - 53.81) \times (-0.2823)}{2} \right\} = 16.68\ \text{N/mm}^2$$

Average shear stress on ligament:

$$C_1 = \frac{(43.06 - 53.81) \times 0.9593}{2 \times 0.3555} = -\ 14.50\ \text{N/mm}^2$$

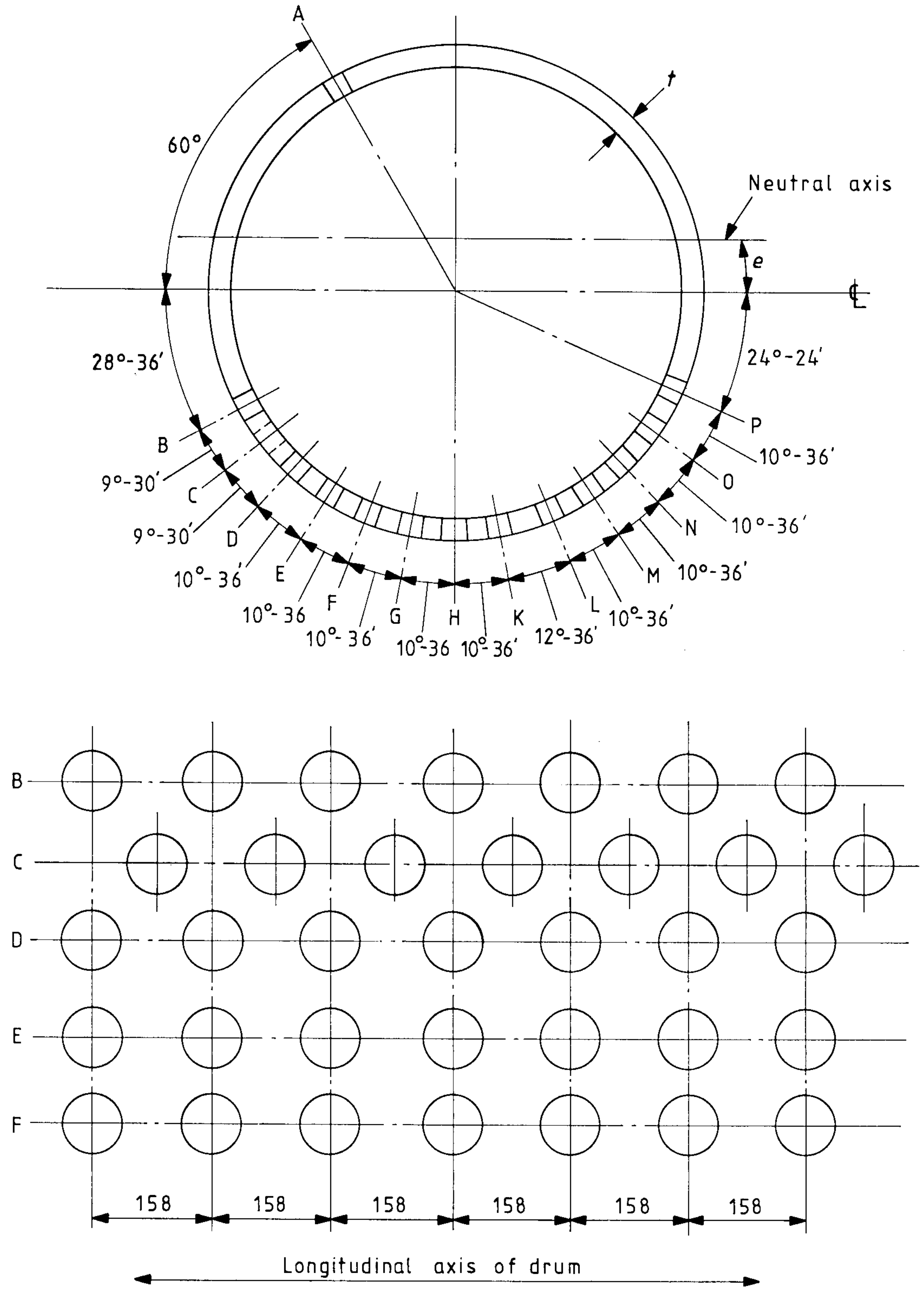
The stress on the diagonal ligament (see equation (13)):

$$f = ½\ [140.51 + 16.68 + \sqrt{\{(140.51 - 16.68)^2 + 4 \times (-14.50)^2\}}]$$

$$= 142.18\ \text{N/mm}^2$$

This is the stress on the diagonal ligaments between rows C and D and exceeds the design strength f(114.16 N/mm^2). The drum thickness will therefore need to be increased, or alternatively, the circumferential pitch of the staggered tube holes will need to be increased.

In the former case try increasing the drum plate thickness to 70 mm. After allowing for the increase in load due to extra plate thickness the stress on the diagonal ligaments for a 70 mm thick drum is 111.0 N/mm^2. The design strength for a plate of this thickness is 113.30 N/mm^2. A plate thickness of 70 mm will therefore be satisfactory.



Tube row C is staggered relative to all other tube rows.

Figure B.3 Position of tube holes in drum

Annex C
Recommended forms of connections

The following types of connection are covered:

a) set-on branches;

b) set-in branches;

c) forged branches;

d) studded and welded sockets.

The recommended details in this annex are drawn to indicate the parts of the connection shown in figure C.1.

Figure C.2 shows standard weld preparation details for branches.

For flange weld details see BS 806.

Figures C.3 to C.20 show examples of good practice which are in general use. Other arrangements may be adopted provided that they are shown to be sound. The examples may be modified to allow for improvements effected in:

1) welding techniques;

2) non-destructive testing capability;

3) the characteristics of the material used;

4) knowledge concerning joint behaviour.

In selecting the appropriate detail to use from the several alternatives shown for each type of connection, consideration should be given to the service conditions under which it will be required to function.

Weld dimensions, as shown in the various figures, are those which are used in good practice but it is necessary in each case to ascertain that these welds are adequate for strength and suitable for the welding process.

When set-in partial penetration welds are used, root defects may be present and these cannot always be detected by means of non-destructive examination. The use of partial penetration joints may not be suitable for cases where there are severe temperature gradients especially when these are of a fluctuating nature. Partial penetration welds of set-in branches are not acceptable for use in the creep range.

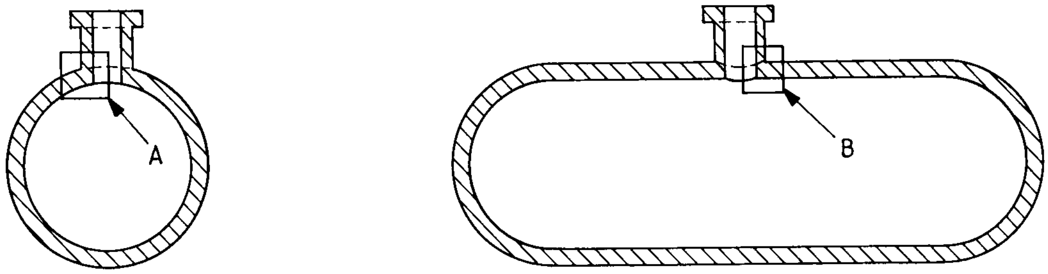
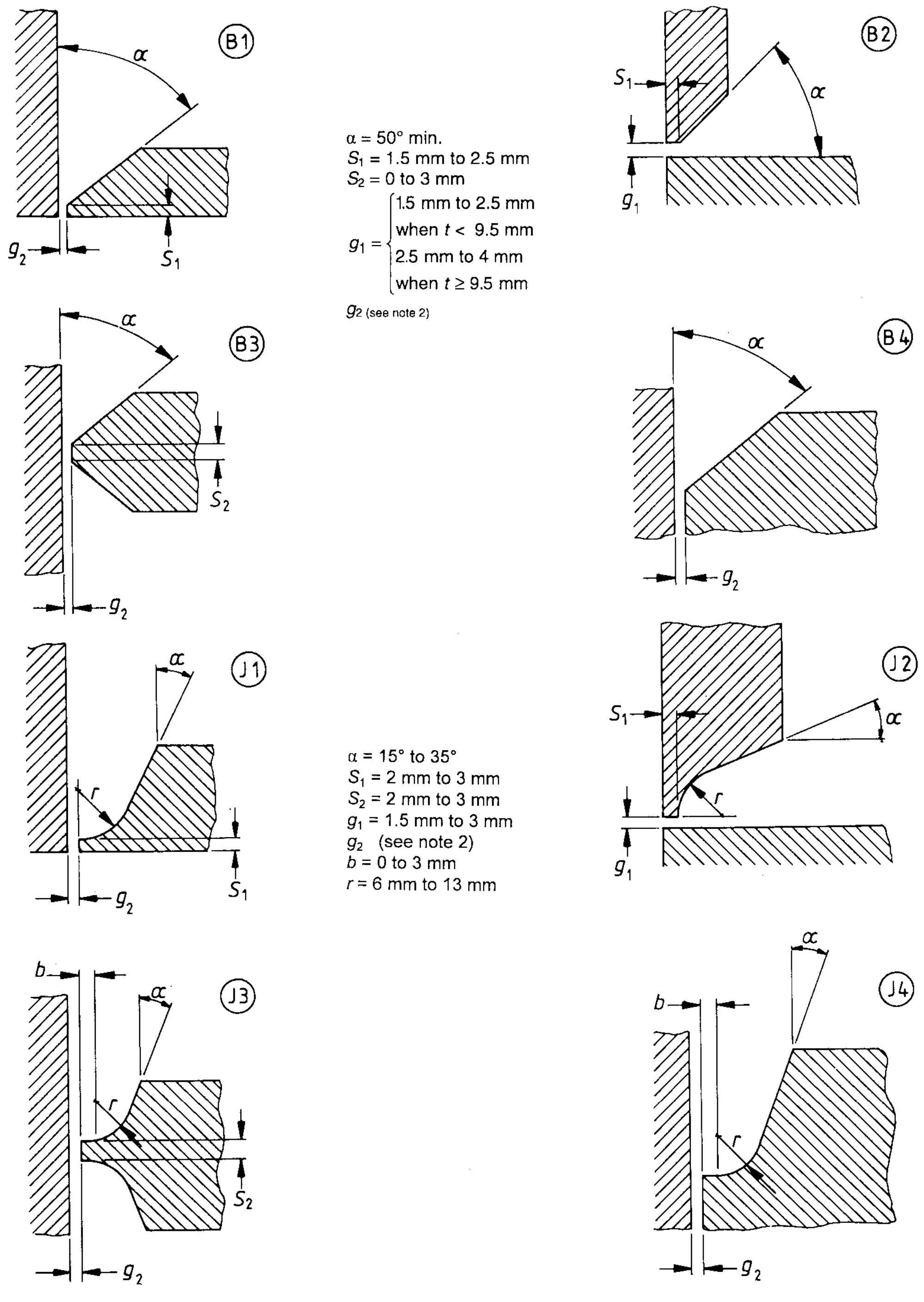


Figure C.1 Transverse and longitudinal sections of branch connections



α = 50° min.
S_1 = 1.5 mm to 2.5 mm
S_2 = 0 to 3 mm
g_1 = { 1.5 mm to 2.5 mm when $t < 9.5$ mm; 2.5 mm to 4 mm when $t \geq 9.5$ mm
g_2 (see note 2)

α = 15° to 35°
S_1 = 2 mm to 3 mm
S_2 = 2 mm to 3 mm
g_1 = 1.5 mm to 3 mm
g_2 (see note 2)
b = 0 to 3 mm
r = 6 mm to 13 mm

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) and also to the position in which the welding is carried out.

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

Figure C.2 Standard weld preparation details

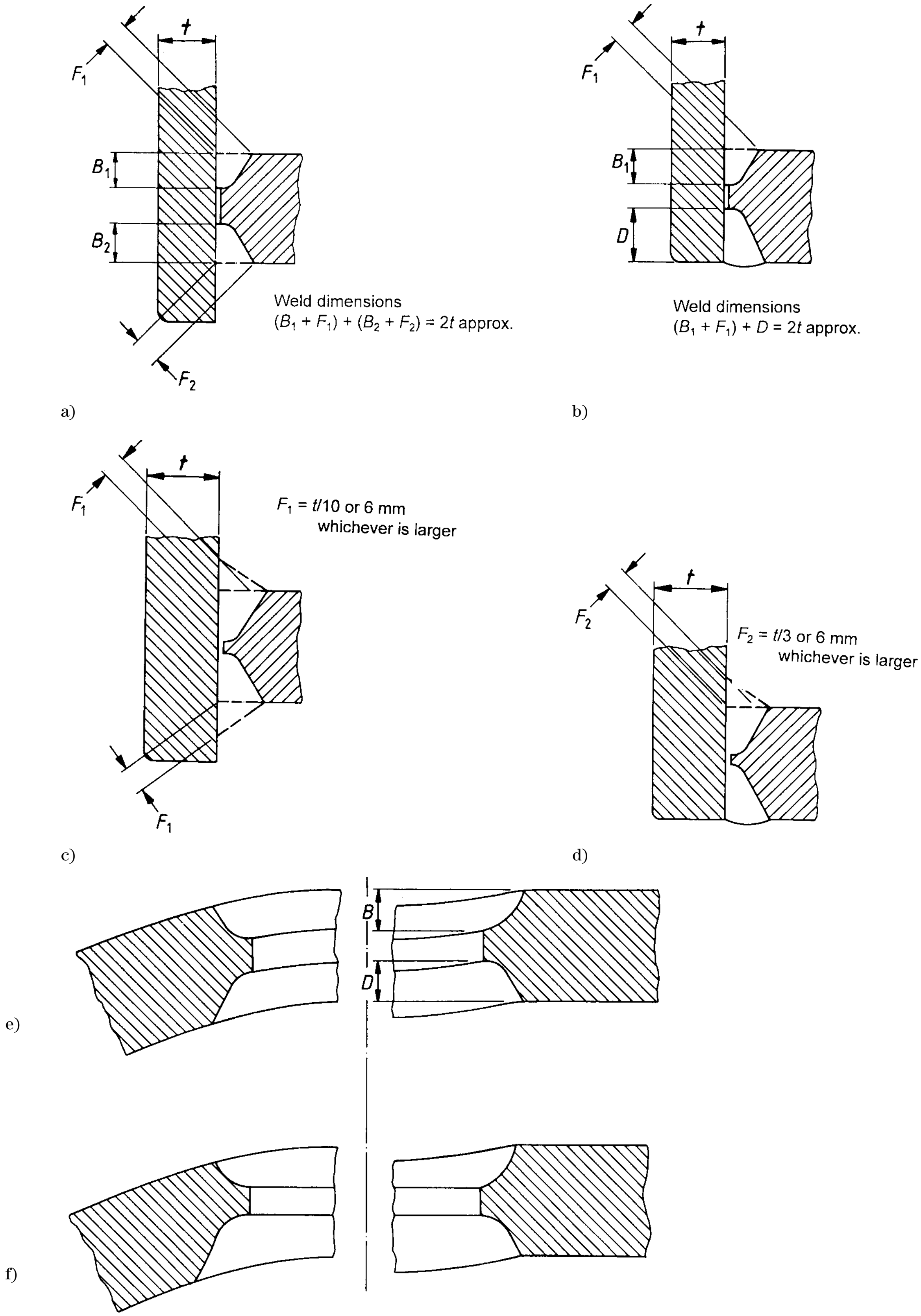
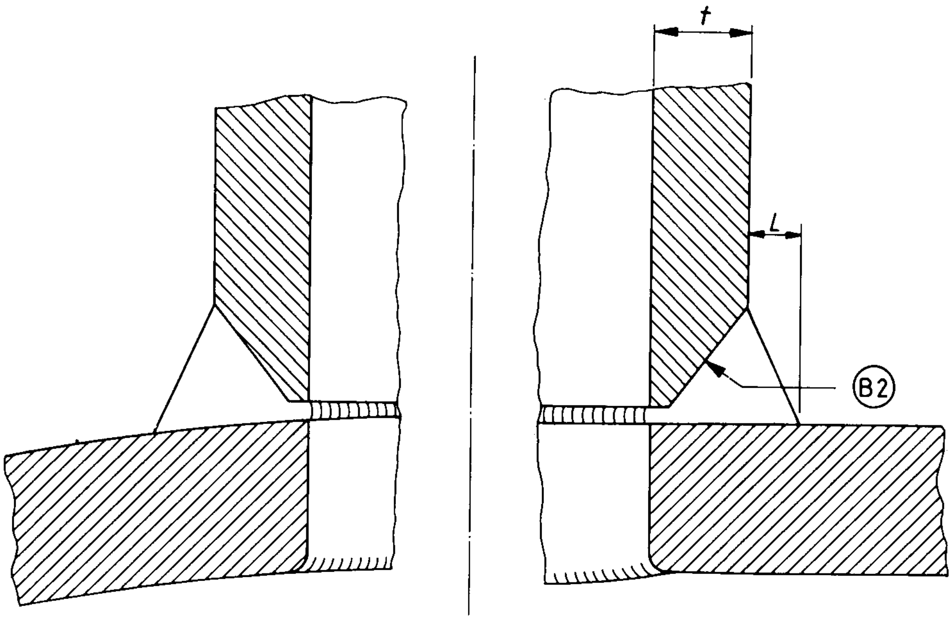


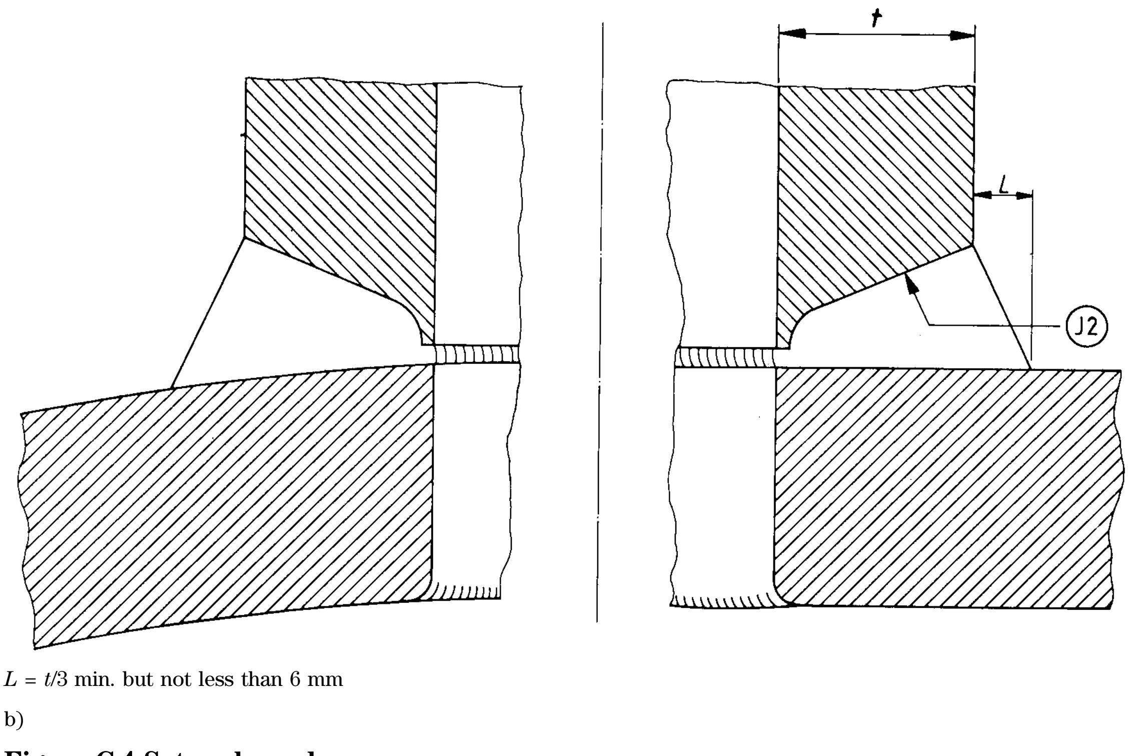
Figure C.3 Weld details for set-in branches



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

Preference should be given to the detail shown in b) if the thickness *t* exceeds about 16 mm

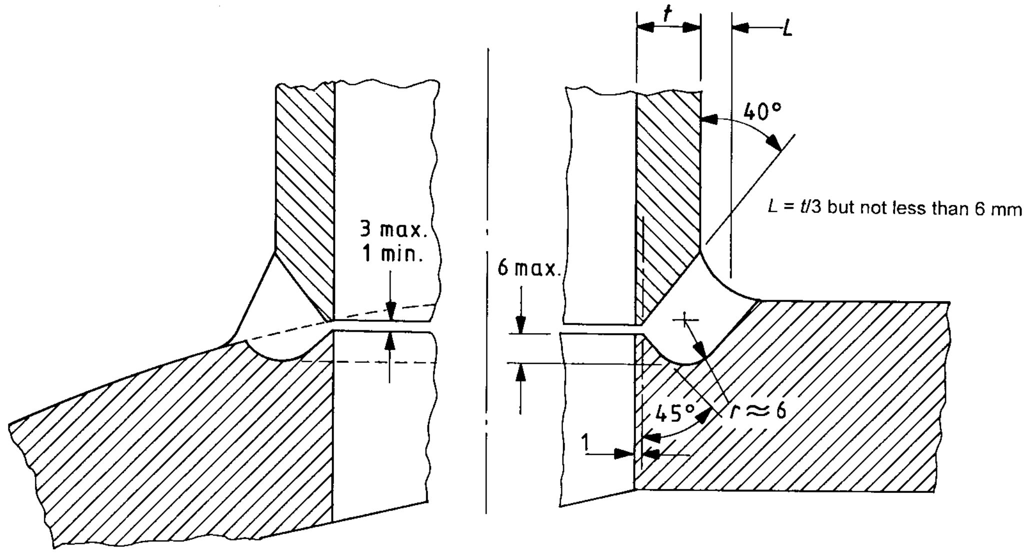
a)



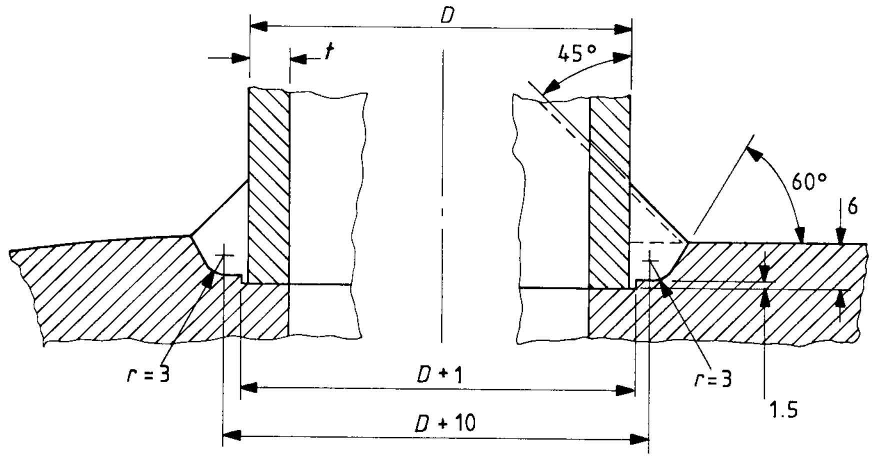
L = *t*/3 min. but not less than 6 mm

b)

Figure C.4 Set-on branches



a) Preference should be given to figure C.4b) if the wall thickness *t* exceeds about 16 mm

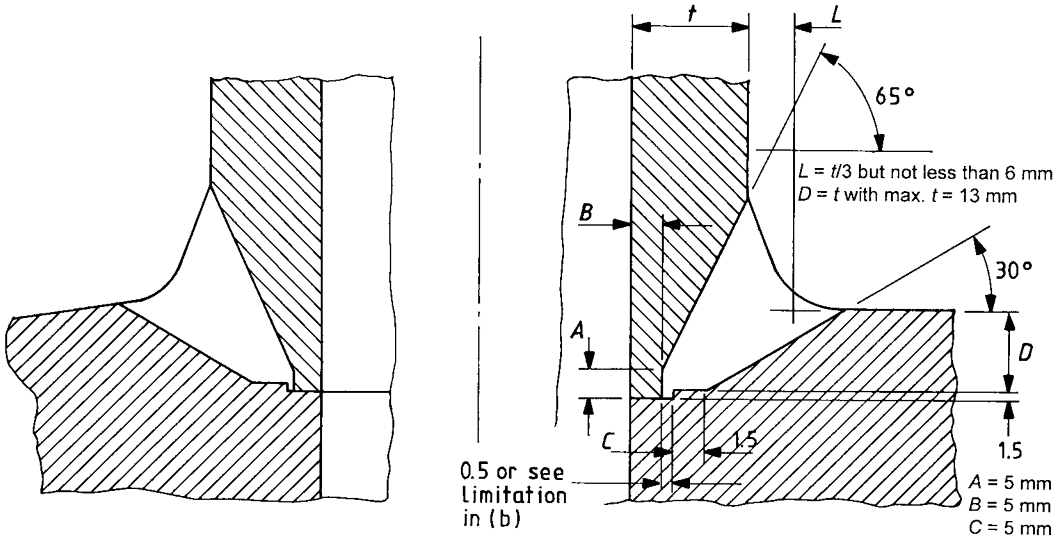


b) For nozzles up to approximately 100 mm bore and 6 mm wall thickness *t*

All linear dimensions are in millimetres.

NOTE. For nozzles up to and including 150 mm bore see figure C.5c.

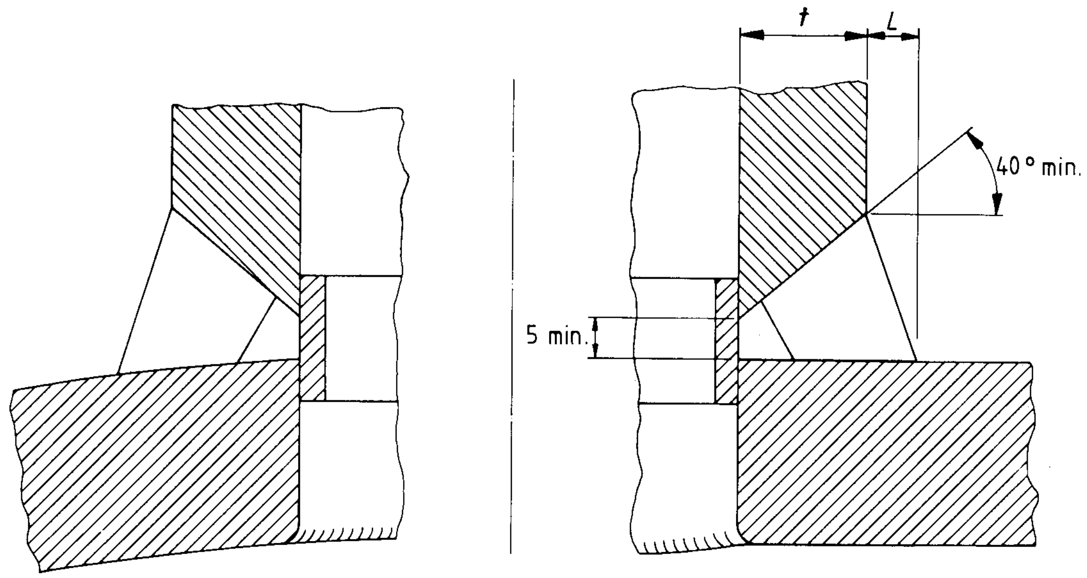
Figure C.5 Set-on branches



c) For nozzles up to and including 150 mm bore and wall thickness t over 6 mm and up to and including 13 mm

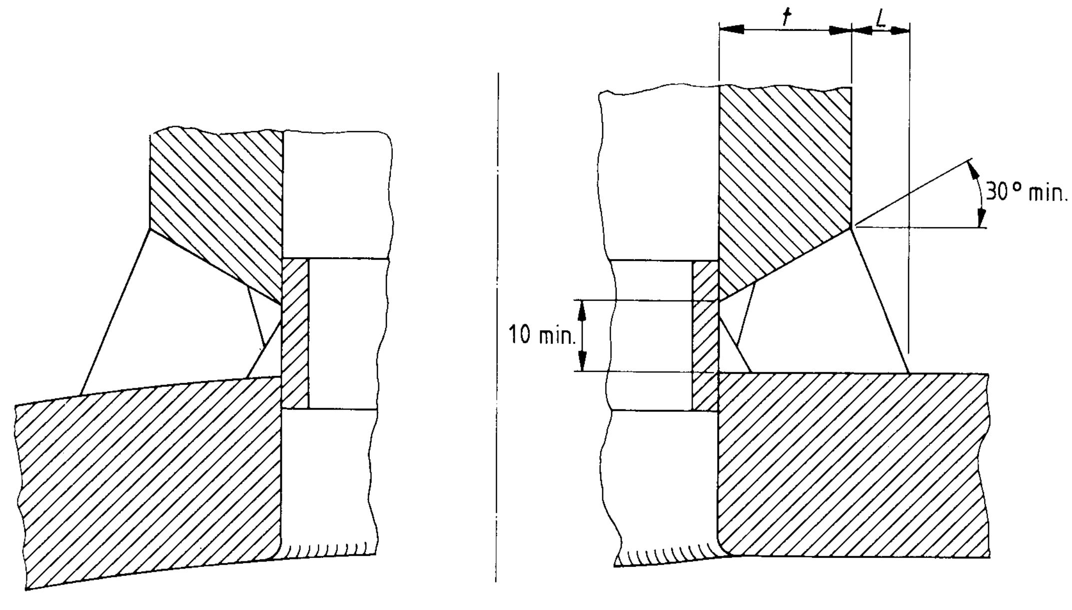
All linear dimensions are in millimetres.

Figure C.5 Set-on branches (*continued*)



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

a) Single root run technique



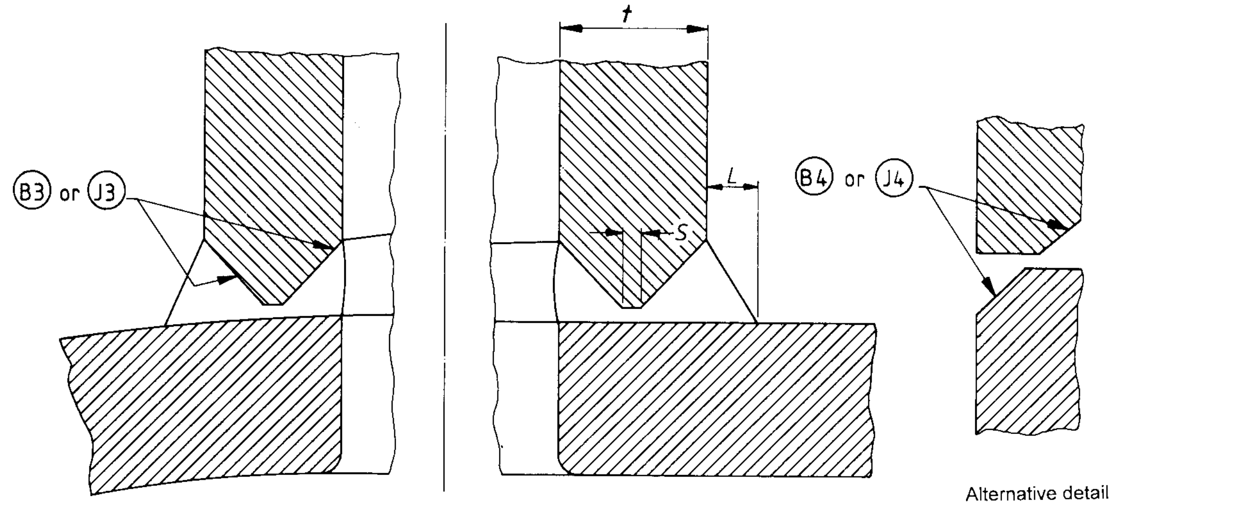
$L = t/3$ min. but not less than 6 mm

b) Double root run technique

NOTE. The backing ring should be of the same nominal composition as that of the shell. Care should be taken to ensure close fitting of the backing rings which should be removed after welding.

All linear dimensions are in millimetres.

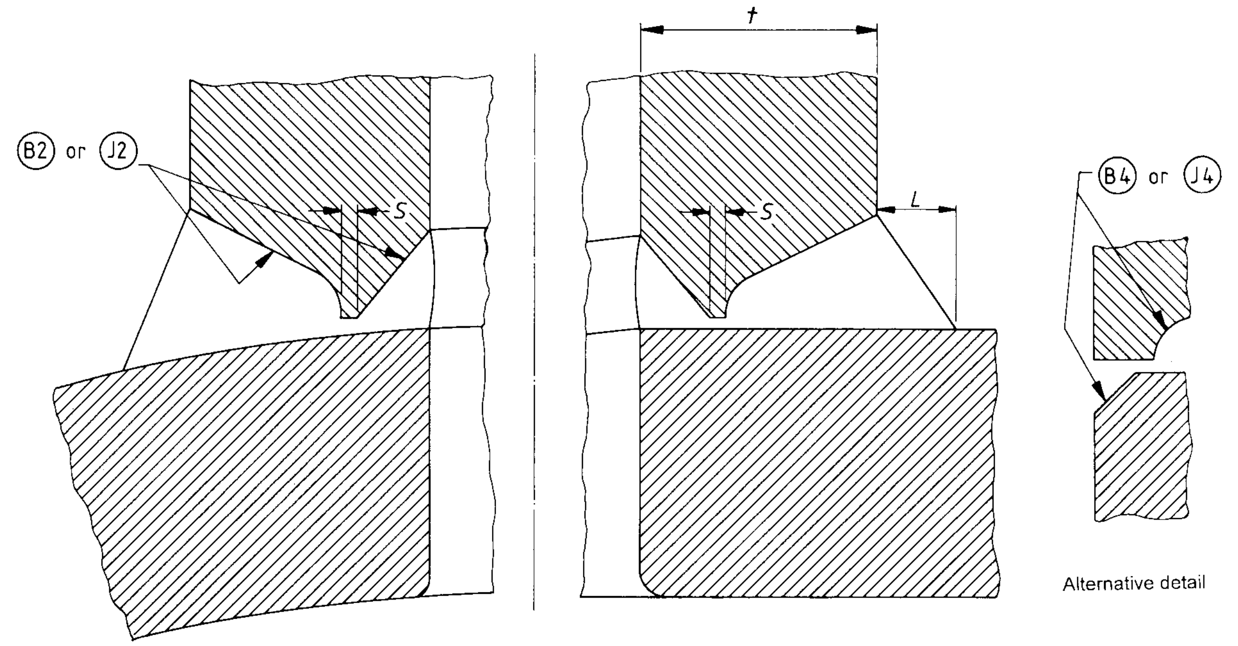
Figure C.6 Set-on branches



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

Preference should be given to the detail shown in b) if t exceeds about 16 mm

a)

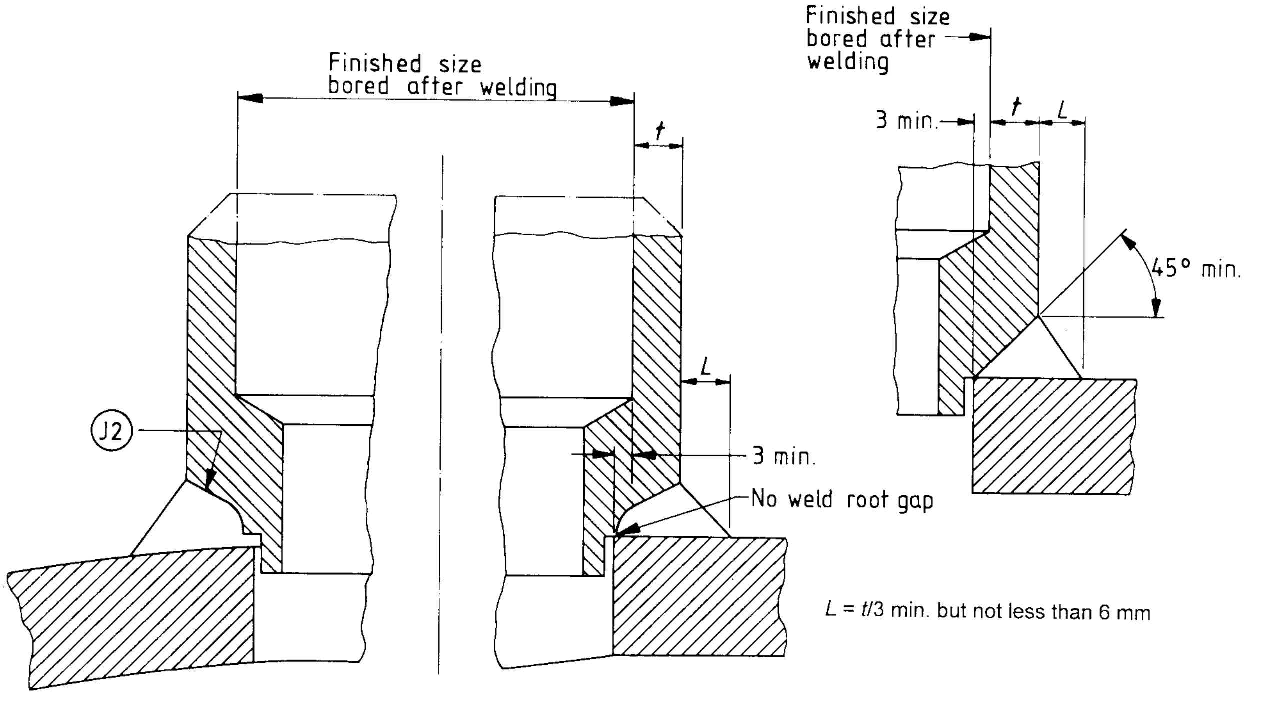


S = 1.5 mm to 2.5 mm
L = t/3 min. but not less than 6 mm

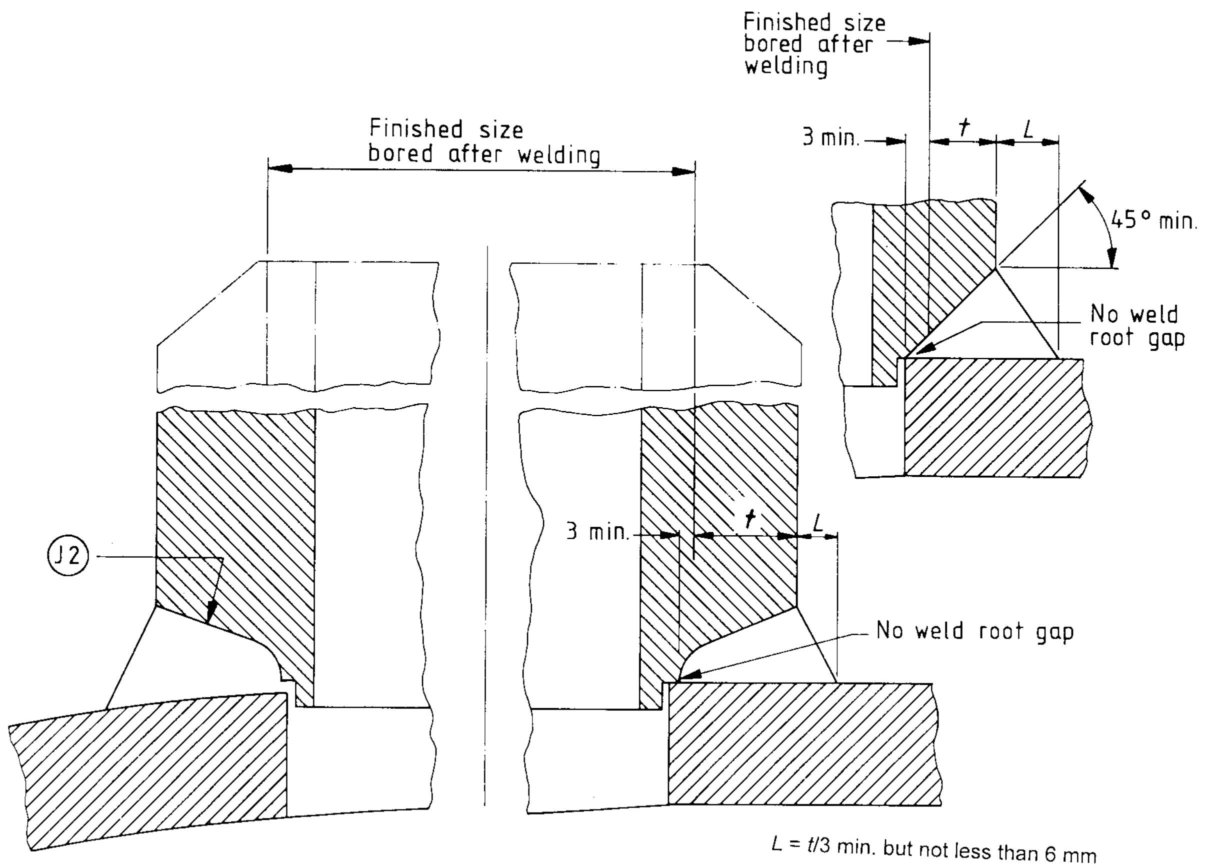
b)

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 C.7 Set-on branches



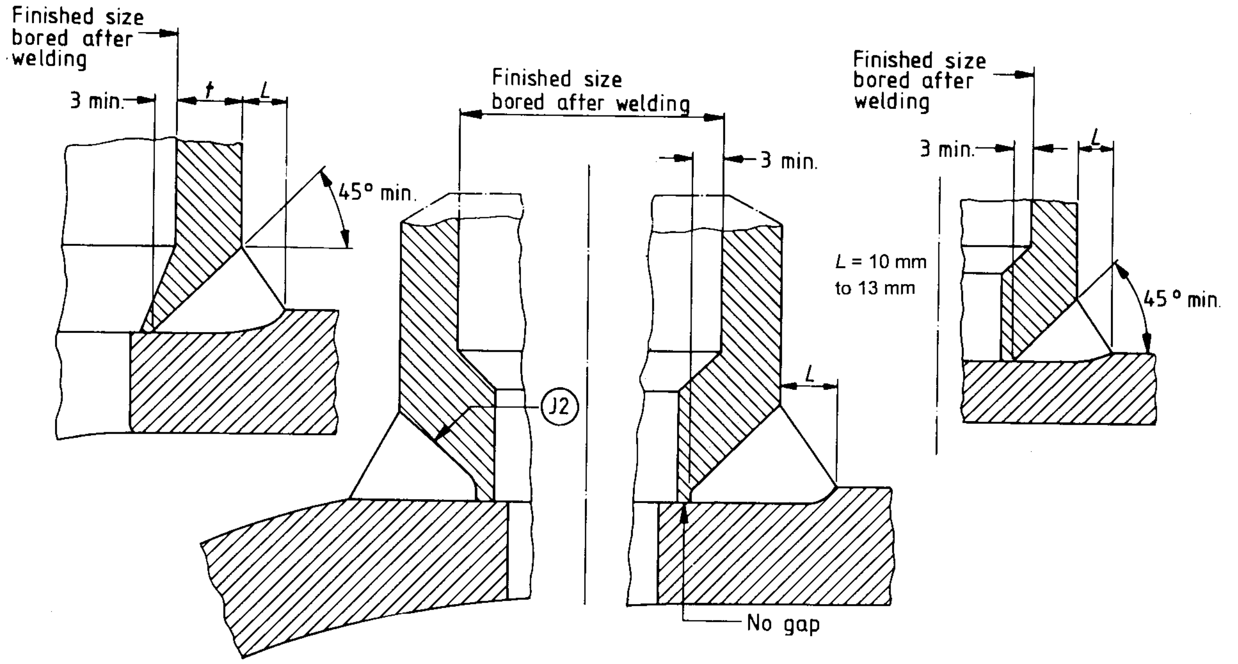
a)



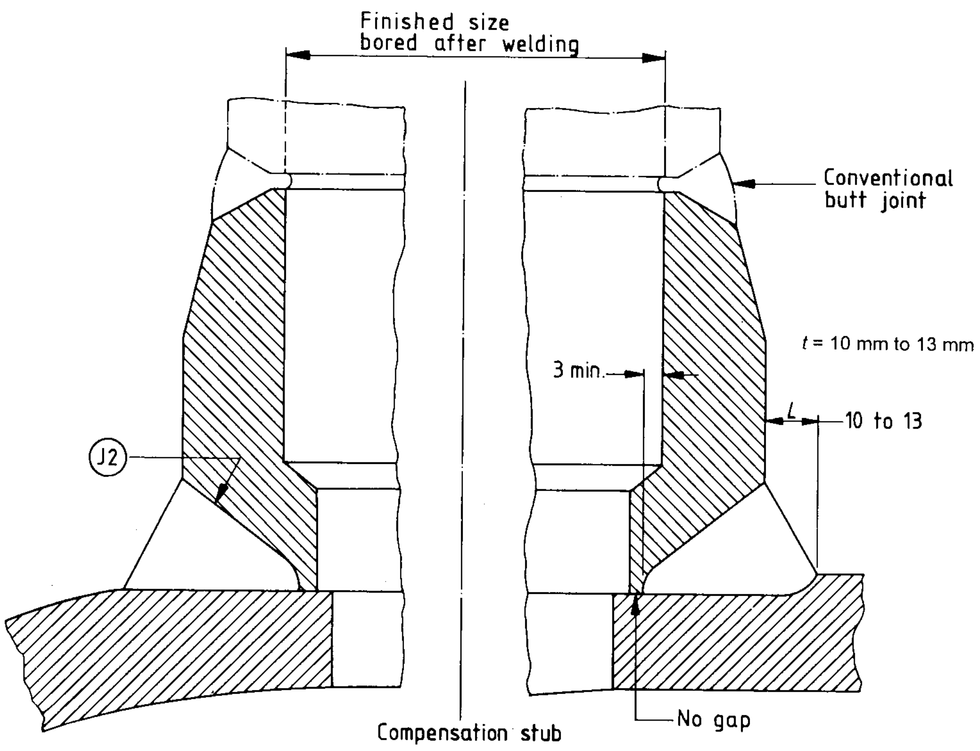
b)

All linear dimensions are in millimetres.

Figure C.8 Set-on branches



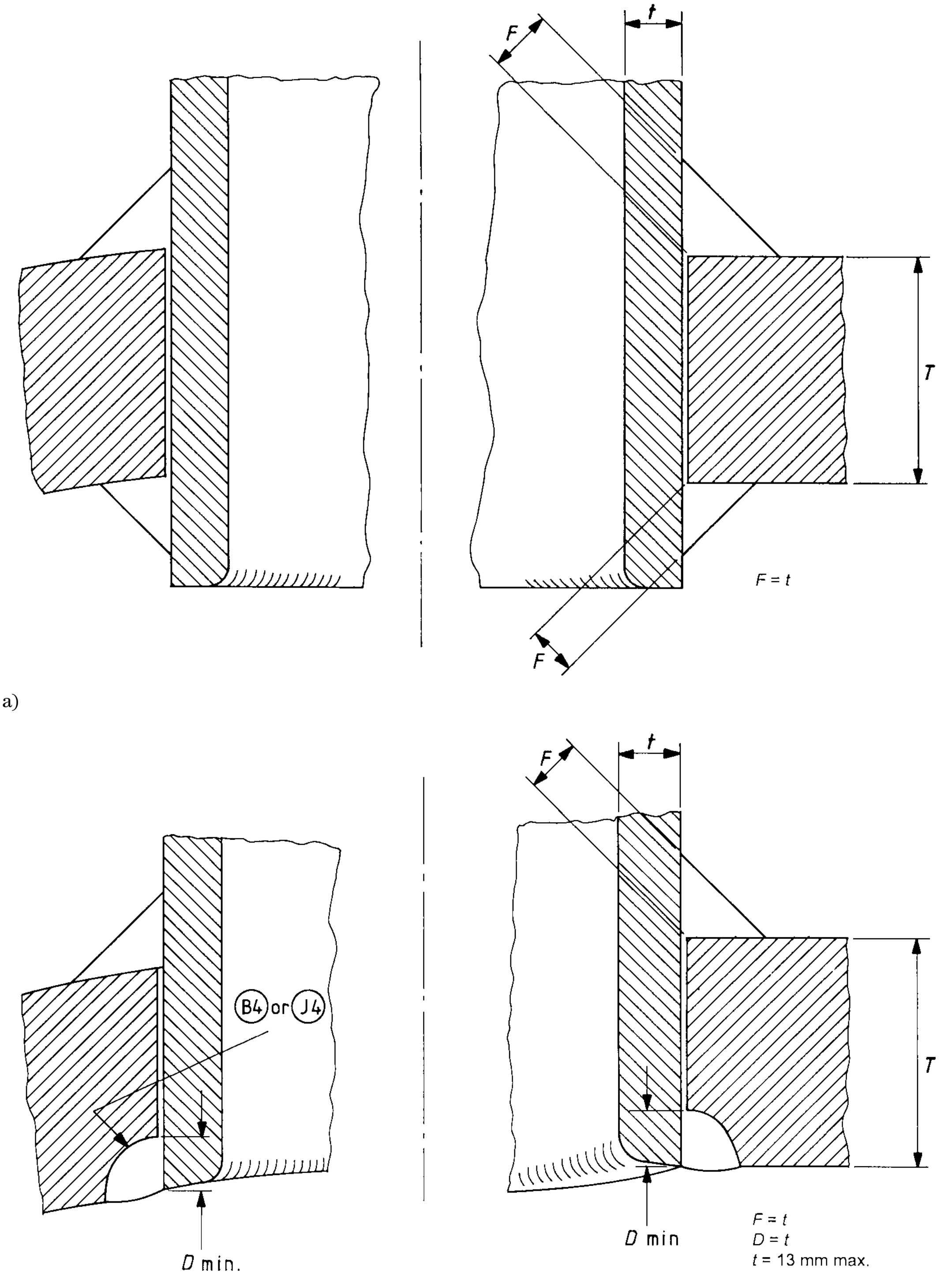
a)



b)

All linear dimensions are in millimetres.

Figure C.9 Set-on branches

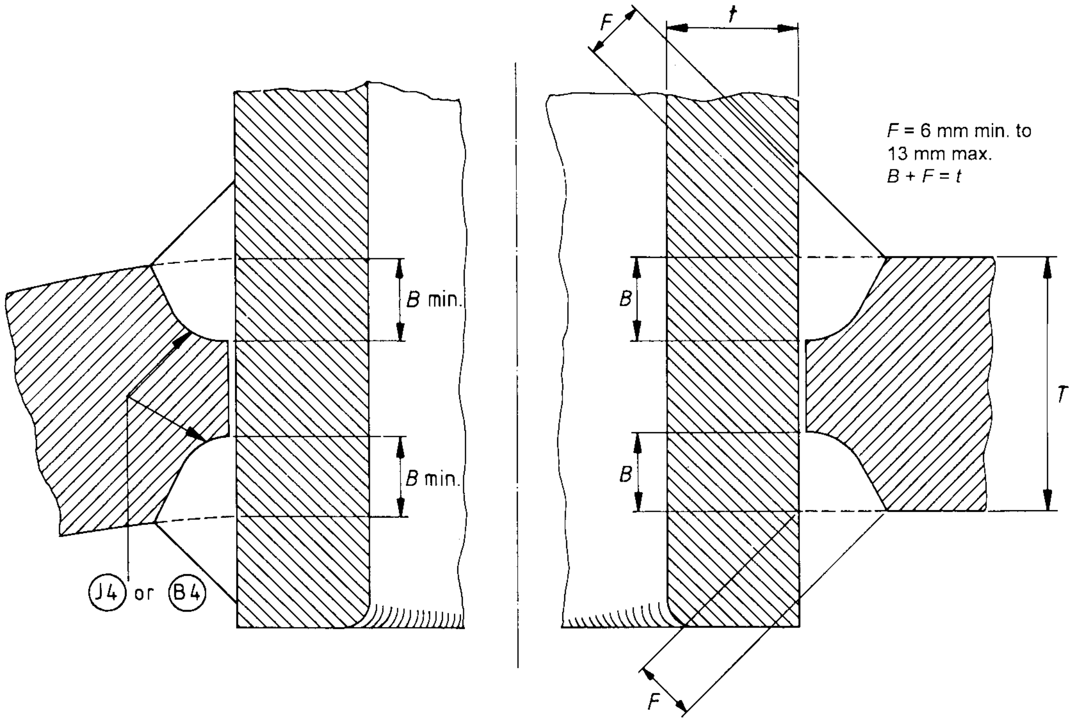


a)

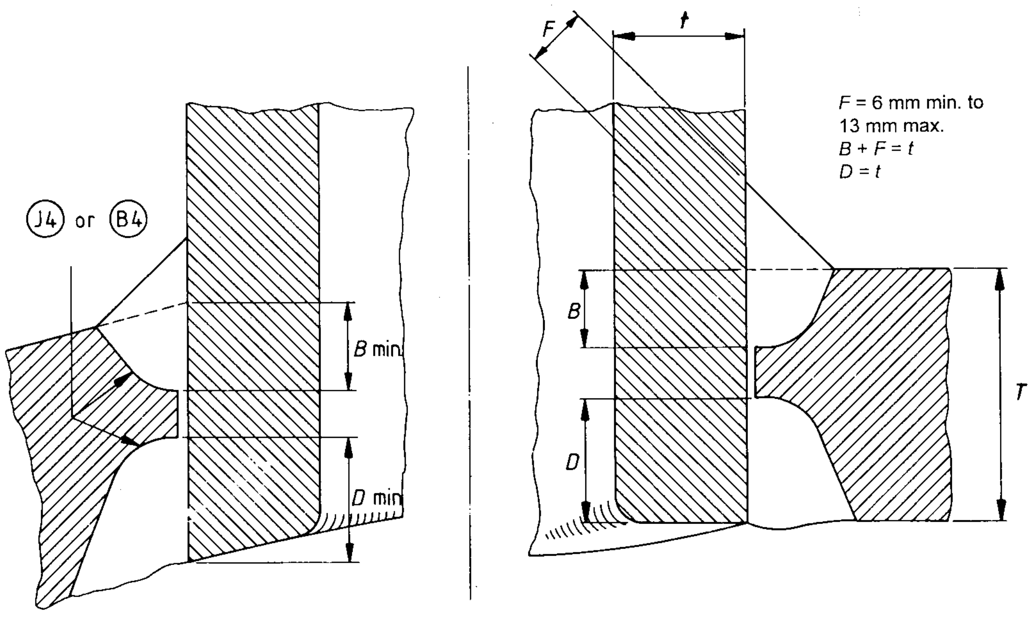
b)

These connections are permitted only for branches up to and including 100 mm bore and 13 mm wall thickness in carbon or carbon manganese steel

Figure C.10 Set-in branches: fillet welded connections



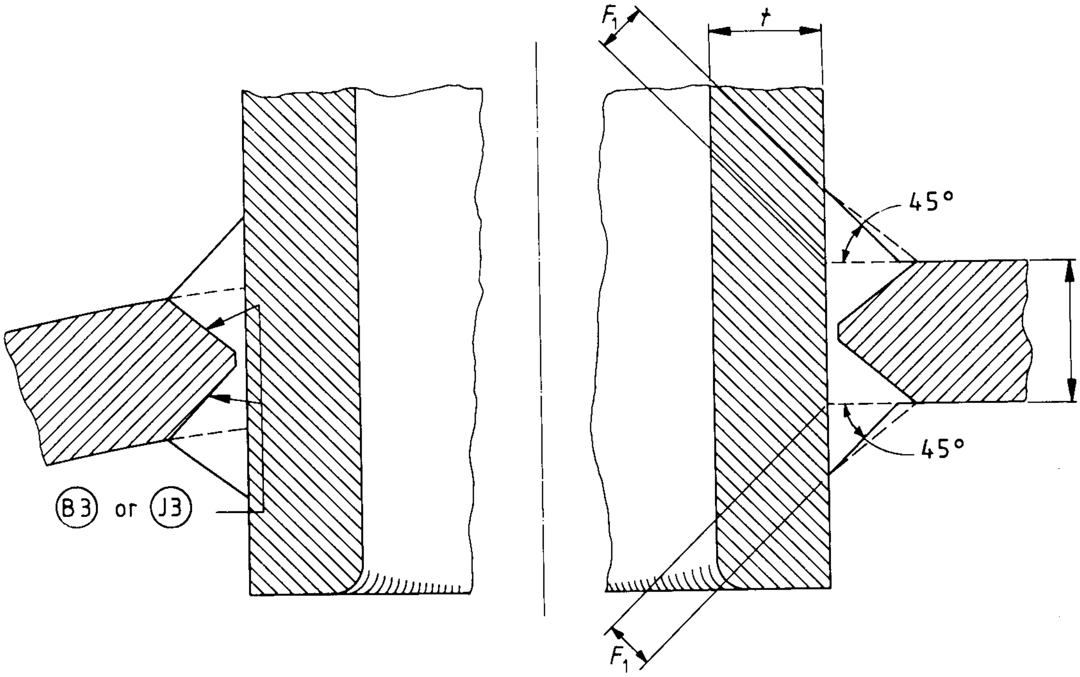
a)



b)

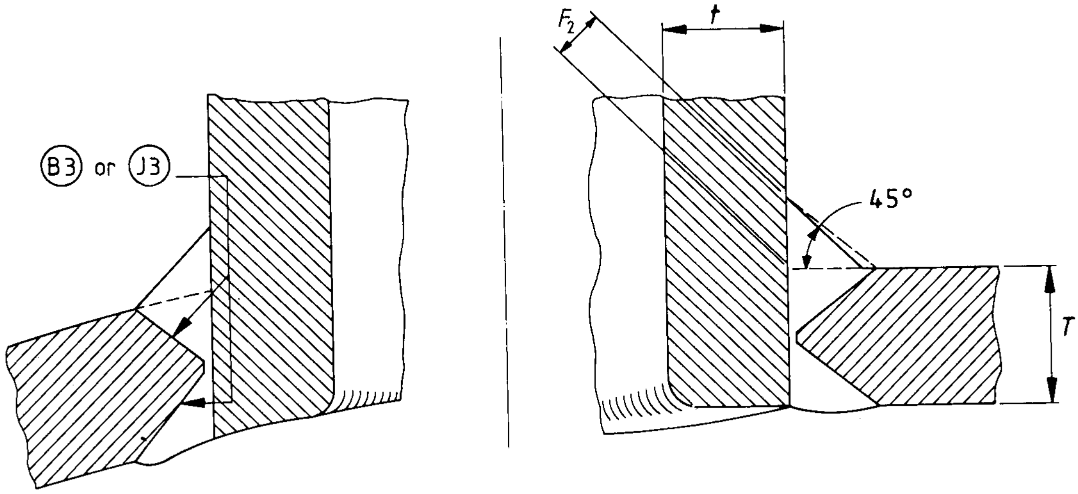
These connections are permitted only for branches up to and including 200 mm bore in carbon or carbon manganese steels or 100 mm bore for alloy steels but in no case for a branch thickness over 25 mm

Figure C.11 Set-in branches: partial penetration butt-welded connections



F_1 = T/10 min. or 6 mm whichever is larger

a)

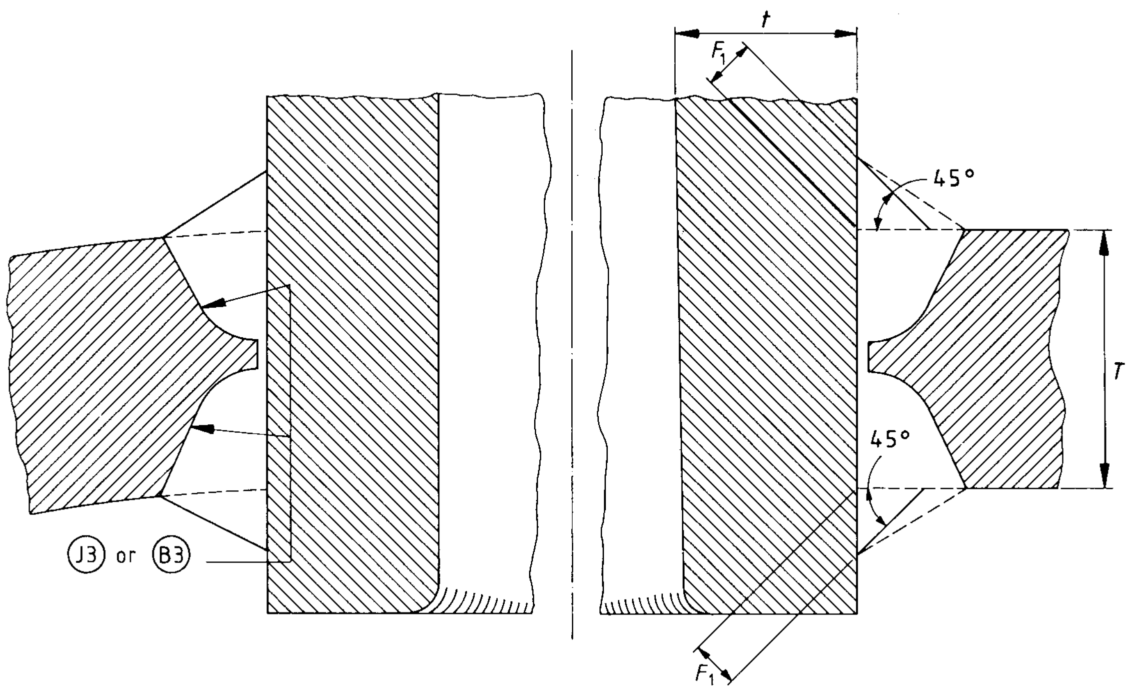


F_2 = T/5 min. or 6 mm whichever is larger

b)

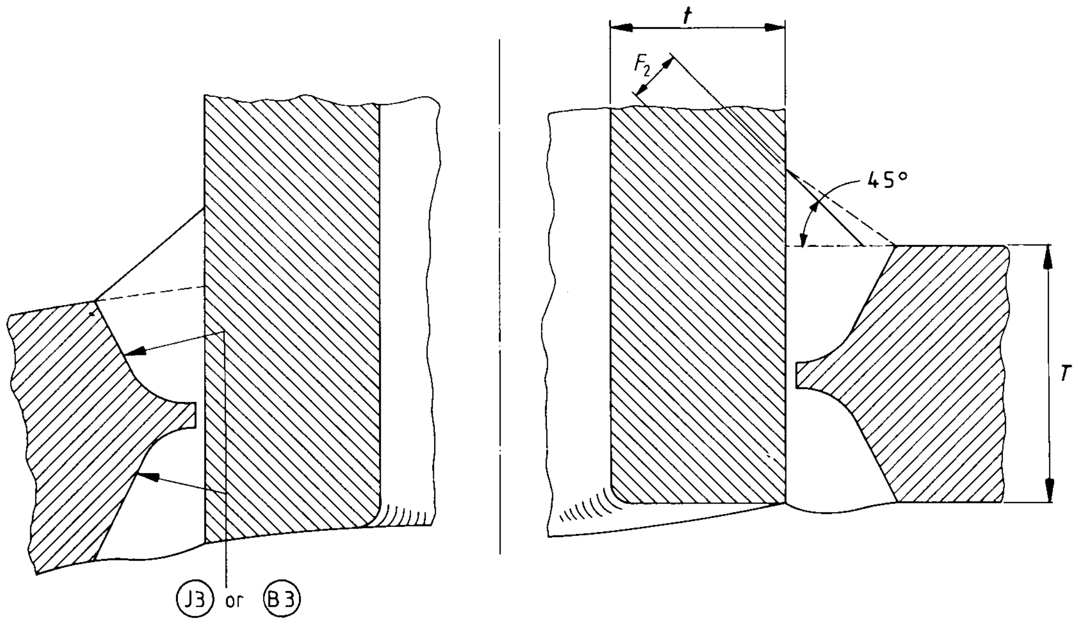
Preference should be given to figures C.13 or C.14 if T exceeds about 32 mm

Figure C.12 Set-in branches: full penetration connections



F_1 = T/10 min. or 6 mm whichever is larger

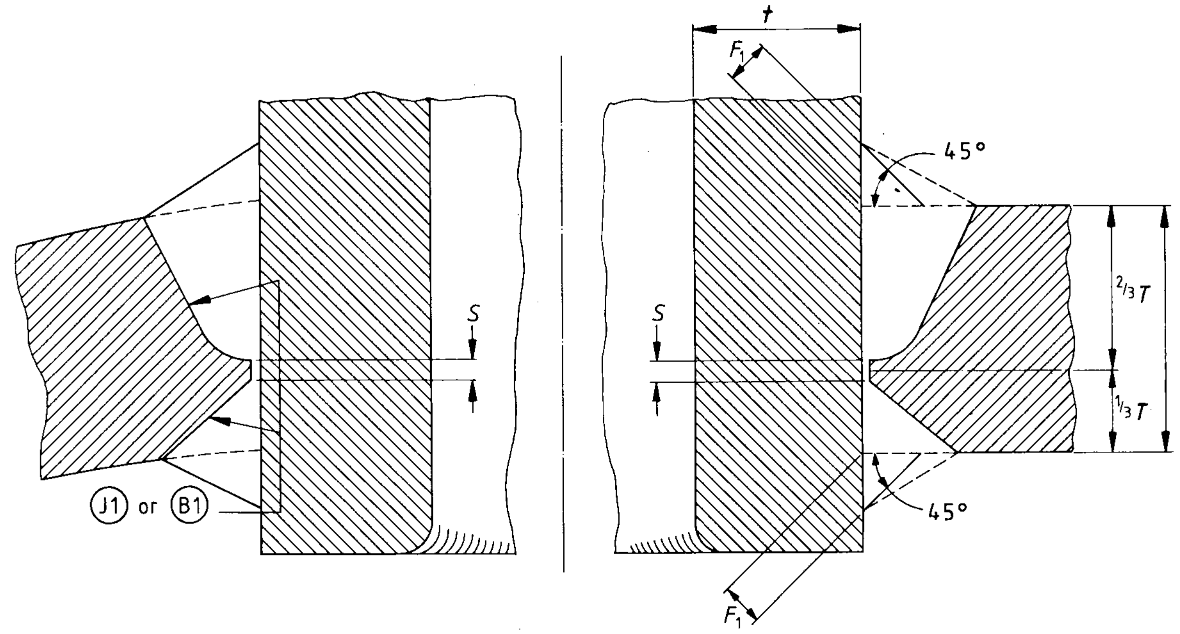
a)



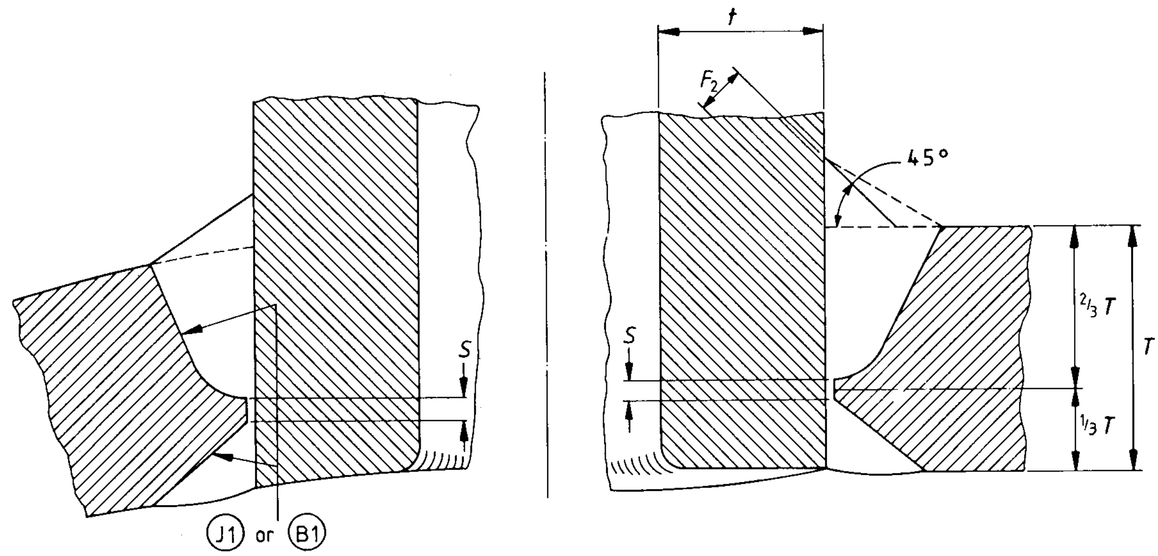
F_2 = T/5 min. or 6 mm whichever is larger

b)

Figure C.13 Set-in branches: full penetration connections

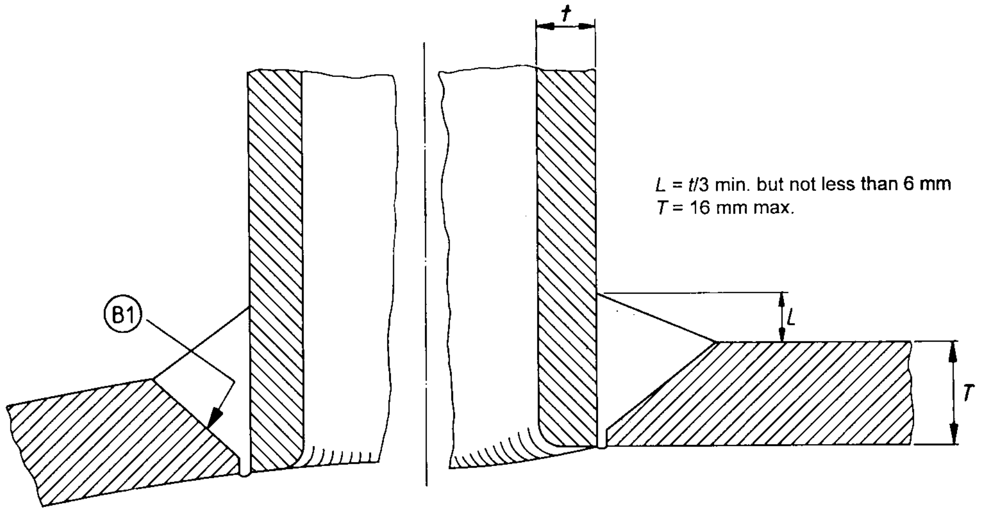


S = 1.5 mm to 2.5 mm
F_1 = T/10 min. or 6 mm whichever is larger
a)

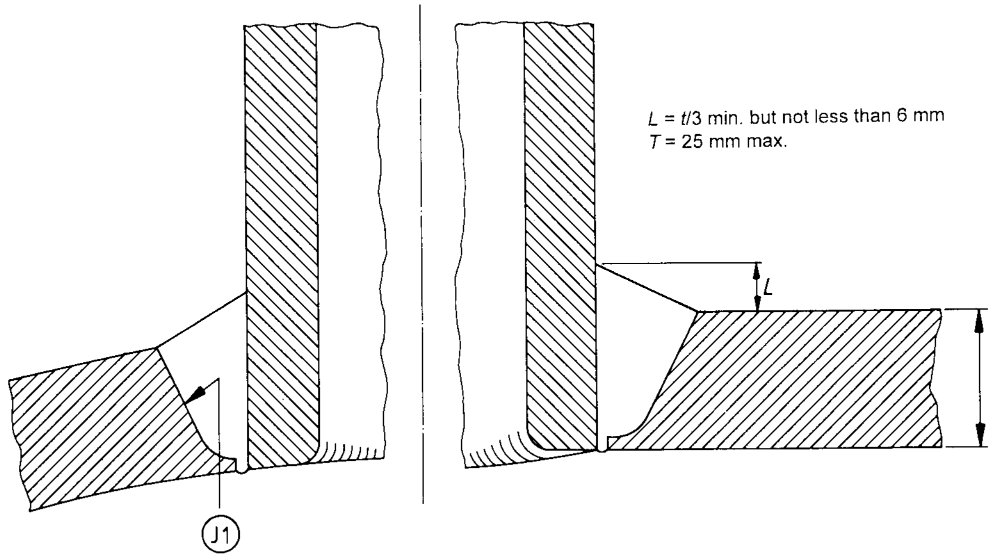


S = 1.5 mm to 2.5 mm
F_2 = T/5 min. or 6 mm whichever is larger
b)

Figure C.14 Set-in branches: full penetration connections with asymmetrical butt joints



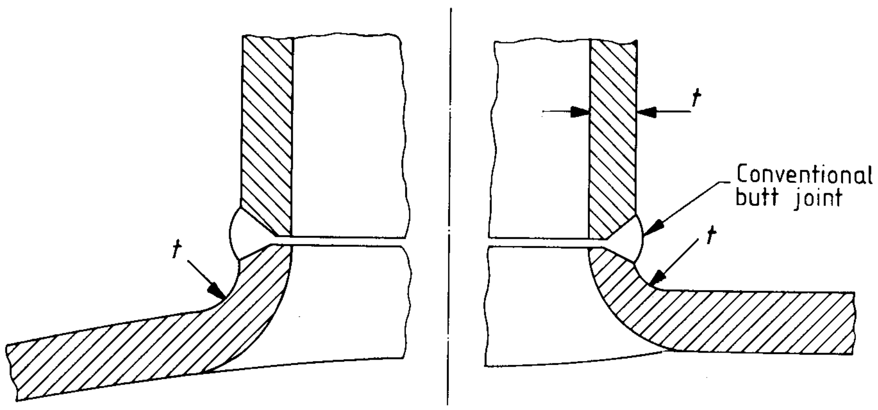
a)



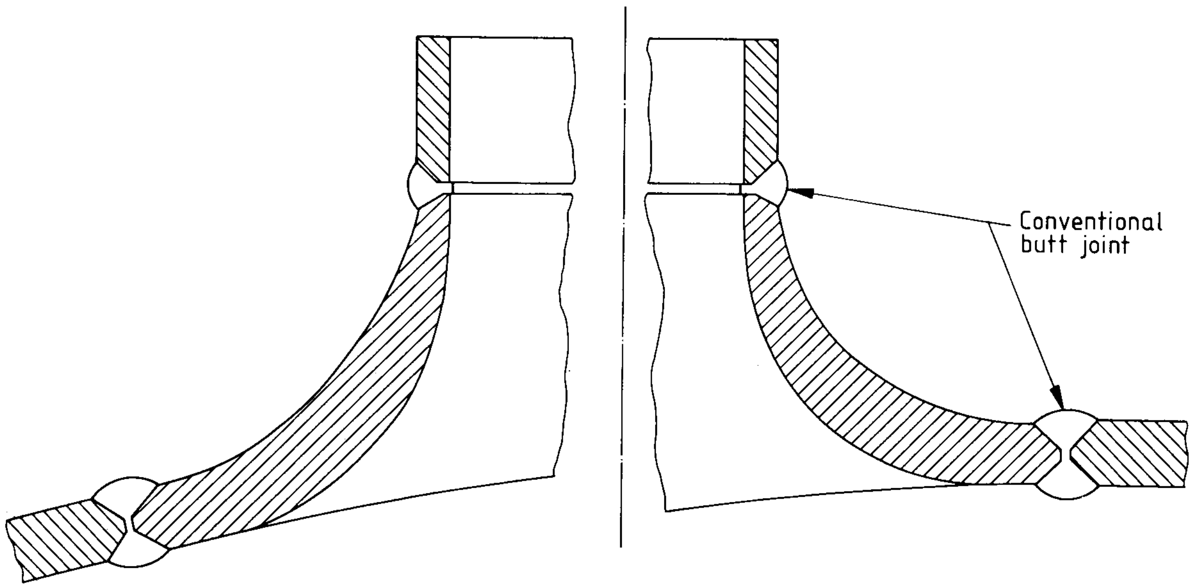
b)

These connections are considered to be acceptable only if assurance can be provided that the welding procedure employed will ensure sound and consistent root conditions with uniform penetration

Figure C.15 Set-in branches: full penetration connections welded from one side only



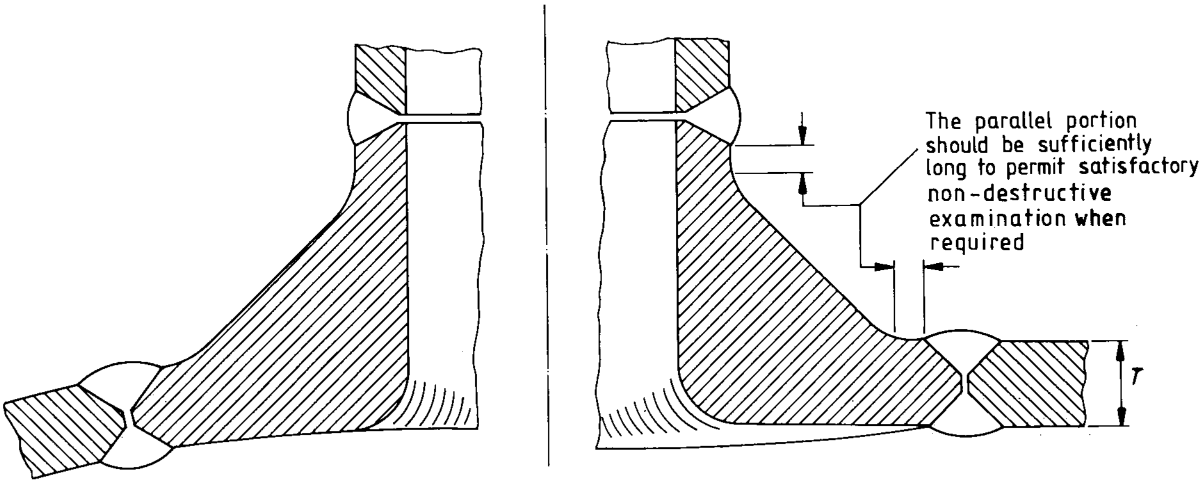
a)



b)

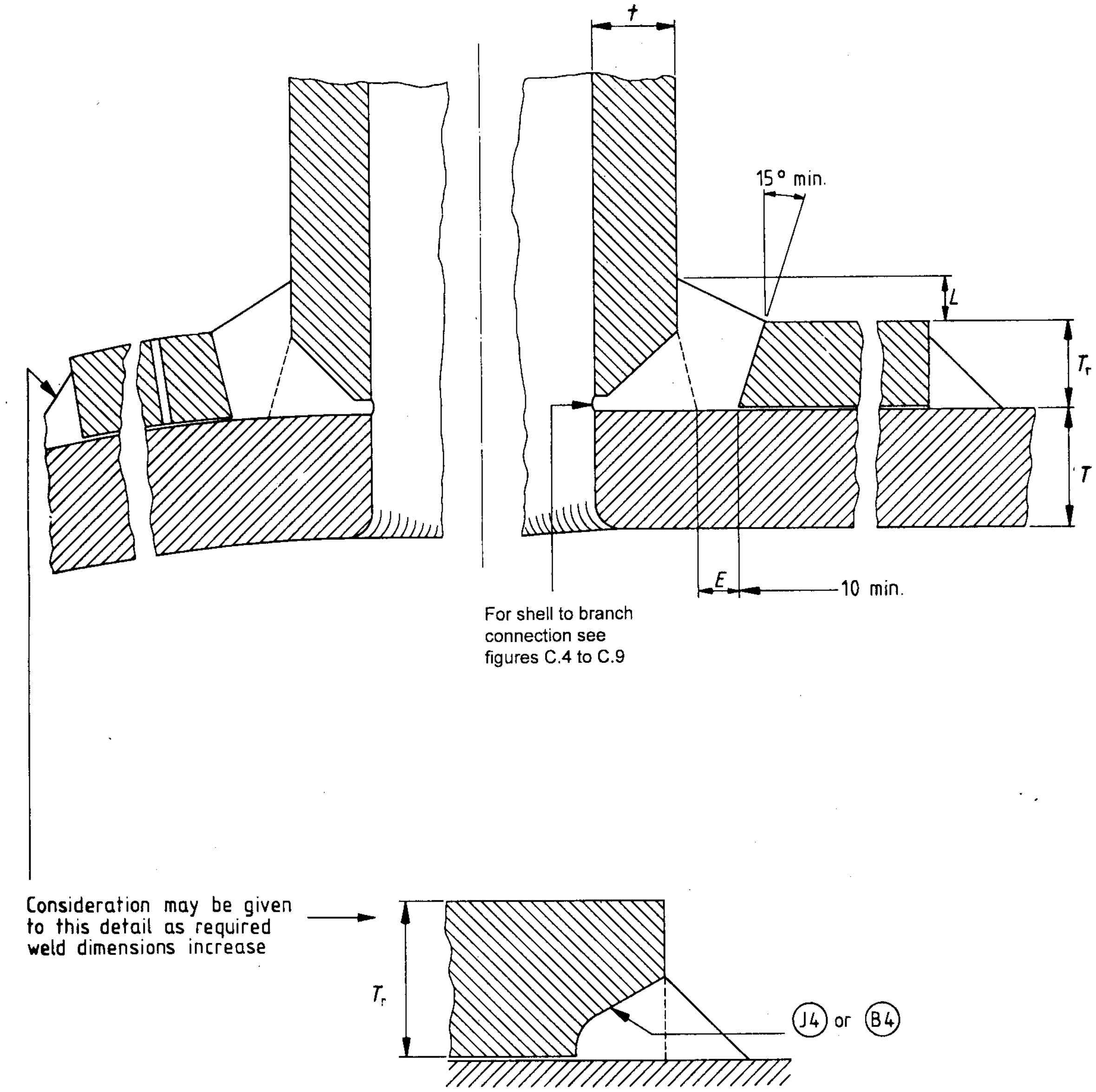
NOTE. Conventional butt joints are used to weld the forged branch connections to the shell and branch, and may not necessarily be of the form shown

Figure C.16 Forged branch connections



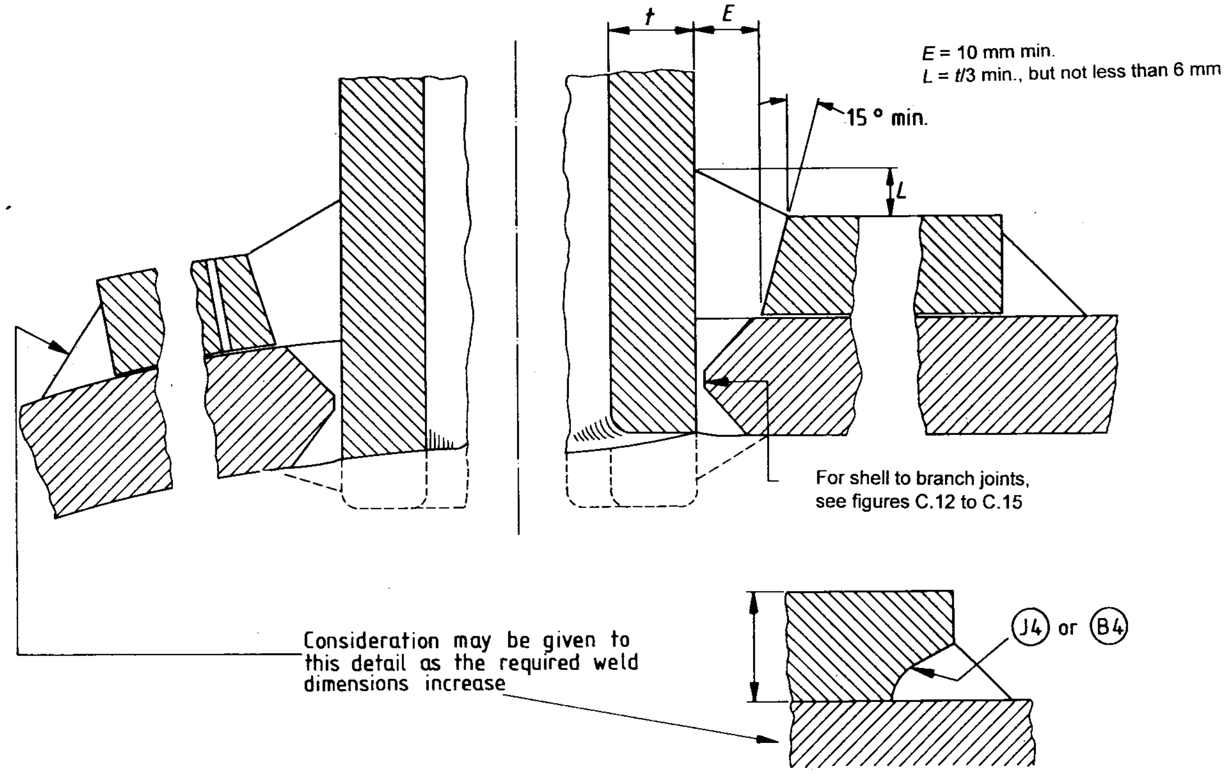
NOTE. Conventional butt joints are used to connect the forging to the shell and may not necessarily be of the form shown. These forgings connecting branches to shells are used with various forms to profile.

Figure C.17 Forged branch connections



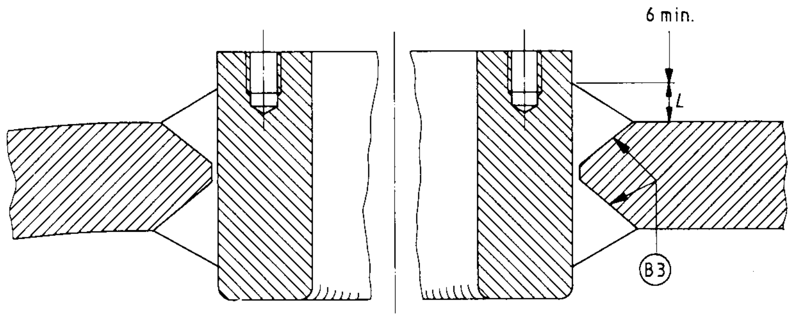
NOTE. Compensating plates should not be used when severe temperature gradients occur across the thickness of the shell (see **3.4.6.1**).

Figure C.18 Set-on branches with added compensation plates

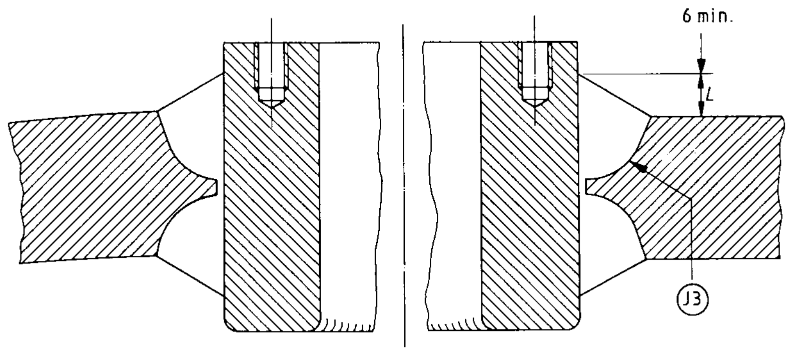


NOTE. Compensating plates should not be used when severe temperature gradients occur across the thickness of the shell (see **3.4.6.1**).

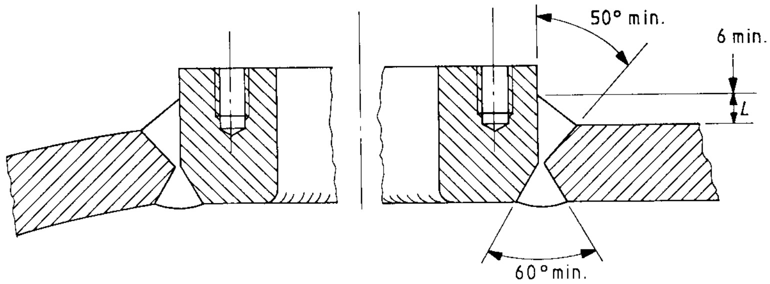
Figure C.19 Set-on branches with added compensation plates



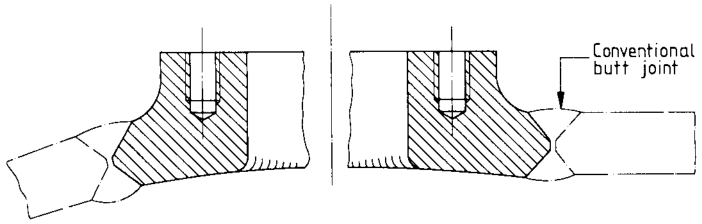
a)



b)



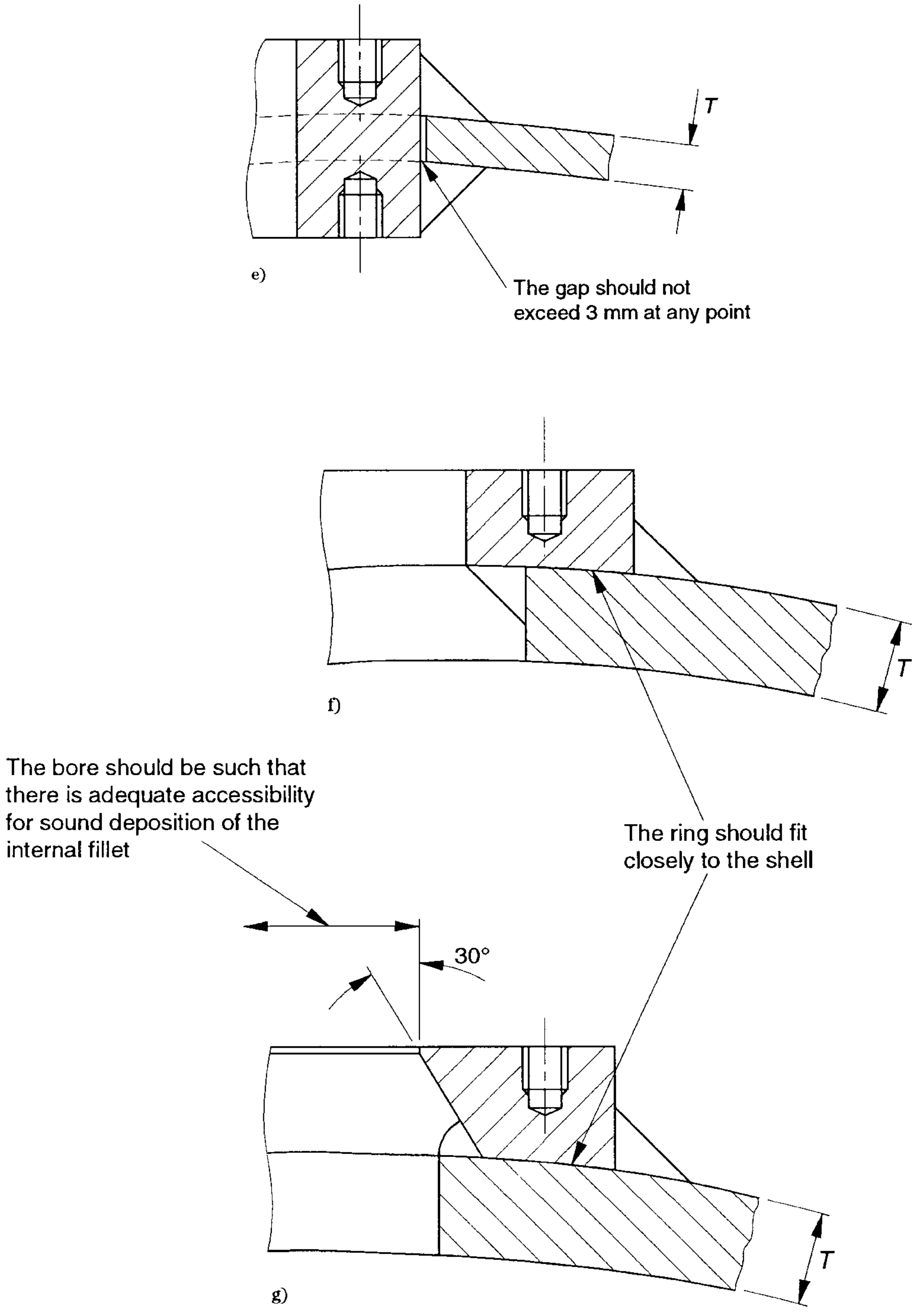
c)



Butt welded studded connections

d)

Figure C.20 Studded connections (see also **3.4.8**)



NOTE 1. Fillet welded details are not recommended if the vessel is subjected to pulsating loads when preference should be given to the details shown in a) to d).

NOTE 2. Fillet welded connections are not permitted where the calculation pressure exceeds 4 N/mm^2.
Detail e) is permitted only for connections up to and including 100 mm bore in carbon or carbon manganese steel.

NOTE 3. The dimensions of the fillet welds should be based on the loads treansmitted paying due regard to all fabrications and service requirements, but in any case should not be less than 6 mm.

Figure C.20 Studded connections (see also 3.4.8) (*continued*)

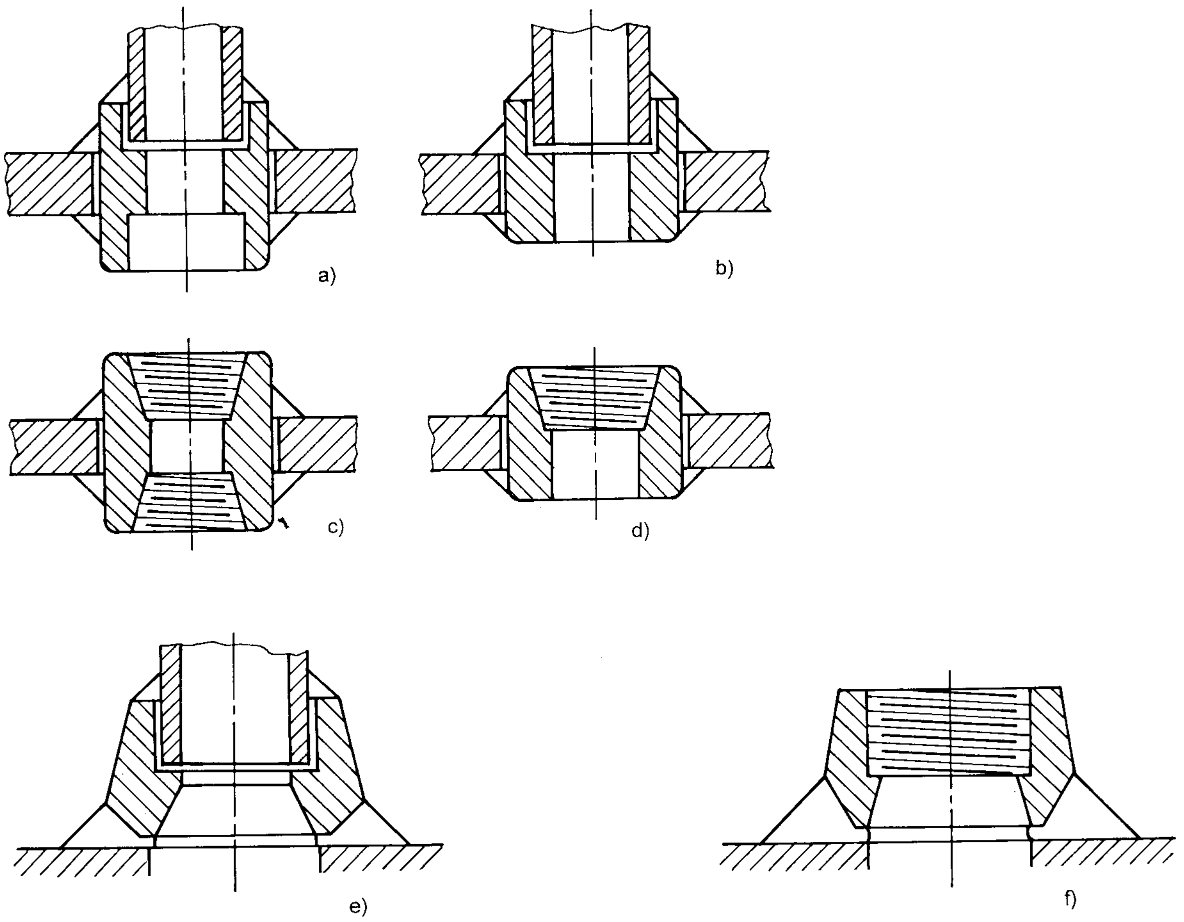
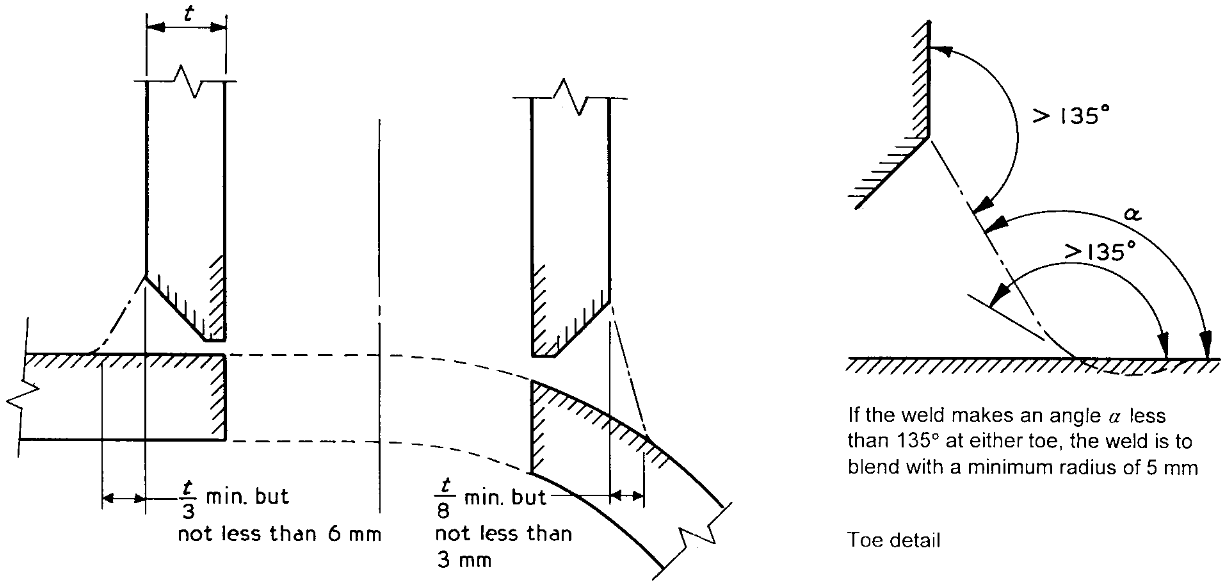


Figure C.21 Socket welded and screwed connections

t is the mean thickness of branch

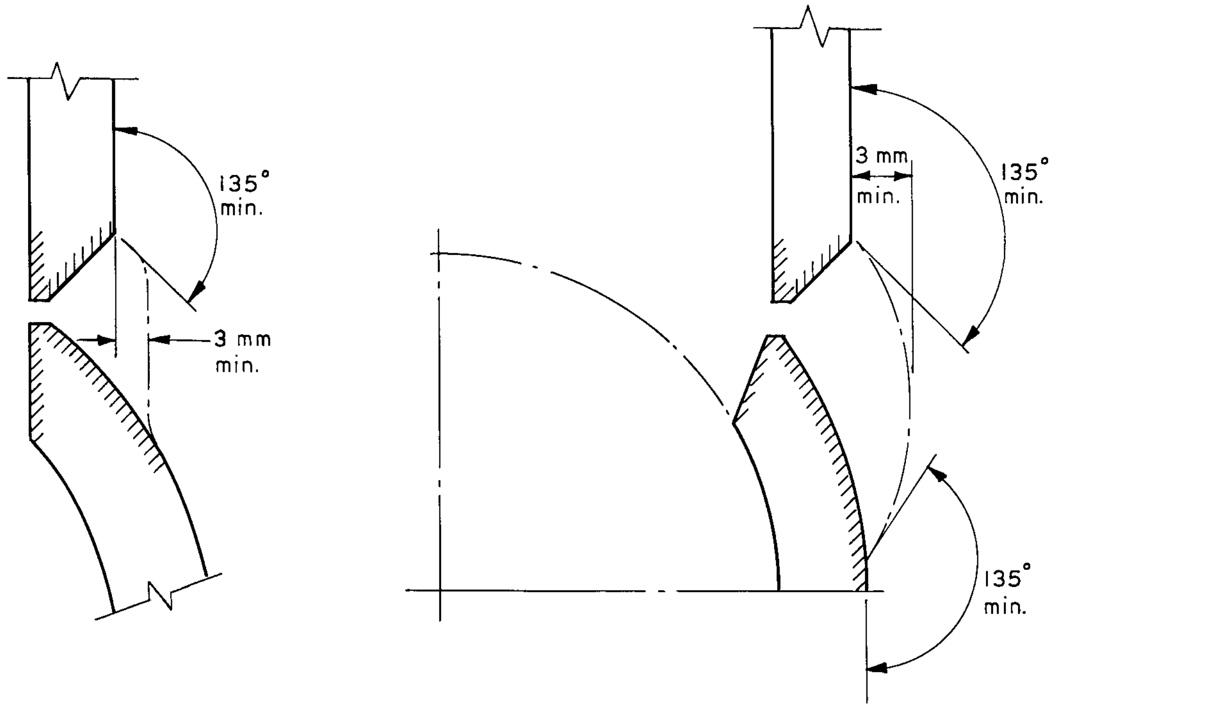


Crotch

For all branch-main ratios

Flank a)

For ratio of branch o.d. to main o.d. of ⅔ or less



Flank b)

For ratio of branch o.d. to main o.d. greater than ⅔

Flank c)

For equal branch and main o.d

NOTE. The welded preparation in the shaded areas needs to be determined by the weld process and the appropriate welding standard.

Figure C.22 Minimum dimensions for external profiles of welds at branches: class 1 welding

Annex D

Basis of the design charts for openings and branches (see 3.4)

D.1 General

The design curves have been produced from consideration of the requirement to avoid incremental plastic strain during repeated pressure loading of the vessel. The method is closely related to that which was incorporated in BS 1515 (withdrawn), and in BS 3915, but has been extended to cater for large diameter flush branches in a cylindrical shell.

A distinction is drawn between openings or branches that are closely pitched and those that can be treated as isolated. For isolated openings and branches, a limited amount of plastic deformation in the most severely stressed regions can safely be permitted during initial operating cycles. A residual stress distribution is established and subsequent structural response is entirely elastic. This 'shakedown' behaviour is achieved by controlling the maximum stress (calculated on a linear elastic basis) in the region of the branch. For multiple openings or branches, the primary requirement is to limit the ligament stresses in the shell.

D.2 Isolated openings and branches

D.2.1 *Branches in spherical shells*

Theoretical stress concentration factors (s.c.f.), defined as the ratio of the maximum direct stress component to the hoop stress in the unpierced shell, are used. They are given in reports by Leckie and Penny (see [1][13)]) and are derived from thin shell analyses. This means that very local effects arising for example from fillet weld details are not represented, although the gross behaviour of the structure is well predicted. It is found that, where the shell has uniform thickness T_r in the region of the branch (or opening), the theoretical s.c.f. can, to a good approximation, be obtained as a function of the branch to shell thickness ratio t_r/T_r and the parameter $\rho = (d/D) \sqrt{(D/2T_r)}$ independently of the particular values of d/D and D/T_r for the range considered. For a fixed shell diameter, increasing the thickness T_r reduces the general stress level in the shell so permitting an intrinsically higher s.c.f. to be used without exceeding the shakedown limit. The allowable maximum, elastically calculated stress is set at 2.25 times the allowable stress in the unreinforced shell. Hence a set of curves can be plotted giving the required branch to shell thickness ratio t_r/T_r as a function of the ρ parameter and the shell thickening.

D.2.2 Branches in a cylindrical shell

Where the ratio of the diameter of the branch (or opening) to the diameter of the shell is small ($d/D < 0.2$), s.c.f. values from axisymmetric cylinder/sphere analyses are used as approximations for the cylinder/cylinder geometries with the same ρ and t_r/T_r parameters and experimental results indicate it is a reasonable approach (see [2]). For larger branch to shell diameter ratios ($d/D > 0.3$), an axisymmetric analysis is not sufficiently realistic. Protruding nozzle designs are unlikely to be used, and specific rules are not given. For flush designs, s.c.f. values have been based on an empirical formula derived by Money (see [3]) in 1966 from a review of experimentally determined stresses, and subsequently revised to take account of some more recent results, e.g. those of Findlay, Moffat and Spence (see [4]). In the intermediate range, $0.2 < d/D < 0.3$, linear interpolation is used to avoid possible step changes in thickness requirements for certain small changes in branch diameter. For branches in cylindrical shells, the maximum allowable stress is not set at a unique value but allowed to vary according to the estimated shakedown factor for the geometry (i.e. ratio of the maximum shakedown pressure to the minimum pressure to cause yielding). This is related to the s.c.f. by a formula derived by Macfarlane and Findlay (see [5]) in a simplified theoretical analysis assuming a Tresca yield criterion.

D.3 Design factors

The idealized nature of the mathematical models used in the calculations makes it prudent to have a factor of safety between the design pressure and the maximum pressure for which the theory predicts that shakedown will occur. The factor C is incorporated in the design charts for this purpose. When C is taken as 1.1 (the maximum value permitted) there is a 10 % margin on pressure. Smaller values of C result in more branch reinforcement, and may be used to cater for mechanical loads that may be present in addition to normal pressure loading.

Pipework can exert considerable forces and moments at terminal points. The effect can only be accurately qualified by a full computer analysis of all anticipated operating conditions. However, experience suggests that, for well designed and correctly erected piping systems, the combined pressure and pipework stresses at the shell intersection will not exceed the maximum stress due to design pressure alone by more than 10 %. This is accommodated in the design charts by choosing the factor $C = 1.0$.

Under high temperature conditions, creep may interact with the shakedown process in a complex manner depending upon the operational cycle. A more conservative design should therefore be adopted by taking the maximum value of C as 1.0 for any such application.

---

13) The numbers in square brackets relate to the bibliographical references given in **D.6**.

D.4 Multiple branches

Where the minimum pitch in a group of openings or branches is less than the limit specified in **3.4.5**, the design rules are based on the long established area replacement concept. In order to avoid undesirable and unwarranted changes in thickness at an arbitrary pitch, a transition range is provided where linear interpolation is used between the requirements for isolated branches and those of full area replacement.

D.5 Flush nozzles in cylindrical shells

A more detailed account of the derivation of the method with particular reference to flush nozzles in cylindrical shells is given in a paper by Lewis and Price (see [6]).

D.6 Bibliography

1. LECKIE, F.A. and PENNY, R.K. 1963. Weld. Res. Coun. Bull. No. 90.

2. ROSE, R.T. Pressure vessel research towards better design. Proc. Symp. 1962. Institution of Mechanical Engineers.

3. MONEY, H.A. A.S.M.E. Meeting. Dallas. September 1968. Paper 68-PVP-17.

4. FINDLAY, G.E., MOFFAT, D.G. and SPENCE, J. Proc. 4th Inst. Conf. Experimental stress analysis. Cambridge. 1970. Institution of Mechanical Engineers. Paper 5.

5. MACFARLANE, W.A. and FINDLAY, G.E. Proc. Instn. Mech. Engrs. 1972: 186. Paper 4.

6. LEWIS, D.J. and PRICE, R.H. A shakedown approach to the reinforcement of flush branches in cylindrical pressure vessels below the creep range. CEGB Report No. RD/B/N2569.

Annex E
Area replacement design method

E.1 This method of compensation has been widely used and has a satisfactory history. However it will sometimes provide excessive thickness because of the simplified nature of the calculations and it is not suitable in all cases. It is recommended that its use be restricted to cases where experience has shown it to be satisfactory.

E.2 This method of compensation takes account of the cross-sectional area of locally disposed material; including the attachment welds, in excess of the minimum requirements for plate and branch thicknesses as shown in figure E.2a) and b), the branch thickness being increased where required as shown in figure C.9b). For compensation of opening without a branch, see figure E.2c).

Area *X* should be calculated as the product of the inside radius of the branch or opening and the thickness *T* which would be required for the shell if it were entirely unpierced by tube or other holes.

Area *Y* should be measured in a plane through the axis of the branch parallel to the longitudinal axis of the drum and should 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 *N* 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 equations (31) and (32) disregarding the minimum thickness from table 3.7.1.1.

b) Add to it the full sectional area of that part of the stem which projects inside the shell up to a distance *N* 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 *T* by length *S*.

Where achievement of an adequate area *Y* is not practicable using the above method, additional requirement should be provided in accordance with any of the typical arrangements shown in figures C-17, C-18 or C-19 or by using an alternative method mutually agreed between the purchaser, the manufacturer and the Inspecting Authority.

In this case the sectional area of the additional reinforcement and its attachment welds should be taken into account within the confines of dimensions *N* and *S*. *S* being as shown in figure E.2 and *N* being amended to equal the smaller of the two values $2.5T_a$ or $T_p + 2.5t_a$ where:

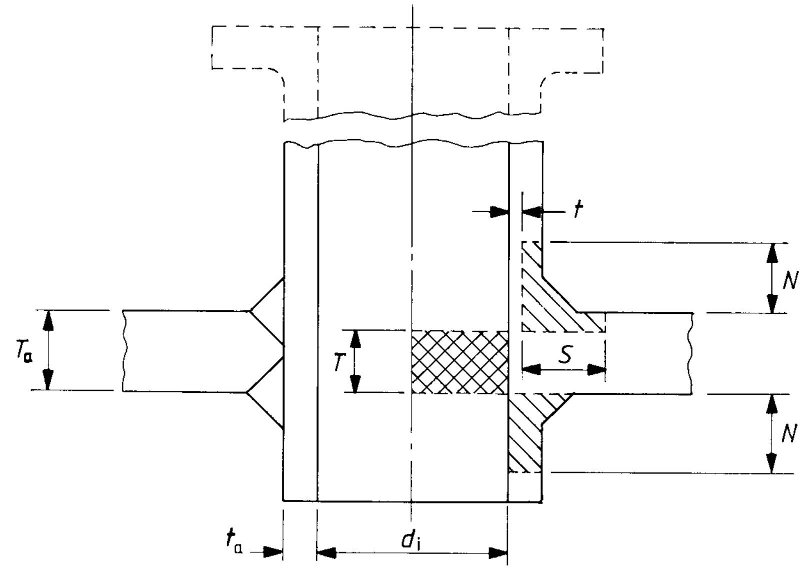
– T_a is the actual thickness of the shell plate (in mm);

– t_a is the actual thickness of the branch wall (in mm);

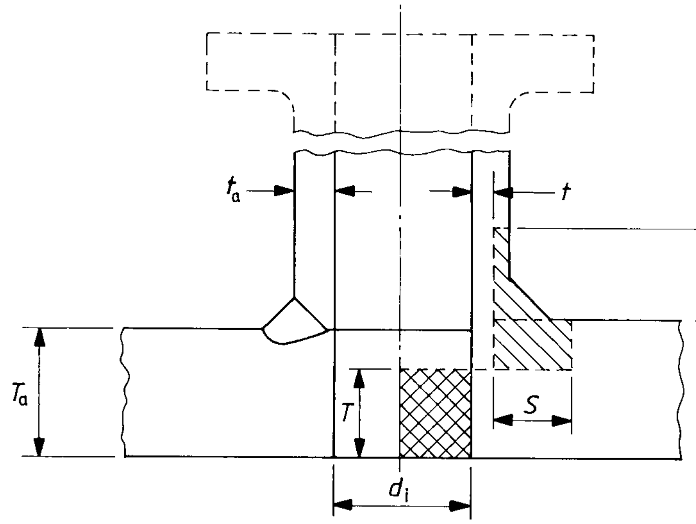
– T_p is the actual thickness of the added reinforcement on the outside of the shell plate (in mm).

Where material having a lower allowable stress than that of the shell or end is taken as compensation, its effective area should be assumed to be reduced in the ratio of the design stresses at the design temperature. No credit should be taken for the additional strength of material having a higher stress value than that in the shell or end plate.

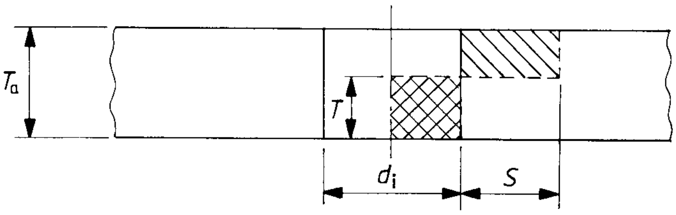
Where reinforcement is achieved by taking account of the cross-sectional area, compensation should be considered adequate when the compensation area *Y* is equal to or greater than the area *X* requiring compensation.



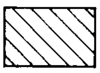
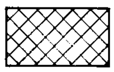
a) Set-through branch



b) Set-on branch



c) Opening

The area Y  should not be less than the area X 

T is the thickness calculated in accordance with equation (1) or (2), disregarding the minimum thickness required by **3.3.1**;

t is the thickness calculated in accordance with **3.7.1** disregarding the minimum thickness given in table 3.7.1.1;

N is the smaller of the two values: $2.5T_a$ or $2.5t_a$;

S is the greater of the two values: $(T_a + 75\text{ mm})$ or $d_i/2$

Figure E.2 Compensation of welded branch or standpipe

Annex F *Text deleted*

Annex G
Inspection and testing facilities

G.1 Inspection facilities

The purchaser or his representative should have access, at all reasonable times, to those portions of the manufacturer's works in which the production is being carried out and in which the testing is taking place.

G.2 Testing facilities

The manufacturer should supply labour and appliances for such testing as may be carried out on his premises in accordance with this standard. Failing facilities at his own works for making the prescribed tests, the manufacturer should make arrangements for carrying out the tests elsewhere.

Annex H (normative)
Tube bending procedure tests

H.1 General

H.1.1 Tube bending procedure tests, in accordance with **H.2**, shall be carried out on tubes of the material groups listed in table 2.1.2.

Conformance of steel boiler and superheater tubes with this annex shall be deemed as sufficient qualification for other lower alloyed or softer materials (lower UTS) in the same group. In particular, conformance of steel grade 243 shall be sufficient to qualify steel of grades 320, 360 and 440; conformance of steel grade 622 qualifies steel grade 620 and steel grade 762 qualifies steel grades 629 and 91.

H.1.2 Demonstration bends produced for these tests shall be bent to an angle of at least 90°. This shall be deemed to represent the minimum requirements for all bend angles. The DFC shall be measured at the bend apex and the thickness measurements shall be taken at 30° intervals from within the bend angle. Thickness determination shall be by sectioning. If required by **H.2.4.6**, mechanical test specimens shall be taken from either:

a) within the bend angle; or

b) from the straight tube adjacent to the commencement of the bend, which shall have been subject to the same heat treatment, if any, as the bend.

NOTE. Option a) is preferred.

H.1.3 The manufacturer shall prepare documented records of all tube bend procedure tests.

H.2 Procedure tests and requirements

H.2.1 *Tube bending processes*

The tube bending processes employed shall be any of the following:

- rotary draw bend (with or without mandrel);
- boost bending (with or without mandrel);
- press or squeeze bending;
- roll bending;
- any of the above, in conjunction with local automatic strip heating on the intrados of the bend;
- gang bending for water wall panels;
- another bending process, subject to agreement with the Inspecting Authority.

NOTE. The bending process is characterized by the form of tooling used on a specific machine. A change to a similar machine, of different load capacity, using the same tooling, does not require requalification.

Other than for local automatic strip heating, where hot bending is employed, heating shall be by an induction process or by heating in a gas fired or other form of furnace or muffle.

H.2.2 *Post bend heat treatment*

Demonstration bends shall be subject to post bend heat treatment (PBHT), if required, in accordance with **4.2.4.6** prior to testing.

Separate qualification shall be carried out for the following:

- cold bending with PBHT;
- cold bending without PBHT;
- hot bending with PBHT;
- hot bending without PBHT.

Any test bends made using controlled local automatic strip heating on the intrados of the bend, except those in steel grades 320, 360, 440 and 243, shall be normalized, or normalized and tempered in accordance with **4.5.2.3**.

H.2.3 *Tube forming ratio*

The tube forming ratio (TFR) shall be calculated for a tube of each material group and each process, using the following equation:

$$\text{TFR} = \frac{D^2}{e \times r}$$

where:

D is the tube outside diameter (in mm);

e is the nominal tube wall thickness (in mm);

r is the radius of bend measured to the centreline of the tube (in mm).

The TFR for other tube bends of the same material group, and made using the same bending process, may be calculated, and shall fall within 110 % of the first value calculated for the first bend.

NOTE. Any combination of D, e and r is acceptable.

EXAMPLE:

The following is an example of the calculation of the TFR for a tube bend of material group 1, produced by cold rotary drawing, with the following dimensions:

–	outside diameter of tube (D)	51 mm;
–	nominal tube thickness (e)	5 mm;
–	radius of bend (r)	150 mm.

$$\text{TDR} = \frac{D^2}{e \times r} = \frac{51^2}{5 \times 150} =$$

$$= 3.468 \times 110\,\% \text{ for validity range} = 3.815$$

Table H.2.3 gives examples of dimensions and subsequently calculated TFR for other tube bends, of the same material group and bent on the same machine, and indicates which tube bends would fall within the validity range.

Table H.2.3 Examples of validity range

Dimensions in millimetres

Outside diameter of tube *D*	Nominal tube thickness *e*	Radius of bend *r*	Tube forming ratio TFR	Within validity range
44.5	4	133	3.772	Yes
44.5	5	133	2.978	Yes
51	4	150	4.335	No[1)]
51	6	200	2.168	Yes
63.5	5	190	4.244	No[1)]
63.5	8	150	3.360	Yes
70	6	210	3.889	No[1)]
70	8	250	2.450	Yes
76.1	7	228	3.628	Yes
76.1	8	190	3.810	Yes

[1)] New qualification required.

H.2.4 *Test requirements*

H.2.4.1 *General*

The demonstration bend produced in accordance with **H.1.2** on the nominated bending machine, subjected to PBHT in accordance with **H.2.2** if required, shall be subjected to the tests specified in **H.2.4.2** to **H.2.4.8**.

H.2.4.2 *Visual examination*

The outer surface of the bend shall be visually examined and shall conform to **4.2.4.7**.

H.2.4.3 *Transverse examination*

Demonstration bends made from steel grades 91, 629 and 762 shall be examined for transverse defects on the outside diameter of the bend by means of magnetic particle examination in accordance with BS EN 1290. Demonstration bends made from steel grades 304, 316, 321, 347 and 215 shall be examined for transverse defects by means of dye penetrant examination in accordance with BS EN 571 : Part 1.

H.2.4.4 *Bend geometry*

The tube bend geometry shall conform to **4.2.4.5**.

H.2.4.5 *Hardness tests*

For hot formed bends, or bends requiring PBHT, the hardness at the extrados of the bend shall be measured after completion of the heating process. The hardness shall not be more than 80 Hv 10 higher than the hardness of the undeformed material.

H.2.4.6 *Mechanical tests*

All hot formed bends, or bends requiring PBHT other than stress relieving, shall be sectioned and subjected to the following mechanical tests:

– tensile tests in accordance with BS EN 10002 : Part 1;

– Charpy V-notch tests in accordance with BS EN 10045 : Part 1, if required by the material standard for the bend concerned.

NOTE. Specimens should be taken from within the bend, see **H.1.2**.

The number and position of the specimens shall be as specified in BS 3059 and the resulting values shall conform to the material values specified in BS 3059.

H.2.4.7 *Thickness measurement*

The thickness at any point, determined in accordance with **H.1.2** after bending, shall be determined and shall conform to **4.2.4.4**.

H.2.4.8 *Gang bending of tube panels*

Demonstration tube bends produced by the gang bending method shall conform to the requirements for single tube demonstration bends specified in this annex.

The gang bending method shall be qualified by a tube bending procedure test valid for the specific gang bending machine used. The tube panel shall consist of at least three tubes which have been welded together prior to gang bending.

Annex J (informative)
Manufacture of welded tubewalls

J.1 Methods of manufacture

J.1.1 *General*

The manufacturing processes should be in accordance with either **J.1.2**, **J.1.3** or **J.1.4**.

NOTE. This annex applies to gas tight welded tubewalls which are usually used in water-tube boiler construction.

J.1.2 *Tubes finned by welding*

Tubes finned by welding should be manufactured by one of the following processes:

– welding tubes together by the insertion of a fin (bar steel) between them, with closure welds between the edges of the fin and the adjacent tubes in accordance with a), b), and c) of figure J.1.2;

– welding of individual fins (bar steel), of half the fin space width, to each tube to form a series of finned tubes with closure welds between the edges of the abutting fins in accordance with figure J.1.2d.

J.1.3 *Integrally finned tubes*

Integrally finned tubes should be welded so that the closure welds are between the edges of the abutting fins in accordance with figure J.1.2e.

NOTE. Integrally finned tubing is supplied directly by the tube manufacturer, with fins produced by a rolling or extrusion process.

Integrally finned tubes should be subjected to an acceptance test to ensure that fin twisting, centreline deviation and offset are contained within the limits set by the boiler manufacturer, to ensure that dimensional requirements and weld quality can be achieved.

J.1.4 *Other methods*

Alternative methods of manufacture can be used, in which case the finned tube should conform to **J.4** and **J.5**.

J.2 Materials

J.2.1 *Tubes*

Materials for tubes used for tubewall construction should be supplied in accordance with **2.1.2**.

J.2.2 *Fins*

Steels for fins should be in accordance with **2.1.3**.

NOTE. Fins may be made from plate, bar steel or flat rolled wire.

J.2.3 *Filler metals*

Filler metals should be compatible with tube and fin materials.

J.3 Manufacturing processes and controls

J.3.1 *Welding processes*

The welding processes used should be selected according to the material, tube dimensions, manufacturing process and welding conditions involved. The selection should be at the discretion of the manufacturer and may include the following processes:

– manual metal arc;

– gas shielded metal arc;

– submerged arc;

– tungsten inert gas.

J.3.2 *Specific conditions for manufacture*

J.3.2.1 *Surface cleanliness*

The surface of the tube and the fin within the welding zone should be cleaned, to a level suitable for the welding process used, prior to welding.

J.3.2.2 *Fin to tube attachment welds*

J.3.2.2.1 *Unpenetrated tube wall*

The weld penetration should be such as to leave either a) or b).

a) A minimum of 2 mm of unpenetrated tube wall thickness, t_{unp} which may be achieved by the preselection of an appropriate tube wall thickness.

b) If t_{unp}, is less than 2 mm, it should not be less than the thickness specified in equations (31) or (32). In this case, post weld heat treatment should be applied in accordance with the time and temperature requirements specified in table 4.5.4, irrespective of the tube thickness.

J.3.2.2.2 *Weld attachment of the fin to the tube*

In order to ensure adequate heat transfer from the fin to the tube wall the attachment welds should conform to figures J.3.2.2-1 and J.3.2.2-2.

J.3.2.3 *Welding imperfections in fin to tube welds*

The limits of welding imperfections should be in accordance with table J.3.2.3.

J.3.2.4 *Site welding*

The site weld which joins the fin edges of adjacent panel sections of tubewalls should be a continuous longitudinal weld between fin edges. Any site welding directly to the tube surface should be limited to the small areas of make-up fin local to the tube butt welds between panel ends.

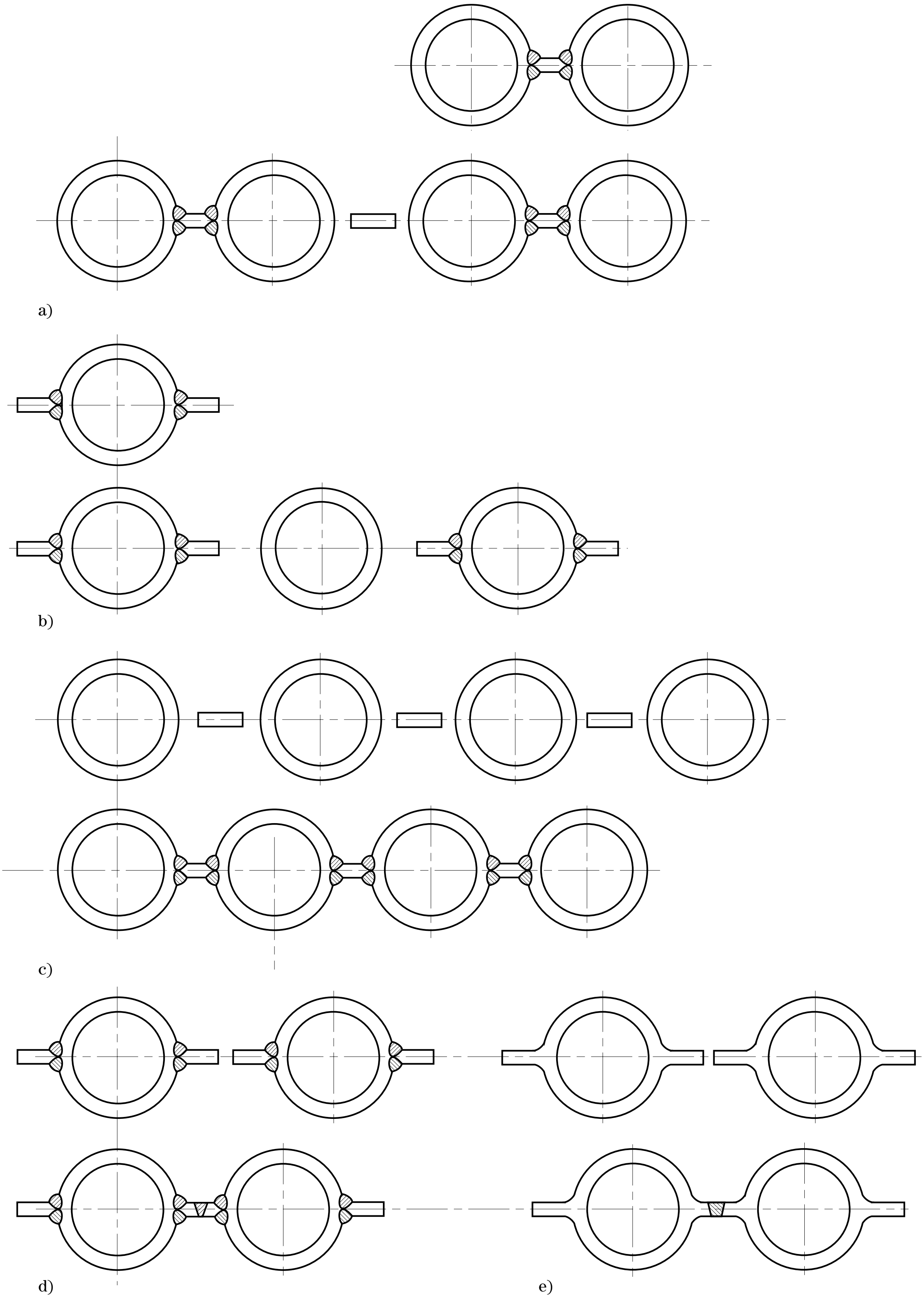
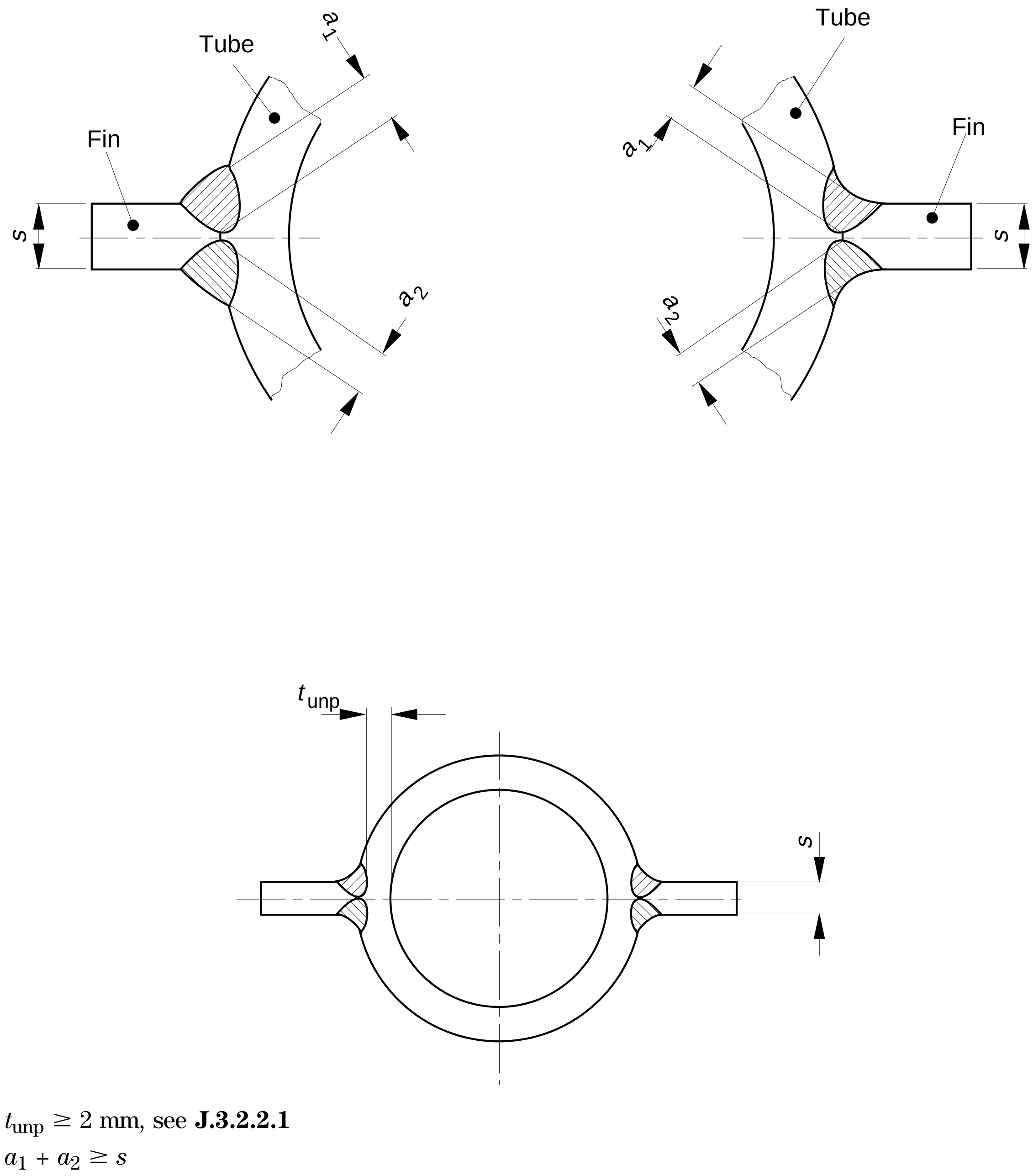


Figure J.1.2. Examples of tubewall construction



$t_{unp} \geq 2$ mm, see **J.3.2.2.1**

$a_1 + a_2 \geq s$

Figure J.3.2.2-1 Weld requirements for fin to tube welds

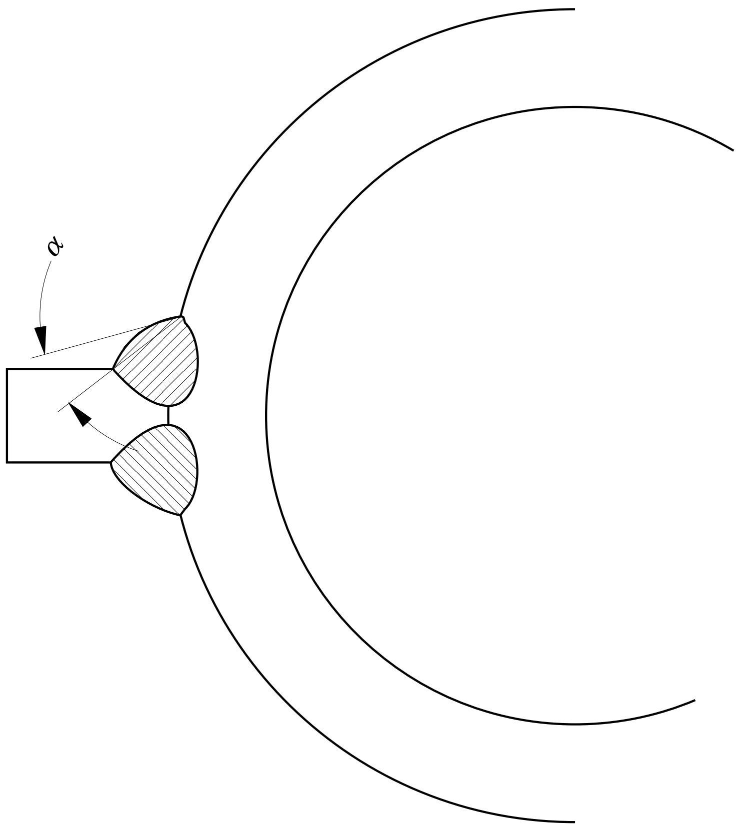


Figure J.3.2.2-2 Allowable excessive convexity for fin to tube welds

Table J.3.2.3. Limits for weld imperfections in fin to tube welds

BS EN 26520 Defect No.	Type of imperfection	Maximum permitted imperfection
100	Cracks (all)	Not permitted
200	Cavities (all)	When occurring at the surface, diameter ≤ 2 mm, with the additional condition that it does not occur at a stop or restart
301X 302X 3031 304X	Slag inclusions (all) Flux inclusions (all) Oxide inclusions Metallic inclusions (all)	Not permitted when occuring at the surface (shall be removed by grinding for example) Local oxide layers due to GTAW[1)] or GMAW[2)] are not defined as inclusions and are acceptable
401X	Lack of fusion (all)	Not permitted
5011 5012	Undercut	Depth ≤ 0.5 mm (whatever the length is), a smooth transition is required.
503	Excessive convexity	Weld shape should not be more than 30° convex, see figure J.3.2.2-2
507	Misalignment[3)]	≤ 2 mm, see figure J.4a
508	Angular misalignment[3)]	≤ 3 mm, see figure J.4b
510	Burn through	Not permitted. Unmelted remaining wall required ≥ 2 mm, but see **J.4.2.2**.
517	Poor restart	Not permitted
601	Stray flash or arc strike	Not permitted. Grinding is required plus DPE or MPE to ensure that no crack is left.
602	Spatter	Shall normally be removed; isolated spatter may however be permitted.
604	Grinding mark	Not permitted. Shall be flushed by grinding; a smooth transition is required.
605	Chipping mark	Not permitted. Shall be flushed by grinding; a smooth transition is required.
606	Underflushing	Not permitted. Minimum wall thickness required by design.

1) Gas tungsten arc weld (GTAW).

2) Gas metal arc weld (GMAW).

3) The misalignment is additional to any deliberate off-set included as part of the design.

J.3.3 *Heat treatment*

J.3.3.1 *Preheating*

If preheating is required, it should be carried out in accordance with **4.5.3**.

J.3.3.2 *Post weld heat treatment*

If post weld heat treatment is required, it should be carried out in accordance with table 4.5.4.

J.4 Welding procedure approvals

A welding procedure approval qualification test should be performed by the production of a test panel consisting of not less than three tubes to demonstrate that welding conforms to **5.2** and that the tubewall welds conform to figures J.3.2.2-1, J.3.2.2-2 and table J.3.2.3.

J.5 Production tests

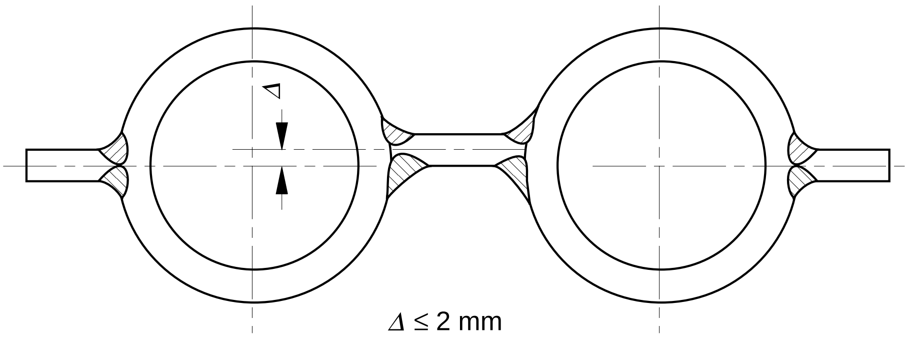
Prior to the commencement of a production run, a production test should be performed to demonstrate conformance of tubewall welds with figures J.3.2.2-1, J.3.2.2-2 and J.4.

If there are any significant changes in welding parameters or equipment during a production run then an additional production test should be carried out.

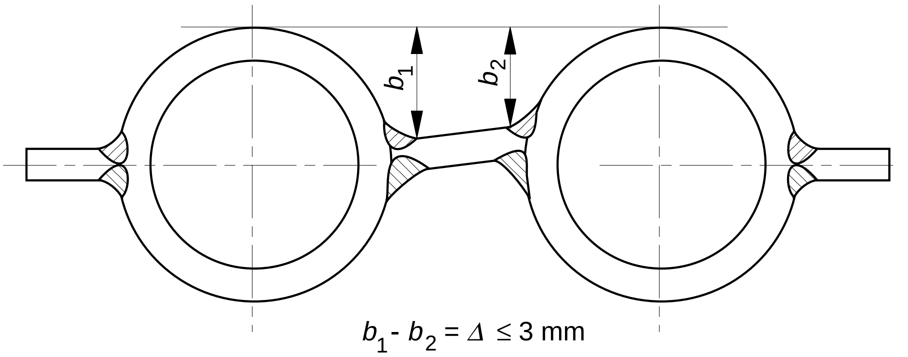
NOTE. A production run entails welding a series of tubes of the same size and material, to form a panel on a specific machine within the same machine set-up.

J.6 Non-destructive examination

100 % visual examination of all fin to tube welds should be performed and should be subject to the acceptance criteria recommended in table J.3.2.3.



a) Linear misalignment



b) Angular misalignment

Figure J.4. Allowable misalignment for fin to tube welds

List of references

See also references given in D.6

BSI publication

BSI publications

BRITISH STANDARDS INSTITUTION, London

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*
	Part 1 Glossary for welding, brazing and thermal cutting
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 1134	*Assessment of surface texture*
BS 1501	*Steels for pressure purposes: plates*
	Part 1 Specification for carbon and carbon manganese steels (withdrawn)
	Part 2 Specification for alloy steels: plates (withdrawn)
	Part 3 Specification for corrosion- and heat-resisting steels: plates, sheet and strip
BS 1502	*Specification for steels for fired and unfired pressure vessels: sections and bars*
BS 1503	*Specification for steel forgings for pressure purposes*
BS 1504	*Specification for steel castings for pressure purposes* (withdrawn)
BS 1515	*Fusion welded pressure vessels for use in the chemical, petroleum and allied industries* (withdrawn)
BS 1560	*Circular flanges for pipes, valves and fittings (class designated)*
	Section 3.1 Specification for steel flanges
BS 1640	*Specification for steel butt-welding pipe fittings for the petroleum industry*
	Part 1 Wrought carbon and ferritic alloy steel fittings
BS 1821	*Specification for class 1 oxyacetylene welding of ferritic steel pipework for carrying fluids*
BS 1957	*Presentation of numerical valves (fineness of expression; rounding of numbers)*
BS 1965	*Specification for butt-welding pipe fittings for pressure purposes*
	Part 1 Carbon steel
BS 2486	*Recommendations for treatment of water for steam boilers and water heaters*
BS 2600	*Radiographic examination of fusion welded butt joints in steel*
	Part 1 Methods for steel 2 mm up to and including 50 mm thick
	Part 2 Method for steel over 50 mm up to and including 200 mm thick
BS 2633	*Specification for class I arc welding of ferritic steel pipework for carrying fluids*
BS 2910	*Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes*
BS 3059	*Steel boiler and superheater tubes*
	Part 1 Specification for low tensile carbon steel tubes without specified elevated temperature properties
	Part 2 Specification for carbon, alloy and austenitic stainless steel tubes with specified elevated temperature properties
BS 3500	*Methods for creep and rupture testing of metals*
BS 3601	*Specification for carbon steel pipes and tubes with specified room temperature properties for pressure purposes*

BS 3602	*Specification for steel pipes and tubes for pressure purposes: carbon and carbon manganese steel with specified elevated temperature properties* *Part 1 Specification for seamless and electric resistance welding including induction welded tubes* *Part 2 Specification for longitudinally arc welded tubes*
BS 3604	*Specification for steel pipes and tubes for pressure purposes: ferritic alloy steel with specified elevated temperature properties* *Part 1 Specification for seamless and electric resistance welded tubes*
BS 3605	*Austenitic stainless steel pipes and tubes for pressure purposes* *Part 1 Specification for seamless tubes*
BS 3799	*Specification for steel pipe fittings, screwed and socket-welding for the petroleum industry*
BS 3915	*Specification for carbon and low alloy steel pressure vessels for primary circuits of nuclear reactors* (obsolescent)
BS 3920	*Derivation and verification of elevated temperature properties for steel products for pressure purposes*
BS 3923	*Methods for ultrasonic examination of welds* *Part 1 Methods for manual examination of fusion welds in ferritic steels* *Part 2 Automatic examination of fusion welded butt joints in ferritic steels*
BS 3971	*Specification for image quality indicators for industrial radiography (including guidance on their use)* (withdrawn)
BS 4124	*Methods for ultrasonic detection of imperfections in steel forgings*
BS 4204	*Specification for flash welding of steel tubes for pressure applications*
BS 4504	*Circular flanges for pipes, valves and fittings (PN designated)* *Section 3.1 Specification for steel flanges*
BS 4570	*Specification for fusion welding of steel castings*
BS 4677	*Specification for arc welding of austenitic stainless steel pipework for carrying fluids*
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 5046	*Method for the estimation of equivalent diameters in the heat treatment of steel*
BS 5135	*Specification for arc welding of carbon and carbon manganese steels*
BS 5500	*Specification for unfired fusion welded pressure vessels*
BS 5750	*Quality systems*
BS 5970	*Code of practice for thermal insulation of pipework and equipment (in the temperature range −100 °C to +870 °C)*
BS 5996	*Specification for acceptance levels for internal imperfections in steel plate, strip and wide flats, based on ultrasonic testing*
BS 6072	*Method for magnetic particle flaw detection*
BS 6208	*Method for ultrasonic testing of ferritic steel castings including quality levels*
BS 6693	*Diffusible hydrogen* *Part 2 Method for determination of hydrogen in manual metal-arc weld metal*
BS 6759	*Safety valves* *Part 1 Specification for safety valves for steam and hot water*
BS 7448	*Fracture mechanics toughness tests*
BS EN 287-1	*Approval testing of welders for fusion welding* *Part 1 Steels*
BS EN 288-1	*Specification and approval of welding procedures for metallic materials* *Part 1 General rules for arc welding*

BS EN 288-2	*Specification and approval of welding procedures for metallic materials* *Part 2 Welding procedure specification for arc welding*
BS EN 288-3	*Specification and approval of welding procedures for metallic materials* *Part 3 Welding procedure test for arc welding of steels*
BS EN 288-6	*Specification and approval of welding procedures for metallic materials* *Part 6 Approval related to previous experience*
BS EN 288-8	*Specification and approval of welding procedures for metallic materials* *Part 8 Approval by a pre-production welding test*
BS EN 473	*General principles for qualification and certification of NDT personnel*
BS EN 571-1	*Non-destructive testing — Penetrant testing*
BS EN 875	*Destructive tests on welds on metallic materials — Impact tests — Test specimen location, notch orientation and examination*
BS EN 876	*Destructive tests on welds in metallic materials — Longitudinal tensile test on weld metal in fusion welded joints*
BS EN 970	*Non-destructive examination of fusion welds — Visual examination*
BS EN 1011	*Welding — Recommendations for welding of metallic materials* *Part 1 General guidance for arc welding* *Part 2 Guidance for arc welding of ferritic steels*[14]
BS EN 1290	*Non-destructive examination of welds — Magnetic particle examination of welds*
BS EN 1321	*Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds*
BS EN 1418	*Welding personnel — Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanised and automatic welding of metallic materials*
BS EN 1435	*Non-destructive examination of welds — Radiographic examination of welded joints*
BS EN 1712	*Non-destructive examination of welds — Ultrasonic examination of welded joints — Acceptance levels*
BS EN 1713	*Non-destructive examination of welds — Ultrasonic examination — Characterization of indications in welds*
BS EN 1714	*Non-destructive examination of welded joints — Ultrasonic examination of welded joints*
BS EN 10002	*Tensile testing of metallic materials* *Part 1 Method of test at ambient temperature* *Part 5 Method of test at elevated temperatures*
BS EN 10028	*Specification for flat products made of steels for pressure purposes* *Part 1 General requirements* *Part 2 Non-alloy and alloy steels with specified elevated temperature properties* *Part 3 Weldable fine grain steels, normalized*
BS EN 10045	*Charpy impact test on metallic materials* *Part 1 Test method (V- and U- notches)*
prEN 10216	*Seamless steel tubes for pressure purposes — Technical delivery conditions* *Part 1 Non-alloy steel tubes with specified room temperature properties* *Part 2 Non-alloy and alloy steel tubes with specified elevated temperature properties* *Part 3 Non-alloy and alloy fine grain steel tubes* *Part 5 Stainless steel tubes*
prEN 10217	*Welded steel tubes for pressure purposes — Technical delivery conditions* *Part 1 Non-alloy steel tubes with specified room temperature properties* *Part 2 Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties* *Part 3 Alloy fine grain steel tubes* *Part 5 Stainless steel tubes*

[14] Not yet published.

BS EN 10222	*Steel forgings for pressure purposes*
	Part 2 Ferritic steels with elevated temperature properties
	Part 4 Fine grain steels with high proof strength
	Part 5 Martensitic, austenitic and austenitic-ferritic stainless steels
BS EN 10228	*Non-destructive testing of steel forgings*
	Part 2 Non-destructive testing of steel forgings
	Part 3 Ultrasonic testing of ferritic or martensitic steel forgings
BS EN 22553	*Welds — Symbolic representation on drawings*
BS EN 25817	*Arc-welded joints in steel — Guidance on quality levels for imperfections*
BS EN ISO 6520	*Welding and allied processes. Classification of imperfections in metallic materials*
	Part 1 Fusion welding
prEN ISO/TR 15608	*Welding — Guidelines for a metallic material grouping system*
PD 6493	*Guidance on methods for assessing the acceptability of flaws in fusion welded structures*
PD 6510	*A review of the present state of the art of assessing remnant life of pressure vessels and pressurized systems designed for high temperature service*

Other publications

Health and Safety Executive. *Standards significant to Health and Safety at Work*[15)]
COE, F.R. *Welding steels without hydrogen cracking.* The Welding Institute
ASME Boiler and pressure vessel code. *Section VIII Rules for construction of pressure vessels Division*[16)]
ASTM Specification SE-446. *Standard Reference Radiographs for Steel Castings Thickness*[16)]
ASTM Specification SE-186. *Standard Reference Radiographs for Heavy-Walled (2 to 4½* in) *Steel Castings*[16)]
ASTM Specification E125-63. *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Casting*[16)]

15) Referred to in the foreword only.
16) Available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL. Tel. 020 8996 9001.

blank

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

BS 1113 : 1999 Specification for design and manufacture of water-tube steam generating plant (including superheaters, repeaters and steel tube economizers)

Enquiry Cases — Introduction

In accordance with the provisions of clause **1.2**, the publication of Enquiry Cases will be notified in *Update Standards* and will be made available for inclusion in the ring-binder in a separate section following the text of this specification and the annexes.

The table below is for recording cases as they are published and included in the binder, and for noting their subsequent routing.

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 final page of 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 numbers in the first column will not be continuous because of these omissions.

Enquiry Case No.	Date of publication	Subject of the Enquiry Case	No. of pages	Subsequent Enquiry Case routing (e.g. incorporated into BS 1113)	Date of subsequent action
1113/2	November 1986	Use of ASTM A105, A106, A182, A234, A335 and A321 materials	3		Issue 3, June 1992
1113/4	August 1988	Implications of BS 3923 'Ultrasonic examination of welds' Part 1 : 1986 'Methods for manual examination of fusion welds in ferritic steels'	1		Issue 2, October 1989
1113/7	June 1992	Use of butt welds in tubes for manufacture of coils for coil type boilers/superheaters	1		Issue 2, January 1998
1113/8	October 1992	Ultrasonic acceptance criteria		Incorporated into 1999 edition	Withdrawn, November 1999
1113/9	September 1993	Welding procedure specification, welding procedure approval and welder approval		Incorporated into 1999 edition	Withdrawn, November 1999
1113/10	June 1995	Use of steel 91 tubing and piping			Withdrawn, January 1998
1113/11	March 1996	Combination of calculation pressure and design temperature	1		
1113/12	November 1996	Use of steel 91 forgings		Incorporated into 1999 edition	Withdrawn, November 1999
1113/13	October 2000	Essential Safety Requirements of the Pressure Equipment Directive	4		

blank

Enquiry Case 1113/2
Use of ASTM A105, A106, A182, A234, A335 and A312 materials

Enquiry

In order to deal with instances where materials complying with BS 1503, BS 1640, BS 1965, BS 3602, BS 3604 and BS 3605 are not available for use in the construction of water-tube steam generating plant complying with BS 1113, and where materials certified as complying with the following ASTM standards are available, can they be used as acceptable alternatives and, if so, what design stresses can be used without values of R_e(T) being verified?

ASTM A105	Specification for forgings, carbon steel, for piping components
ASTM A106	Specification for seamless carbon steel pipe for high temperature service
ASTM A182	Specification for forged or rolled alloy steel pipe flanges, forged fittings and valves and parts for high temperature service
ASTM A234	Specification for piping fittings of wrought carbon steel and alloy for moderate and elevated temperatures
ASTM A312	Specification for seamless and welded austenitic stainless steel pipe
ASTM A335	Specification for seamless ferritic alloy steel pipe for high temperature service

Reply

Based on the issues current in 1984 and subject to agreement on the use of such materials in accordance with **2.1.2.1**b, the following steels are acceptable.

ASTM A105	With maximum carbon 0.25 %
ASTM A106	Grade B with maximum carbon 0.25 %
ASTM A182	Grades F11, F12 and F22*
ASTM A234	Grades WPB, WP11, WP12, and WP22*
ASTM A312	Grades 304, 316, 321 and 347
ASTM A335	Grades P11, P12 and P22*

The design stresses given in table 1 of this Enquiry Case may be used without the verification of R_e(T) values.

* See note (B) to table 1 of this Enquiry Case.

Table 1. Design stress values (N/mm^2)

Letters in parentheses refer to the notes following this table.

Material	**Standard**	**Grade**	**Thickness** mm	**Values of *f* for design temperature (°C) not exceeding**														**Design lifetime**	**Notes**
				250	**300**	**350**	**380**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	h	(A)
Carbon	ASTM	—	≤ 100	130	119	113	111	110	*108*	*98*	*88*	*79*	*69*	*60*	*52*	*44*	*36*	100 000	
	A105		> 100	125				110	*103*	*93*	*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
								110	*100*	*90*	*80*	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
								107	*97*	*87*	*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
	ASTM	B		110	99	91			85	85	84	*79*	*69*	*60*	*52*	*44*	*36*	100 000	
	A106										*83*	*74*	*65*	*56*	*48*	*40*	*32*	150 000	
											80	*71*	*62*	*53*	*45*	*37*	*28*	200 000	
	ASTM	WPB									*78*	*68*	*59*	*51*	*42*	*35*	*26*	250 000	
	A234																		

Material	**Standard**	**Grade**	**Values of *f* for design temperature (°C) not exceeding**																**Design lifetime**	**Notes**
			250	**300**	**350**	**400**	**450**	**500**	**510**	**520**	**530**	**540**	**550**	**560**	**570**	**580**	**590**	**600**	h	(A)
1¼Cr½Mo	ASTM	F11	115	98	86	84	83	80	78	*76*	*62*	*52*	*42*	*33*	*27*				100 000	
1Cr½Mo	A182	F12							78	*67*	*55*	*44*	*35*	*29*	*24*				150 000	
	ASTM	WP11							*76*	*61*	*49*	*40*	*32*	*26*	*22*				200 000	
	A234	WP12							*70*	*57*	*45*	*37*	*30*	*25*	*20*				250 000	
	ASTM	P11																		
	A335	P12																		
2¼Cr1Mo	ASTM	F22	91	89	86	83	77	71	70	69	68	*61*	*53*	*45*	*39*	*34*	*29*	*26*	100 000	2,4, (B)
	A182	(N+T)								69	*63*	*56*	*48*	*42*	*36*	*31*	*27*	*23*	150 000	
	ASTM	WP22								*68*	*59*	*52*	*45*	*38*	*33*	*28*	*25*	*22*	200 000	
	A234	(N+T)								*65*	*57*	*49*	*42*	*36*	*32*	*27*	*23*	*20*	250 000	
	ASTM	P22																		
	A335	(N+T)																		
	ASTM	F22	56	53	51	48	46	44					39	38	37	*34*	*29*	*26*	100 000	2,4, (B)
	A182	(annealed)												38	*36*	*31*	*27*	*23*	150 000	
	ASTM	WP22												*38*	*33*	*28*	*25*	*22*	200 000	
	A234	(annealed)												*36*	*32*	*27*	*23*	*20*	250 000	
	ASTM	P22																		
	A335	(annealed)																		

Table 1. Design stress values (N/mm^2) (*concluded*)

Letters in parentheses refer to the notes following this table.

Material	Standard	Grade	Values of *f* for design temperature (˚C) not exceeding																			Design lifetime	Notes
			250	**300**	**350**	**400**	**450**	**500**	**540**	**550**	**560**	**580**	**590**	**600**	**620**	**640**	**650**	**660**	**680**	**700**	**720**	h	(A)
18Cr10Ni	ASTM	304L	91	86	83	78	77															—	
	A312	304	103	98	93	89	87															—	
		304H	103	98	93	89	87	85		83		82	81	*76*	*65*	*55*	*50*	*45*	*38*	*33*	*28*	100 000	
												82	*78*	*72*	*61*	*51*	*46*	*42*	*36*	*31*		150 000	
												81	*75*	*69*	*58*	*48*	*44*	*40*	*34*	*30*		200 000	
												78	*72*	*66*	*55*	*46*	*42*	*38*	*33*	*29*		250 000	
18Cr12NiMo	ASTM	316L	93	89	85	82	79															—	
	A312	316	111	106	101	99	96															—	
		316H	111	106	101	99	96	93		90		89	88	88	*74*	*58*	*53*	*46*	*35*	*28*	*23*	100 000	4
													88	*85*	*66*	*52*	*46*	*41*	*32*	*25*	*19*	150 000	
													88	*79*	*62*	*48*	*43*	*38*	*29*	*22*	*18*	200 000	
													85	*75*	*58*	*45*	*40*	*35*	*27*	*22*	*18*	250 000	
18Cr12NiTi	ASTM	321	121	117	113	110	107															—	
	A312	321H	121	117	113	110	107	104	102	102	101	*86*		*71*	*57*	*42*	*36*	*31*				100 000	
									102	*101*	*93*	*78*		*64*	*49*	*36*	*32*	*27*				150 000	
									102	*97*	*89*	*74*		*58*	*45*	*33*	*28*	*25*				200 000	
									100	*93*	*85*	*71*		*55*	*42*	*31*	*26*	*22*				250 000	
18Cr12NiNb	ASTM	347	127	123	120	118	116															—	
	A312	347H	127	123	120	118	116	115	113	113	113	*99*		*82*	*66*	*53*	*47*	*41*	*31*	*23*		100 000	
										113	*112*	*93*		*75*	*61*	*48*	*42*	*37*	*28*	*22*		150 000	
										113	*106*	*88*		*72*	*58*	*45*	*39*	*34*	*25*	*19*		200 000	
										112	*102*	*85*		*68*	*55*	*42*	*37*	*32*	*24*	*19*		250 000	

Notes to table 1

(A) The general notes and notes 2 and 4 of table 2.1.2 of BS 1113 : 1998 apply as indicated.

(B) If test certificates certifying that normalizing within the range 900 ˚C to 960 ˚C and tempering within the range 650 ˚C to 750 ˚C are not available, the design stress values for the annealed steel should be used.

blank

Enquiry Case 1113/4 : August 1988
to BS 1113 : 1985
Issue 2, October 1989

Enquiry Case 1113/4

Implications of BS 3923 'Ultrasonic examination of welds' Part 1 : 1986 'Methods for manual examination of fusion welds in ferritic steels'

Enquiry

Will the Technical Committee advise whether or not, in the absence of any specified Examination Level in **5.6.3**, Examination Level 2, as specified in table 1 of BS 3923 : Part 1 : 1986, should be applied where ultrasonic techniques are used for the non-destructive examination of welds in components designed and manufactured to BS 1113?

Will the technical committee further advise whether it is considered necessary to use the surface finish specified for Examination Level 2 in BS 3923 : Part 1 : 1986 in consideration of the fact that satisfactory coupling has been achieved without resort to such finishes in the past?

Reply

The Technical Committee considers that until further data become available, and with the exception of steels 622, 629, 660, 762, the following Examination Levels should be used to comply with **5.6** to **5.9**:

(a) all butt welds: Examination Level 2B;

(b) all branch, nozzle and stub welds: Examination Level 2.

The Technical Committee further considers that, in these cases, provided the achievement of satisfactory coupling can be demonstrated, it should not be necessary to use the surface finishes specified in BS 3923 : Part 1 : 1986 for these Examination Levels.

In respect to steels 622, 629, 660, 762, the Technical Committee considers that the Examination Levels to be used and the associated surface finish requirements should be the subject of agreement between the manufacturer and the Inspecting Authority.

blank

Enquiry Case 1113/7
Use of butt welds in tubes for manufacture of coil type boilers/superheaters

Enquiry

In the manufacture of coiled boilers/superheaters, it is necessary to use intermediate butt welds in the tube lengths used to form the tube coils. Such a construction is not currently admissible under **4.3.2.5.5** of BS 1113 : 1998, where it is stated that butt welds shall not be permitted within bends.

Does the committee consider that for this application, where coils of relatively large *R*/*D* ratio are used, the requirement of **4.3.2.5.5** might be waived?

Reply

The committee recognizes that the requirements are formulated on a basis applicable to conventional water tube boilers, superheaters and reheaters. The prohibition of welds within bends is considered good engineering practice in this type of plant and its imposition does not promote any manufacturing difficulties. The committee will not agree to a change to this limitation.

However, the committee does recognize that, in the case of coiled boilers and superheaters, intermediate butt welds in the coiled length are in some situations unavoidable. The committee considers in this case that such butt welds are acceptable, provided the general requirements of BS 1113 are complied with, and subject to the following additional or modified conditions:

(a) The *R*/*D* ratio should preferably be greater than or equal to 10,

where

R is the mean radius of the coil;

D is the outside diameter of the tube.

For coils constructed from carbon steel, carbon manganese steel or austenitic stainless steel, where the *R*/*D* ratio is less than 10, or for other materials of any *R*/*D* ratio, the ability to bend the tube without detrimental effect on the weld metal should be demonstrated by a weld procedure test involving welding a coil and then bending to the minimum *R*/*D* ratio to be used in production for a given thickness of tube, and then subjecting the test weld to destructive and non-destructive tests.

The nature of the tests carried out on this procedure test should be agreed with the manufacturer and the Inspecting Authority.

(b) The maximum departure from circularity of the tube diameter should not exceed 5 %.

(c) Backing rings should not be used.

(d) Oxyacetylene welding should not be used.

(e) The minimum thickness of the straight tube prior to coiling should be not less than 1 mm greater than the value determined by equation (31) or (32) of **3.7.1.1**.

(f) Upon completion of construction, the coil should be subjected to a hydraulic test to 1,5 times the calculation pressure.

Enquiry Case 1113/11

Combination of calculation pressure and design temperature

Enquiry

Often the maximum metal temperature for a pressure part, as specified in **2.2.3.1**a), occurs at an operating condition when the operating pressure is reduced below the calculation pressure as defined in **1.3.6**. This maximum metal temperature cannot occur at calculation pressure.

Clause **3.1.1** requires the pressure part thickness to be determined using the calculation pressure at the design temperature sustained (where relevant) for the design lifetime.

Should the design temperature be the maximum metal temperature even when this temperature and calculation pressure cannot co-exist?

Reply

No.

The pressure part thickness should be at least that determined using calculation pressure and the maximum metal temperature that can occur at this pressure.

In addition, the pressure part thickness should be sufficient-to withstand all other combinations of pressure and metal temperature which can co-exist.

Where stresses are time dependent, addition of the effects of creep for the occurring combinations of pressure, temperature and duration should predict failure at a time not less than the design lifetime.

blank

Enquiry Case 1113/13

Guidance on the use of BS 1113 to satisfy the Essential Safety Requirements of the Pressure Equipment Directive

Enquiry

Can the committee give guidance on the use of BS 1113 to satisfy the Essential Safety Requirements (ESRs) of the Pressure Equipment Directive (PED) within the European Community?

Reply

The PED was adopted by the European Union in May 1997 and implemented into UK law in The Pressure Equipment Regulations 1999 [SI 1999 No 2001].

The following table provides a summary of all the ESRs that are contained in Annex 1 of the PED (reproduced as Schedule 2 to the Pressure Equipment Regulations 1999) and shows, by reference to the relevant BS 1113 clause, where it is considered that BS 1113 satisfies the ESR.

PED Annex 1 reference	Summary of the Essential Safety Requirement of the PED	Relevant BS 1113 reference
1	**General**	
1.1	Equipment to be designed, manufactured, checked, equipped and installed to ensure safety, when put into service in accordance with manufacturer's instructions. The scope of the PED Annex 1 is generally satisfied by BS 1113:1999. Specific items not covered by BS 1113:1999 are highlighted by reference to Notes (1), (2) and (3).	—
1.2	Principles to be used by manufacturer in assessing appropriate solutions to: • eliminate or reduce hazards; • apply protection measures against hazards; • inform user of residual hazard.	(1)
1.3	Equipment to be designed to prevent danger from foreseeable misuse: • warning to be given against misuse.	(1)
2	**Design**	
2.1	Equipment to be designed to ensure safety throughout intended life and to incorporate appropriate safety coefficients.	**3.1** and **2.2**
2.2.1	Equipment to be designed for loadings appropriate to its intended use.	**3.1**
2.2.2	Equipment to be designed for adequate strength based on calculation method and to be supplemented, if necessary, by experimental methods.	**3.1** and **3.8**
2.2.3(a)	Allowable stresses to be limited with regard to foreseeable failure modes; safety factors to be applied. Requirements to be met by applying one of the following methods: • design by formula; • design by analysis; • design by fracture mechanics.	**2.2** and **3.1**
2.2.3(b)	Design calculations to establish the resistance of equipment, in particular: • calculation pressure to take account of maximum allowable pressure, static head, dynamic fluid forces; • calculation temperature to allow appropriate safety margin; • account to be taken of combinations of temperature and pressure; • maximum stresses and peak stresses to be within safe limits; • calculations to utilize values appropriate to material properties and to be based on documented data and have appropriate safety factors; • use of joint factors; • to take account of foreseeable degradation mechanisms and attention to be drawn in instructions to features which are relevant to the life of equipment.	**3.1** **1.3.6** **2.2.7** EC 1113/11 **3.1** **2.2.1** (2) **2.2.8**
2.2.3(c)	Allow for adequate structural stability during transport and handling.	(1)

PED Annex 1 reference	Summary of the Essential Safety Requirement of the PED	Relevant BS 1113 reference
2.2.4	Experimental design method. Design to be validated by appropriate test programme on representative sample of equipment. Test programme to include: • pressure strength test to check equipment does not exhibit leaks or deformation.	 **3.8**
2.3	Provisions to ensure safe handling and operation. Methods to be specified for operation of equipment to preclude any foreseeable risk with attention being paid to: • closures and openings; • discharge of pressure relief blow-off; • access whilst pressure or vacuum exists; • surface temperature; • decomposition of unstable fluids; • access doors equipped with devices to prevent hazard from pressure.	 **4.4.2** **7.2.4** (2) (2) (3) **4.4.2.1**
2.4	Means of examination: • to be designed and constructed so that examinations can be carried out; • able to determine internal condition; • alternative means of ensuring safe condition.	**4.4.2**
2.5	Means to be provided for draining and venting where necessary: • to avoid water hammer, vacuum collapse, corrosion and chemical reactions; • to permit cleaning, inspection and maintenance.	**1.1.4** and **7.8**
2.6	Adequate allowance or protection provided against corrosion.	**3.2**
2.7	Adequate measures to be taken against effects of erosion or abrasion by design, replacement parts and instructions.	**3.2**
2.8	Assemblies to be designed so that: • components to be assembled are suitable and reliable for their duty; • components are properly integrated and assembled.	 Sections **3** and **4**
2.9	To be provided with accessories or provision made for their fitting, to ensure safe filling or discharge with respect to hazards: • on filling, by overfilling or overpressurization and instability; • on discharge, by uncontrolled release of fluid; • on unsafe connection or disconnection.	Section **7**
2.10	Protection against exceeding the allowable limits. Equipment to be fitted with, or provision made for, suitable protective devices which are determined on basis of characteristics of equipment.	**7.2**
2.11.1	Safety accessories to be designed and constructed to be reliable and suitable for intended duty, including maintenance; to be independent or unaffected by other functions.	**7.1** and **7.2.3.1**
2.11.2	Pressure limiting devices to be designed so that design pressure will not be exceeded except for short duration pressure surges of 1.1 times design pressure.	**7.2.2.2**
2.11.3	Temperature monitoring devices to have adequate response time on safety grounds.	(2)
2.12	External fire. Pressure equipment to be designed and fitted with accessories to meet damage limitation requirements.	(1)
3	**Manufacturing**	
3.1.1	Preparation of component parts not to give rise to defects or cracks or changes in mechanical characteristics likely to affect safety.	**4.2**

PED Annex 1 reference	Summary of the Essential Safety Requirement of the PED	Relevant BS 1113 reference
3.1.2	Permanent joints and adjacent zones: • to be free from surface and internal defects detrimental to safety; • properties to meet minimum specified for materials to be joined or taken into account in design calculations; • permanent joining to be carried out by suitably qualified personnel according to suitable procedures; • personnel and procedures to be approved by third party for Category II, III and IV equipment.	**4.3**
3.1.3	Non-destructive tests of permanent joints to be carried out by suitably qualified personnel: • personnel to be approved by third party for Category II, III and IV equipment.	**5.6.1.2**
3.1.4	Suitable heat treatment to be applied at appropriate stage of manufacture.	**4.5**
3.1.5	Traceability. Materials making up component parts to be identified by suitable means from receipt, through production, up to final test.	**4.1.3**
3.2.1	Final inspection to be carried out to assess visually, and by examination of documentation, compliance with the requirements of the Directive: • tests during manufacture to be taken into account; • inspection as far as possible to be carried out internally and externally on every part.	**5.1** and **5.1.5**
3.2.2	Hydrostatic pressure tested to a pressure at least equal to value laid down in ESR 7: • category I series equipment may be tested on a statistical basis; • other test, of equivalent validity, may be carried out where hydrostatic is harmful or impractical.	**5.10**
3.2.3	For assemblies, the safety devices to be checked to confirm compliance with ESR 2.10.	Section **7**
3.3	Marking. In addition to CE marking, all relevant information to be provided as listed in ESR 3.3.	**4.1.3** and **6.3**
3.4	Operating instructions. All relevant instructions to be provided for the user as listed in ESR 3.4.	(2)
4	**Materials**	
4.1(a)	Materials to have appropriate properties for all operating and test conditions, to be sufficiently ductile and tough (refer to ESR 7.5).	**2.1**
4.1(b)	Materials to be chemically resistant to contained fluids: • properties not to be significantly affected within scheduled lifetime of equipment.	**2.1.1.1**
4.1(c)	Materials not to be significantly affected by ageing.	**2.2.8**
4.1(d)	Materials to be suitable for intended processing (manufacturing) procedures.	**2.1.1.1**
4.1(e)	Materials to avoid undesirable effects when joining.	**2.1.1.1**
4.2(a)	Manufacturer to define material values necessary for design and for requirements of ESR 4.1.	**2.1.2** and **2.2.1.1**
4.2(b)	Manufacturer to provide technical documentation relating to compliance with material specifications of PED in one of the following forms: • by using materials which comply with harmonized standards; • by using materials covered by European approval in accordance with Article II of PED; • by a particular material appraisal.	**2.1.2** (1) (1)
4.2(c)	For equipment in PED Categories III or IV, the particular material appraisal to be performed by notified body in charge of conformity assessment.	(1)

PED Annex 1 reference	Summary of the Essential Safety Requirement of the PED	Relevant BS 1113 reference
4.3	Manufacturer to take appropriate measures to ensure: • materials conform to specification; • documentation by material manufacturer affirms compliance with a specification; • documentation for main pressure parts in PED Categories II, III or IV to be a certificate of specific product control.	 **5.1.2**(a) **5.1.3**(a) **5.1.4**(a)
5	**Fired or process heated pressure equipment**	
5(a)	Means of protection to be provided to restrict operating parameters to avoid risk of local or general overheating.	(1) and **7.4**
5(b)	Sampling points to be provided for evaluation of properties of the fluid to avoid risks from deposits and/or corrosion.	**7.8.1**
5(c)	Adequate provisions to be made to eliminate risk of damage from deposits.	**3.2.2**
5(d)	Means to be provided for safe removal of residual heat after shutdown.	(1)
5(e)	Steps to be taken to avoid dangerous accumulation of combustible substances and air, or flame blowback.	(1)
6	**Piping**	
7	**Supplementary requirements to sections 1 to 6**	
7.1	Allowable stresses.	**2.2**
7.2	Joint coefficients.	(2)
7.3	Pressure limiting devices. The momentary pressure surge to be kept to 10 % of design pressure.	**7.2.2.2**
7.4	Hydrostatic test pressure to be not less than the greater of: • maximum loading to which equipment may be subject to in service, taking into account design pressure and design temperature, multiplied by 1.25; or, • design pressure multiplied by 1.43.	 **5.10**
7.5	Material characteristics. Unless other values are required in accordance with other criteria that must be taken into account, a steel is considered sufficiently ductile to satisfy 4.1(a) if in a tensile test carried out by a standard procedure the following are met: • elongation after rupture is not less than 14 %; • bending rupture energy measured on an ISO V test piece not less than 27 J at a temperature not greater than 20 °C but no higher than the lowest scheduled operating temperature.	(2) and **2.1.2**

Notes:
(1) Outside the scope of BS 1113:1999.
(2) Requirements are not covered in BS 1113:1999 but will be covered in future editions.
(3) Not applicable to water tube boilers.

Manufacturers should be aware that:
a) the UK Pressure Equipment Regulations 1999 apply to the design, manufacture and placing on the market of pressure equipment and assemblies within the scope of the PED;
b) the UK Pressure Systems Safety Regulations 2000 cover all aspects of the use of the pressure equipment and assemblies in a).