AS 1210—1997
(Incorporating Amendment Nos. 1, 2 and 3)

AS 1210

Australian Standard™

Pressure vessels

Standards Australia

This Australian Standard was prepared by Committee ME-001, Pressure Equipment. It was approved on behalf of the Council of Standards Australia on 31 January 1997 and published on 5 July 1997.

The following interests are represented on Committee ME-001:

A.C.T. WorkCover
Australasian Corrosion Association
Australasian Institute of Engineering Inspection
Aluminium Development Council, Australia
Australian Building Codes Board
Australian Chamber of Commerce and Industry
Australian Institute of Energy
Australian Institute of Petroleum
Australian Liquefied Petroleum Gas Association
Boiler and Pressure Vessel Manufacturers Association of Australia
Bureau of Steel Manufacturers of Australia
Department for Industrial Affairs, S.A.
Department of Labour, New Zealand
Department of Training and Industrial Relations, Qld
Electricity Corporation of New Zealand
Electricity Supply Association of Australia
Institute of Metals and Materials, Australasia
Institution of Engineers, Australia
Insurance Council of Australia
Metal Trades Industry Association of Australia
National Association of Testing Authorities, Australia
New Zealand Engineering Federation
New Zealand Heavy Engineering Research Association
New Zealand Petrochemical Users Group
New Zealand Timber Industry Federation
Victorian WorkCover Authority
Welding Technology Institute of Australia
WorkCover N.S.W.
Work Health Authority, N.T.
Workplace Standards Authority, Tas.
WorkSafe W.A.

Keeping Standards up-to-date

Standards are living documents which reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued. Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments which may have been published since the Standard was purchased.

Detailed information about Standards can be found by visiting the Standards Australia web site at www.standards.com.au and looking up the relevant Standard in the on-line catalogue.

Alternatively, the printed Catalogue provides information current at 1 January each year, and the monthly magazine, *The Australian Standard*, has a full listing of revisions and amendments published each month.

We also welcome suggestions for improvement in our Standards, and especially encourage readers to notify us immediately of any apparent inaccuracies or ambiguities. Contact us via email at mail@standards.com.au, or write to the Chief Executive, Standards Australia International Ltd, GPO Box 5420, Sydney, NSW 2001.

This Standard was issued in draft form for comment as DR 95103.

AS 1210—1997
(Incorporating Amendment Nos. 1, 2 and 3)

Australian Standard™

Pressure vessels

Originated in part as AS B31—1931 and AS CB1—1931.
Previous edition 1989.
Fifth edition 1997.
Reissued incorporating Amendment Nos. 1 (February 1998),
2 (September 1998) and 3 (April 2002).

Published by Standards Australia International Ltd
GPO Box 5420, Sydney, NSW 2001, Australia

ISBN 0 7337 1012 3

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee ME/1 on Pressure Equipment to supersede AS 1210—1989, *Unfired Pressure Vessels (known as the SAA Unfired Pressure Vessels Code)*. This Standard is a ‘Primary Applicable Standard’ referenced in AS/NZS 1200 which is the main Standard for pressure equipment and outlines general requirements for water tube, fire tube, shell and miscellaneous boilers, pressure vessels, pressure piping and related matters. AS/NZS 1200 is referred to in the Worksafe Australia, *National Standard for Plant*.

This Standard incorporates Amendment No. 1 (February 1998), Amendment No. 2 (September 1998) and Amendment No. 3 (April 2002). The changes arising from the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure, or part thereof affected.

This Standard is the result of a consensus among representatives on the Joint Committee to produce it as an Australian Standard. Consensus means general agreement by all interested parties. Consensus includes an attempt to remove all objection and implies much more than the concept of a simple majority, but not necessarily unanimity. It is consistent with this meaning that a member may be included in the Committee list and yet not be in full agreement with all clauses of this Standard.

Revisions and additions contained in the published Amendments 1 to 4 to the 1989 edition of this Standard, together with subsequent revisions and additions approved by the Committee, have been included in this edition.

The main changes introduced subsequent to Amendment 4 include an extension to cover fired and unfired pressure vessels, non-metallic pressure vessels, extensive editorial modifications to align with current Standards Australia practice and a number of important technical changes, including the addition, revision and clarification of the scope, stress tables, minimum thickness, flat plates, inspection openings, transportable vessels, relief valve capacity and risk management.

As part of the restructuring of various Standards covered by AS/NZS 1200 into ‘core’ type Standards, most requirements for manufacture and heat treatment, welding and brazing qualification, examination and testing and installation have been deleted, and reference is made to specific Standards covering these matters.

The removal of this data has left a number of appendices and clauses blank. The complete clause renumbering of the whole of the Standard has been avoided as clauses are referred to in many documents, such as quality assurance manuals, manufacturing specifications and computer calculations.

Minor changes have been made in the welding procedure requirements, including relevant postweld heat treatment requirements, principally to align with world practice. It is not intended that qualified welding procedures will be invalidated by these changes nor that the changes will be applied retrospectively.

References to riveted construction have been withdrawn as this type of construction is rarely used at the present time. For guidance, reference may be made to the now superseded AS CB1, Part 1: *Boilers other than water tube boilers and locomotive boilers for railway purposes*, reference copies of which are available at the Standards Australia Information Centres.

A2 A significant change by Amendment No. 2 to this 1997 edition is the reduction of the factor of safety used to determine the material design stress from 4 to 3.5. There are a number of justifications for such a change, including the improvement in the quality of materials, an improvement in the quality of welding and fabrication, improved inspection technology and better information on design, operation, maintenance and vessel failures.

This Standard follows in principle other codes forming part of AS/NZS 1200 in giving guidance to designers, manufacturers, inspection bodies, purchasers and users in the form of minimum engineering requirements which are necessary for the safe design, manufacture and testing of pressure vessels. In special instances additional requirements may be necessary for adequate performance or safety.

The requirements in this Standard have been formulated to afford reasonably certain protection of life and property and to indicate where a margin for deterioration in service may be needed so as to give a reasonably long, safe period of usefulness. The Standard takes into consideration advancements in design and materials, and the evidence of experience.

The Standard contains basic data necessary for design, including material specification, design parameters, requirements for fabrication, testing and inspection. These requirements are specified in terms of principles to the fullest practicable extent, supplemented where necessary by further detail to obtain uniform interpretation of principle and guidance on best methods. In other areas the Standard indicates where caution is necessary but a direct prohibition would be unwise at the present level of knowledge.

The Standard incorporates the class system of vessels based on different classes of construction, and gives basic principles to indicate where such classes should or are to be used. Three main classes are adopted using the present level of stress (safety factor of 4 approximately). Additional classes of vessel, i.e. Class 1 H and 2 H, may be produced in accordance with AS 1210 Supplement 1, which permits the use of design stresses higher than those contained herein.

The specific design requirements of the Standard are based on a simplified engineering approach and are intended to be the standard methods of design. However, in special instances, particularly where guidance is not provided in this Standard, other methods may be used provided that the validity of the design is satisfactorily established and agreed.

No rules for manufacture can be written in sufficient detail to ensure good workmanship in manufacture. Each vessel manufacturer is responsible for taking every necessary step to make sure that the quality of manufacture is such as will ensure compliance with good engineering practice and design.

The user will also need to consider many factors beyond those covered by this Standard in the final specification of a vessel and is cautioned that the Standard is not a complete design handbook and that there is a need for competent engineering judgement.

The Standard continues to be written largely for Australian conditions and to cater for recent moves in various States and Territories to objective or performance regulations rather than the earlier prescriptive ones. These moves also have lead to privatization of inspection functions such as design verification, manufacture and in-service inspection, and agreement by designers, manufacturers, purchasers and others involved.

Thus the Standard uses competent inspection bodies as in European Union practice in place of the previous regulatory authority; and is written as far as practical for clear interpretation and use in contracts to assist all parties and facilitate safety and trade.

It provides flexibility to use alternative methods, materials, Standards and the like where equivalent safety and performance is achieved and any departures from the Standard are clearly identified in all documentation and are agreed.

Acknowledgment is gratefully made to the American Society of Mechanical Engineers for permission to reproduce certain extracts from the *ASME Boiler and Pressure Vessel Code*. In addition, acknowledgment is made of the considerable assistance provided by British and other national Standards.

This Standard makes use of the draft ISO Standard for pressure vessels and the current American and British Standards for pressure vessels as well as other selected leading Standards including the developing European Standards and the experience and development in Australia. This has been done to take advantage of world experience and align with these major Standards to optimize safety and standardization and facilitate trade.

Similarly compliance with the appropriate class of this Standard will satisfy the technical requirements for equivalent vessels to the above international Standards. However compliance with regulatory and quality assurance requirements of the country of use will need to be satisfied. For comparison of this Standard with the above Standards see AS/NZS 1200.

Statements expressed in mandatory terms in notes to tables and figures are deemed to be requirements of this Standard.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the Appendices. A ‘normative’ appendix is an integral part of this Standard and an ‘informative’ appendix is only for information and guidance.

CONTENTS

Page

Page

STANDARDS AUSTRALIA

Australian Standard

Pressure vessels

SECTION 1 SCOPE AND GENERAL REQUIREMENTS

1.1 SCOPE This Standard sets out minimum requirements for the materials, design, manufacture, testing, inspection, certification and despatch of fired and unfired pressure vessels constructed in ferrous or non-ferrous metals by welding, brazing, casting, forging, or cladding and lining and includes the application of non-integral fittings required for safe and proper functioning of pressure vessels. This Standard also specifies requirements for non-metallic vessels and metallic vessels with non-metallic linings.

For detailed requirements for metallic materials, manufacture and testing, reference should be made to the relevant material Standards, and to AS 4458, AS/NZS 3992 and AS 4037. A3

The requirements of this Standard have been formulated on the basis that the required examinations and inspection during manufacture are performed and that appropriate reasonable care is taken of the vessels during subsequent stages in the life of vessels including appropriate inspection for deterioration.

1.2 OBJECTIVE AND PERFORMANCE CRITERIA

1.2.1 Objective of the Standard This Standard aims to specify clear, uniform, safe requirements which—

(a) cover the materials, design, manufacture, testing, inspection, certification and despatch of pressure vessels; and

(b) facilitate the supply of pressure vessels which meet the purchaser's requirements.

1.2.2 Performance requirements To meet the above objective, pressure vessels supplied to this Standard are to satisfy the following performance criteria when produced and used in accordance with the contract, the designed service conditions and sound practice—

(a) provide reasonably certain protection of all persons involved in various stages of the vessel's life and of adjacent property and environment;

(b) provide appropriate economy, performance, reliability, operability, inspectability and maintainability over a reasonably long life; and

(c) control risks to at least satisfy applicable safety, health and environment laws.

The remainder of this Standard gives prescriptive requirements which satisfy the above criteria in the matters covered.

1.3 APPLICATION This Standard is intended to apply to pressure vessels—

(a) with design pressures above the curves in Figures 1.3.1 and 1.3.2 but not exceeding 21 MPa for welded, forged, brazed or cast metallic vessels or non-metallic vessels unless otherwise agreed by the parties concerned; and

(b) with operating temperatures within the temperature limits for various materials and components as stated in the appropriate Section of this Standard.

In relation to pressure-containing parts, the following shall be included in the scope of this Standard:

(i) Where external piping is to be connected to the vessel—

(A) the welding end connection for the circumferential joint for welded connections;

(B) the first threaded joint for screwed connections;

(C) the face of the first flange for bolted, flanged connections; and

(D) the first sealing surface for proprietary connections or fittings.

(ii) The weld attaching a non-pressure part to a vessel where the non-pressure part is welded directly to either the internal or external surface of a pressure vessel.

(iii) Pressure-retaining covers for vessel openings such as manhole and handhole covers.

(iv) Vessel supports which form part of the vessel

(v) Protective devices, pressure relief valves and thermal protection where required by the purchaser.

This Standard is not intended to apply to liquid storage tanks, large low pressure gas storage tanks (such as are dealt with in ANSI/API Std 620), nuclear vessels, machinery such as pump and compressor casings, or vessels subject to pressures caused only by static head of their contents, fire-tube, shell and miscellaneous boilers, water tube boilers, non-integral piping, serially produced pressure vessels, and other plant under pressure but excluded by AS/NZS 1200.

Requirements for pressure vessels of advanced design and construction are given in AS 1210 Supplement 1.

Related Standards which provide alternatives to the requirements in this Standard within the scope of their application are AS 2971 and AS 3509.

Users of this Standard are reminded that it has no legal authority in its own right, but may acquire legal standing in one or more of the following circumstances:

(1) Adoption by a government or other authority having jurisdiction.

(2) Adoption by a purchaser as the required standard of construction when placing a contract.

(3) Adoption where a manufacturer states that a vessel is in accordance with this Standard.

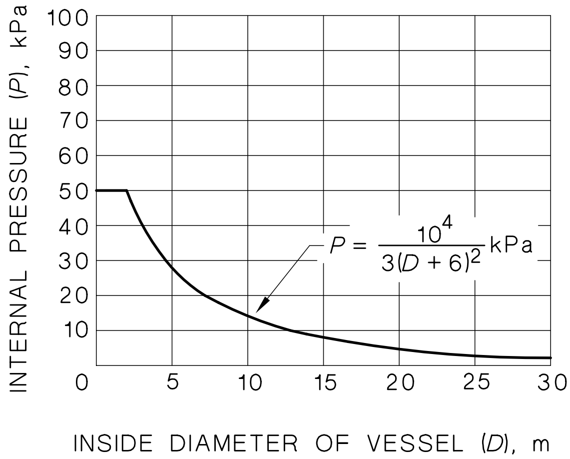


FIGURE 1.3.1 VESSELS SUBJECT TO INTERNAL PRESSURE

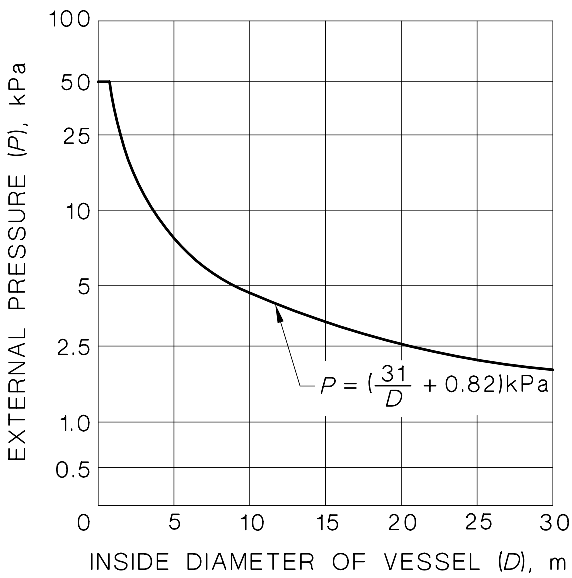


FIGURE 1.3.2 VESSELS SUBJECT TO EXTERNAL PRESSURE

1.4 INTERPRETATION OF STANDARD For interpretation of this Standard refer to AS/NZS 1200.

1.5 NEW DESIGNS, MATERIALS AND MANUFACTURING METHODS This Standard does not prohibit the use of materials or methods of design or manufacture which are not specifically referred to herein. (See AS/NZS 1200 for guidance).

1.6 CLASSES OF VESSEL CONSTRUCTION Welded metallic vessels are categorized into three main classes, according to the design, manufacture, testing and inspection requirements indicated in Table 1.6. Class 2 is subdivided into classifications 2A and 2B, primarily to enable the use of higher weld joint efficiency where spot non-destructive examination is utilized.

For mixing of classes of welded construction, see Clause 1.7.2.4.

Forged and non-metallic vessels are not classified.

Other vessels are not classified but different levels of construction are identified by—

(a) different casting quality factors (see Clause 3.3.1.1(d)) for cast construction; and

(b) different brazed joint efficiencies for brazed construction.

TABLE 1.6
CLASSIFICATION OF WELDED VESSELS

Requirement	Class 1 vessels	Class 2 vessels		Class 3 vessels
		2A	2B	
Material	Section 2	Section 2	Section 2	Section 2
Design: (see Note)				
General	Section 3	Section 3	Section 3	Section 3
Longit. welded joints (and max. welded joint efficiency η)	D-B(1.00) Seamless (1.00) S-Bbs (0.90)	D-B(0.85) Seamless (1.00) S-Bbs (0.80)	D-B(0.80) Seamless (1.00) S-Bbs (0.75)	D-B(0.70) Seamless (1.00) S-Bbs (0.65)
Circ. welded joints (and max. welded joint efficiency η)	D-B(1.00) Seamless (1.00) S-Bbs (0.90)	D-B(0.85) Seamless (1.00) S-Bbs(0.80)	D-B(0.80); S-Bbs(0.75) S-B(0.65)	D-B(0.70); S-Bbs(0.65); S-B(0.60); D-Fillet lap(0.55) S-Fillet lap(0.45) S-Fillet lap with plug welds (0.5)
Connections and branches	See Clause 3.19	See Clause 3.19	See Clause 3.19	See Clause 3.19
Manufacture:				
General	Section 4	Section 4	Section 4	Section 4
Postweld heat treatment	Generally required except for some metals (see AS/NZS 3992 and AS 4458)	Generally not required except for some metals (see AS/NZS 3992 and AS 4458)	Generally not required except for some metals (see AS/NZS 3992 and AS 4458)	Generally not required except for some metals (see AS/NZS 3992 and AS 4458)
Testing:				
General	Section 5	Section 5	Section 5	Section 5
Welding procedure qualification	Required (see AS/NZS 3992)	Required (see AS/NZS 3992)	Required (see AS/NZS 3992)	Required (see AS/NZS 3992)
Production weld test plates	Required (see AS/NZS 3992)	Required (see AS/NZS 3992)	Required (see AS/NZS 3992)	Not Required
Radiographic or ultrasonic examination	100% all main butt welds, except as in AS 4037	Spot examination all butt welds (see AS 4037)	Not required	Not required
Hydrostatic	Required (see Clause 5.10)	Required (see Clause 5.10)	Required (see Clause 5.10)	Required (see Clause 5.10)
Inspection	Section 6	Section 6	Section 6	Section 6

LEGEND:

D-B = double-welded butt joint or equivalent.

S-Bbs = single-welded butt joint with backing strip which remains in service.

S-B = single-welded butt joint without backing strip.

D-Fillet lap = double full fillet lap joint.

S-Fillet lap = single full fillet lap joint.

NOTE: For limits of application of welded joints, see Figure 3.5.1.5.

1.7 APPLICATION OF VESSEL CLASSES AND TYPES

1.7.1 General Compliance with Clauses 1.7.2 and 1.7.3 leads to minimum construction requirements which ensure reasonable protection of life and property. The designer shall identify the hazards with the vessel in operation and examine the consequences of the vessel failing, and assess the risks arising from such failure. This shall include consideration of each of the following aspects:

(a) The adequacy of materials, design, manufacture, operation and maintenance.

(b) The nature of service conditions.

(c) The pressure energy (pressure and volume) of the vessel.

(d) The nature of contents when released.

(e) The location with respect to people and plant.

(f) Where appropriate, the economics of repair, replacement and obsolescence.

Vessels that contain substances which are lethal (see AS 3920.1) shall be seamless, forged or of Class 1 welded construction. Examples of lethal substances are hydrogen cyanide, carbonyl chloride and highly radioactive substances.

Packed floating head exchangers shall not be used when the fluid in contact with the joint is lethal or flammable.

1.7.2 Welded construction

1.7.2.1 *Vessels of Class 1 welded construction* Class 1 construction shall be used for—

(a) vessels constructed of materials of thicknesses which require Class 1 construction (see Table 1.7);

(b) vessels designed with a welded joint efficiency which requires Class 1 construction (see Table 3.5.1.7);

(c) vessels which are to be pneumatically tested to a pressure greater than 20 percent of the test pressure required by Clause 5.10.2.1 prior to hydrostatic testing;

(d) vessels containing lethal substances referred to in Clause 1.7.1;

(e) vessels for special non-corrosive applications, e.g. vacuum insulated cryogenic vessels, where it is not practicable to provide inspection openings for subsequent inspection (see Clause 3.20.6(b)); and

(f) transportable vessels required by Clause 3.26 to be of Class 1 construction.

1.7.2.2 *Vessels of Class 2 welded construction* Class 2A or 2B construction shall be used as a minimum for—

(a) vessels constructed of materials of thicknesses which require Class 2 construction (see Table 1.7);

(b) vessels designed with a welded joint efficiency which require Class 2 construction (see Table 3.5.1.7); and

(c) transportable vessels having a capacity not greater than 5 m^3 water capacity and allowed by Clause 3.26 to be of Class 2 construction.

1.7.2.3 *Vessels of Class 3 welded construction* Class 3 construction may be used where Class 1 or 2 construction is not necessary.

1.7.2.4 *Mixed classes of welded construction* Mixing of classes of welded construction is permitted, provided that the following conditions apply:

(a) The class of construction used for any part or joint is not a lower class than that required by Clause 1.7.2.1 or Clause 1.7.2.2, as applicable at the part or joint.

(b) Where full radiography is not required by this Standard but the longitudinal joints of a vessel are fully radiographed, Type B (see Clause 3.5.1.1) circumferential joints shall be spot radiographed in accordance with the relevant requirements for the Clause 'spot examination' of AS 4037.

Examples of pressure vessels where mixed classes of construction may be used are—

(i) vessels having different sections exposed to different process conditions which warrant different classes of construction, e.g. major refinery towers and heat exchangers;

(ii) vessels having different wall thicknesses over the length of the vessel owing to external load considerations (e.g. wind or self-weight) or different diameters; and

(iii) Class 1 shell joined to a Class 1 end by a Class 2 weld which meets all the provisions and limitations for Class 2 construction.

Mixing of classes of construction to this Standard and AS 1210 Supplement 1 is permitted provided—

(A) the relevant requirements of both Standards apply to the components concerned;

(B) the design, marking and manufacturer's data report record joint compliance; and

(C) the parties concerned agree.

1.7.3 Other types of construction The limits of application of different types of cast, forged or brazed construction are specified in the relevant clauses for these types of construction. The limits of application for non-metallic vessels are specified in Section 10.

TABLE 1.7

NOMINAL MINIMUM SHELL MATERIAL THICKNESS REQUIRING CLASS 1 OR 2 CONSTRUCTION*

Material (Note 6)			Nominal shell thickness (Note 1)	
Group	**Type**	**Typical standard or nominal composition**	**Class 1 construction mm**	**Class 2 construction mm**
A1	Carbon and carbon-manganese steel (low strength)	AS 1548: 7-430, 7-460	> 32 (Note 2)	> 20
A2	Carbon and carbon-manganese steel (medium strength)	AS 1548: 5-490, 7-490	> 32 (Note 2)	> 12
A3	Carbon and carbon-manganese steel (high yield strength)	AS 1594: XF 400, XF 500 API 5L: X52, 60, 65, 70	> 32 (Note 2)	> 20
B	Alloy steel (alloy <¾)	C-½ Mo; ½Cr-½ Mo; 1¼Mn-½Mo	> 20	> 10
C	Alloy steel (¾≤ total alloy <3)	1 Cr-½ Mo; 1¼ Cr-½ Mo	> 16	> 6
D1	Low alloy steel (vanadium type)	½ Cr-½ Mo-¼ V	All	—
D2	Alloy steel (3≤ total alloy <10)	2¼ Cr-1 Mo; 5 Cr-½ Mo; 9 Cr-1Mo	All	—
E	3½ Nickel steel	3½ Ni	> 16	> 6
F	9 Nickel steel	9 Ni	All	—
G	Alloy steel quenched and tempered	AS 3597: 700 PV	All	—
H	Martensitic chromium steel	12 Cr (Type 410) 15 Cr (Type 429)	All	—
J	Ferritic high chromium steel	12 Cr-Al (Type 405) (Note 3) 12 Cr-low C (Type 410S) (Note 4) 12 Cr-low C (Type 410S) (Note 5)	All All > 38	— — > 5
K	Austenitic chromium-nickel steel	18 Cr-8Ni (Type 304) 18 Cr-12Ni-2.5 Mo (Type 316) 18 Cr-10Ni-Ti (Type 321)	> 38	> 10
L	High chromium steel	27 Cr-0.5Ni-0.2C (Type 446)	All	—
M	Ferritic-austenitic chromium-nickel steel	22 Cr-5Ni-3Mo S31803	> 38	> 5
Non-ferrous metals	Aluminium and its alloys	Various	> 12	≤ 12
A1	Copper and its alloys	Various	> 6	≤ 6
	Nickel and its alloys	All grades except those below	> 38	> 5
		Ni-Cr-Fe, Ni-Fe-Cr, Ni-Mo, Ni-Mo-Cr, Ni-Cr-Mo-Nb	> 10	≤ 10
	Other	Various	Note 7	Note 7

* This Table does not prevent Class 1 or Class 2 construction below thickness shown; however it nominates the minimum thickness over which these constructions must be used.

NOTES:

1 See also Clause 1.7, and for clad plate, see Clause 3.3.1.2.

2 This may be increased to 40 mm where a preheat of not less than 100°C is used or the steel used is made
A1 to fully killed fine grain practice with longitudinal impacts of 27 joules at −20°C.

3 Welded with straight chromium electrodes.

4 Welded with any electrode other than in Note 5.

5 Welded with electrodes which produce an austenitic chromium-nickel steel weld or a non-hardening nickel-chromium-iron deposit.

A3 6 For basis of grouping of steels, see AS/NZS 3992 and for specific materials, see Table 3.3.1.

7 By agreement between the parties concerned.

1.8 DEFINITIONS For the purpose of this Standard, the following definitions shall apply.

1.8.1 Actual thickness—the actual thickness of the material used in the vessel part, which may be taken as the nominal thickness, minus any applicable manufacturing under tolerance (see Clause 3.4.2(i)).

1.8.2 Construction—as used in this Standard, is an all-inclusive term comprising the terms given in Figure 1.8.2.

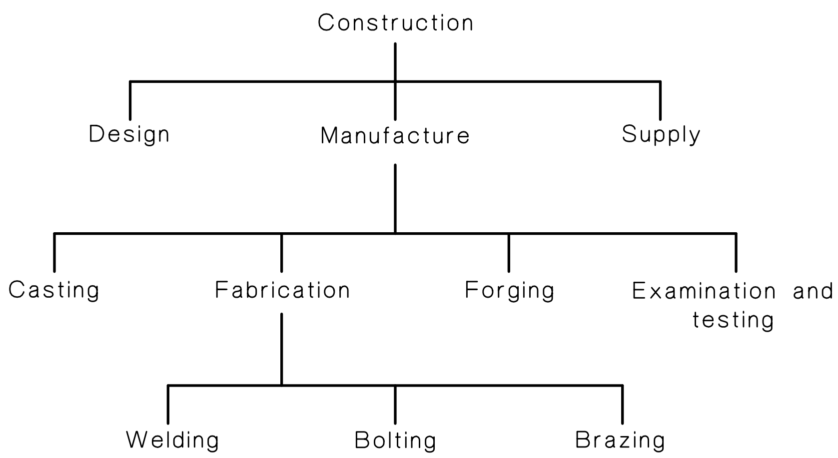


FIGURE 1.8.2 TERMS USED IN CONSTRUCTION

1.8.3 Corrosion—includes oxidation, scaling, mechanical abrasion, erosion and all other forms of wastage.

1.8.4 Design—drawings, calculations, specifications, models and all other information necessary for the complete description of the vessel and its manufacture.

1.8.5 Designer—a body corporate, firm or person who designs pressure equipment or is responsible for the design.

1.8.6 Design lifetime—the lifetime specified for each vessel component operating in the creep (high temperature) range and used in determining material design strength; expressed in hours of service at specified conditions.

NOTE: The design lifetime relates only to the creep performance of the relevant component and is not necessarily related to the life of the vessel.

1.8.7 Design pressure—the maximum gauge pressure, at a designated temperature, which is allowed at the top of the vessel in its operating position. (Also known as maximum allowable working pressure).

1.8.8 Design strength—the maximum allowable stress for use in the equations for the calculation of the minimum thickness or dimensions of pressure parts (see Clause 3.3).

1.8.9 Design temperature—the metal temperature at the coincident calculation pressure used to select the design strength for the vessel part under consideration (see Clause 3.2.2).

1.8.10 Fired heater—a pressure vessel in which a liquid is heated below its atmospheric boiling temperature or a process fluid is heated in tubes above or below its atmospheric boiling temperature by the application of fire, the products of combustion or electric power or similar high temperature means.

NOTE: This is intended to include hot water boilers and fired process heaters.

1.8.11 Inspection body—a body corporate or firm responsible for inspection which may be any one or more of design verification, fabrication inspection, in-service inspection and certification of inspection results.

1.8.12 Ligament efficiency—the ratio (expressed as a decimal) of the lowest calculated working strength of the ligaments between holes, for any way in which any ligament might fail, to the calculated working strength of the solid plate adjacent.

1.8.13 Manufacturer—a body corporate, firm or person who manufactures the pressure vessel.

NOTE: The manufacturer may include the designer.

1.8.14 Material design minimum temperature (MDMT)—a characteristic minimum temperature of a material. It is used in design to select material with sufficient notch toughness to avoid brittle fracture and the temperature at which the material can be used at full design strength.

1.8.15 Maximum operating temperature—the highest metal temperature to which the vessel part under consideration is subjected under normal operation. It is determined by the technical requirements of the process (see Clause 3.2.2.4 for maximum service temperature for liquefied gas).

1.8.16 Maximum operating pressure—the highest pressure to which the vessel part under consideration is subjected under normal operation. It is determined by the technical requirements of the process (see Clause 3.2.1).

1.8.17 May—indicates that a statement is optional.

1.8.18 Minimum calculated thickness—the minimum thickness calculated, according to the equations to resist loadings, before corrosion or other allowances are added.

1.8.19 Minimum operating temperature (MOT)—the lowest metal temperature to which the vessel part under consideration is subjected during normal operation. It is determined by the technical requirements of the process or a lower temperature where specified by the purchaser.

1.8.20 Minimum required thickness—the minimum thickness required which is equal to the minimum calculated thickness plus corrosion and other allowances.

1.8.21 Nominal thickness —the nominal thickness of material selected as commercially available (and to which specified manufacturing tolerances are applicable).

1.8.22 Parties concerned—the purchaser, designer, manufacturer, design verifying and inspection bodies, supplier, installer and owner as appropriate.

1.8.23 Pressure, calculation—the pressure (internal or external) used in conjunction with the design temperature to determine the minimum thickness or dimensions of the vessel part under consideration (see Clause 3.2.1).

1.8.24 Pressures—unless otherwise noted, all pressures used in this Standard are gauge pressures or the difference in pressures on the opposite sides of the vessel part.

1.8.25 Pressure vessel—a vessel subject to internal or external pressure. It includes interconnected parts and components, valves, gauges and other fittings up to the first point of connection to connecting piping. It also includes fired heaters and gas cylinders, but excludes any vessel that falls within the definition of a boiler or pressure piping in this Standard.

NOTE: Gas cylinders are not covered by this Standard. It is intended that the above definition includes vessels, such as heat exchangers, evaporators, air receivers, steam type digesters, steam type sterilizers, autoclaves, reactors, calorifiers and pressure piping components, i.e. separators, strainers and the like. See Clause 1.3 for vessels specifically included and excluded. It should also be noted that throughout this Standard 'pressure vessels' are referred to as 'vessels'.

1.8.26 Purchaser—a body corporate, firm or person who buys the pressure equipment from the manufacturer.

1.8.27 Qualified welding procedure—a welding procedure satisfying the requirements A3 of AS/NZS 3992.

1.8.28 Regulatory authority—any Commonwealth, State or Territory regulatory authority in Australia with the responsibility for pressure equipment safety and includes an officer of that authority with delegated responsibility by that authority.

1.8.29 Shall—indicates that a statement is mandatory.

1.8.30 Should—indicates a recommendation.

1.8.31 Welding terms and welding symbols—(See AS 2812).

A3 **1.8.32 Hazard level**—See AS 4343.

1.8.33 Harmful contents—See AS 4343.

1.9 UNITS Except where specifically noted, units used in the Standard are based on newtons, millimetres and degrees Celsius.

1.10 NOTATION Symbols used in equations in this Standard are defined in relation to the particular equations in which they occur.

1.11 INFORMATION TO BE SUPPLIED BY THE PURCHASER AND MANUFACTURER Appendices E and F summarize the information required in various clauses to be supplied by the purchaser and manufacturer, respectively.

1.12 DESIGNATION Pressure vessels built to this Standard shall be designated by the number of this Standard, i.e. AS 1210, and the method or class of construction (see Clause 7.1(h)) as follows:

For Class 1 welded construction . . . . AS 1210—1.

For Class 2A welded construction . . . . AS 1210—2A.

For Class 2B welded construction . . . . AS 1210—2B.

For Class 3 welded construction . . . . AS 1210—3.

NOTE: See AS 1210 Supplement 1 for designation of vessels constructed to that Supplement.

For brazed construction . . . . AS 1210—B.

For cast construction . . . . AS 1210—C.

For forged construction . . . . AS 1210—F.

For mixed construction . . . . An appropriate combination of symbols (e.g. AS 1210—1/2A).

1.13 REFERENCED DOCUMENTS A list with titles of the documents referred to in this Standard, is given in Appendix R.

Where reference is made to a Standard by its number only, the reference applies to the current edition of the Standard and as amended, unless otherwise agreed to by the parties concerned. Where reference is made to a Standard by number, year and where relevant an amendment number, the reference applies to that specific document.

SECTION 2 MATERIALS

2.1 MATERIAL SPECIFICATIONS

2.1.1 General Any material used in the manufacture of vessels shall comply with an appropriate specification listed in Table 3.3.1, except as permitted in Clause 2.3. Table 3.3.1 contains information for the use of designers on alloys and alloy grades only for those which are expected to be used in Australia.

Where the material is not listed in Table 3.3.1, then the material shall be subjected to the requirements of AS/NZS 1200.

2.1.2 Grades Only those grades of the materials listed, which are suitable for pressure containing parts and their integral attachments, for fabrication and for the conditions of operation for which the vessel is designed shall be used.

Materials used in vessels, which adopt design strengths based on material having adequate properties for plastic deformation at stress concentrations, shall have suitable ductility.

Materials used in the manufacture of welded vessels shall be of satisfactory welding
A3 quality. Qualification of welding procedures in accordance with AS/NZS 3992 shall be considered as a minimum proof of satisfactory welding quality of the material. Materials used in the manufacture of brazed vessels shall be of satisfactory brazing quality.
A3 Qualification of brazing procedures in accordance with AS/NZS 3992 shall be considered as a minimum proof of satisfactory brazing quality of the material.

Steels of Groups A to E, inclusive (see Table 1.7), used in the manufacture of welded pressure vessels which will be subjected to prolonged holding at temperature during postweld heat treatment(s) (e.g. exceeding 6 h total holding time) shall have representative test pieces subjected to the total simulated postweld heat treatment cycle(s). Such test pieces shall be subjected to mechanical testing requirements of the parent metal specification to ensure that any degradation in material properties from such heat treatment has not resulted in the material not meeting specification requirements.

Alloy steels may be selected for either creep or corrosion service. This will normally entail tempering temperatures at the bottom range for creep service and at the upper range for corrosion service. Such variations in tempering temperatures shall be taken into account in the selection of materials.

Plate materials, used as a base in the manufacture of vessels with integrally clad plate or having applied corrosion-resistant linings, shall comply with the requirements of materials given in Table 3.3.1. Metal used for applied corrosion resistant lining may be any metallic material of weldable quality that is suitable for the intended service and acceptable to the purchaser.

Materials used for supporting lugs, skirts, baffles and similar non-pressure parts welded to vessels shall be of weldable quality and suitable in other respects for the intended service.

For Group F and Group G steels, see Clause 2.5.4.

2.2 STANDARD COMPONENTS AND INTEGRALLY CLAD METALS Standard components, e.g. flanges, nozzles, pipe fittings, bolting and valves, and integrally clad metals used in vessel manufacture shall comply with the requirements of the following relevant Standard specifications, except as provided in Clause 2.3. British and American Standards for components and integrally clad metals, which are accepted by the British and American pressure equipment Standards are acceptable.

(a) *Pipe fittings* ANSI B16.47, ANSI B16.9.

A2 (b) *Pipe flanges* AS 2129, AS/NZS 4331, BS 3293 BS 4504, ANSI B16.47, ANSI B16.5.

(c) *Bolting* AS/NZS 1110, AS 1111, AS 1112, AS 2451, AS 2465, AS 2528, AS B148, BS 2693.1, BS 4439, BS 4882, ASTM A 193, ASTM A 320.

(d) *Pipe threads* AS 1722, ANSI B1.20.1, API Std 5B.

(e) *Valves* AS 1271.

(f) *Integrally clad plate* ASTM A 263, ASTM A 264, ASTM A 265.

NOTES (to Item f):

1 These materials are required where design calculations are based on the total thickness, including cladding.

2 Bonding strength to be established in accordance with these specifications.

3 Where any part of the cladding thickness is specified as a corrosion allowance, such added thickness should be removed before tensile tests are carried out.

2.3 ALTERNATIVE MATERIAL AND COMPONENT SPECIFICATIONS

2.3.1 General Where a material or component conforming to one of the specifications in Table 3.3.1 or Clause 2.2 is not available or desired, alternative materials and components may be used provided they comply with the requirements of AS/NZS 1200 for new or alternative materials.

2.3.2 Alternative product form When there is no specification covering a particular product form of a wrought material for which there are specifications covering other product forms, such a product form may be used, provided that the following conditions shall apply:

(a) The chemical, mechanical and physical properties, scope of testing heat treatment requirements, and requirements for deoxidation, or grain size requirements conform to specifications included in Table 3.3.1. The strength values for that specification, listed in Table 3.3.1, shall be used.

(b) The manufacturing procedures, tolerances, tests and marking are in accordance with the specification covering the same product form of a similar material.

(c) The two conditions in Items (a) and (b) are compatible in all respects, e.g. welding and testing requirements in Item (b) are appropriate for the material specified in Item (a).

(d) For welded tube made from plate, sheet or strip, without the addition of filler metal, 0.85 times the appropriate design strength, as listed in Table 3.3.1 or as derived in accordance with Appendix A, is used.

A3 (e) Material manufacturer's test certificates reference the specifications used in producing the material and in addition make reference to this Clause (2.3.2).

2.3.3 Use of structural and similar quality steels Structural and similar quality carbon and carbon-manganese steel plates and sheets, tubes, bars and sections not listed in Table 3.3.1, may be used for pressure parts of Class 3 vessels, provided that the following conditions are fulfilled:

(a) The specified minimum tensile strength of the steel is no greater than 460 MPa.

(b) The ladle analysis does not exceed the following:

Carbon . . . . 0.25%.

Phosphorus . . . . 0.040%.

Sulfur . . . . 0.040%.

Carbon equivalent based on:

$$C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 0.45\%.$$

(c) Test certificates (or equivalent) identifying the steel to a national Standard are provided and the steel is suitably marked or labelled.

(d) Plate used for flanges is not greater than 40 mm thick and the steel is not greater than 16 mm thick for tubes, sections and machined sockets and bosses, or 40 mm diameter for bars.

(e) Welded tube complies with a specification which requires hydrostatic testing of the tube.

Regardless of the vessel classification, a maximum weld joint efficiency of 0.65 is to be used for welded tubes. Factor 0.85 in Clause 2.3.2(d) and factor 0.92 in Item (f) do not apply.

(f) The design strength for calculation purposes is determined in accordance with Appendix A and multiplied by a factor of 0.92.

(g) All weld preparations, openings, tubes, bars and sections shall be visually examined for evidence of lamination which may render the plate unacceptable (see 'Defects in materials' in AS 4458).

(h) The design temperature of the vessel is between 0°C and 250°C.

(i) The vessel is not used for applications with high risk of lamellar tearing or hydrogen blistering.

(j) If the steel is to be hot-formed above 650°C or normalized during fabrication, the specified properties of the material shall be verified by tests on a specimen subjected to a simulated heat treatment equivalent to that which the steel is to be subjected.

(k) Bars and sections which have been manufactured by a cold forming process are not acceptable unless an appropriate heat treatment is used e.g. normalizing.

2.3.4 Specifically tested materials The use of steel outside the limits of Clause 2.3.3 or other materials is permitted for pressure parts in Class 1, 2 or 3 vessels, provided that—

(a) the material is shown by special tests to be equally suitable for the particular application as a similar material listed in Table 3.3.1; and

(b) agreement is given by the parties concerned.

These special tests may include chemical analysis, mechanical tests and non-destructive examination.

2.4 MATERIAL IDENTIFICATION Material identification shall comply with the requirements of AS 4458.

2.5 LIMITS OF APPLICATION OF MATERIALS AND COMPONENTS

2.5.1 Maximum pressure limits The maximum pressure for cast iron pressure parts shall be in accordance with the Notes to Table 3.3.1(C).

Components shall be limited to the maximum pressures for which they are rated by the component specification and by the requirements in this Standard for the specific type of component.

2.5.2 Temperature limits For low and high temperature limits, see Clauses 2.6 and 2.7, respectively.

2.5.3 Service limits

2.5.3.1 *Cast iron* Grey and malleable cast irons and ductile cast irons*, with elongation less than 14 percent (on a gauge length of 5.65 √area), shall not be used for vessels containing lethal or flammable fluids.

2.5.3.2 *Low melting point metals* The low melting points of copper and aluminium and some of their alloys shall be taken into account where vessels will contain flammable fluid.

Materials for which no design strengths are given above 350°C in this Standard shall not be used for transportable vessels containing lethal substances, nor those containing flammable substances unless the vessel is insulated in accordance with Clause 3.26.

2.5.3.3 *Corrosion resistance* In selecting material for vessels, consideration shall be given to the possibility of general or local wastage, corrosion, stress corrosion, corrosion fatigue, abrasion, and the like.

NOTE: For recommended corrosion practice, see Appendix D.

2.5.4 Structural attachments and stiffening rings Where pressure parts are constructed of Group G steel, all permanent structural attachments and stiffening rings welded directly to the pressure part shall be made of materials with specified minimum tensile strength equal to or greater than the material to which it is attached.

Where pressure parts are constructed of Group F steel, all permanent structural attachments and stiffening rings welded directly to the pressure part shall be of nine percent nickel steel or an austenitic stainless steel which cannot be hardened by heat treatment. Where austenitic stainless steel is used for attachments, consideration shall be given to the greater coefficient of expansion of the austenitic stainless steel.

2.6 MATERIAL FOR LOW TEMPERATURE SERVICE

2.6.1 General Materials and components for pressure parts and for non-pressure parts welded directly to pressure parts, for low temperature service or where it is required to guard against brittle fracture, shall comply with the appropriate requirements of this Clause (2.6). These requirements do not apply to non-pressure parts such as internal baffles, trays, supports, and the like. where these are not attached to a pressure part by welding and are not otherwise an integral part of a pressure part.

Where materials are to be welded—

A3 (a) see AS/NZS 3992 for impact test requirements for heat-affected zone and weld metal in welding procedure qualification tests; and

A3 (b) see AS/NZS 3992 for impact test requirements for welded production test plates.

See Clause 3.21.5 for requirements for bolting for low temperatures.

NOTE: See Appendix K for guidance on various requirements in this Standard for low temperature vessels.

2.6.2 Selection of material

2.6.2.1 *General* To select suitable material for each part of the vessel, the following procedure may be used:

(a) For carbon and carbon-manganese steels and steel castings but excluding bolting—see also Clauses 2.6.2.2, 2.6.2.3 and 2.6.2.4, determine the following:

   (i) The minimum operating temperature (MOT) for the part from Clause 2.6.3.1.

* Alternative names for ductile cast iron are ‘spheroidal graphite iron’, ‘SG iron’ and ‘nodular graphite iron’.

(ii) The required material design minimum temperature (MDMT) from Clause 2.6.3.2.

(iii) The material reference thickness (T_m) from Clause 2.6.4.

(iv) Enter the values obtained in Items (a)(ii) and (a)(iii) into Figure 2.6.2(A) or Figure 2.6.2(B), as appropriate. The curve below the intersection of these values gives the permitted grade of steel (and any necessary impact tests or type). See Note 6 to Figures 2.6.2(A) and 2.6.2(B) for interpolation between curves.

(b) For metals other than carbon or carbon-manganese steel or steel castings and excluding bolting—

(i) determine the MOT for the part in accordance with Clause 2.6.3.1; and

(ii) from Table 2.6.3, select the permitted material (and any necessary impact tests) having a required MDMT equal to or less than MOT.

NOTE: Where reference is made in Table 2.6.3 to Figure 2.6.2(A) or Figure 2.6.2(B), see Item (a) for guidance.

The above sequence may be changed as appropriate to determine MOT, MDMT or T_m.

(c) For non-metallic materials, see Clause 2.6.7.

2.6.2.2 *Thin-walled carbon and carbon-manganese steel tubes (seamless and welded)* Heat exchanger tubes of carbon and carbon-manganese steels with less than 0.25 percent carbon and a specified minimum tensile strength of less than 450 MPa, may be used at MOT as shown in Table 2.6.2.2 provided that—

(a) the tubes are used in heat exchangers of the floating head type;

(b) the tubes used in U-tube type heat exchangers are heat-treated after cold bending where required by AS 4458; or

(c) for fixed tubeplate type heat exchangers, it is demonstrated that stresses in the tubes due to differential thermal expansion are low, e.g. where spiral-wound tubes or expansion bellows are used, or calculated stresses are less than 50 MPa.

TABLE 2.6.2.2

MATERIAL DESIGN MINIMUM TEMPERATURE FOR HEAT EXCHANGER TUBES

Thickness mm	Tube to tubesheet attachment method		
	As welded °C	Welded and PWHT °C	Unwelded °C
10	−15	−30	−70
8	−20	−35	−75
6	−25	−40	−80
4	−40	−55	−95
2	−55	−70	−110

2.6.2.3 *Thin materials* Materials having a thickness insufficient to obtain a 2.5 mm Charpy V-notch specimen may be used at a temperature no less than that permitted for non-impact tested material of similar type, or as provided in Clause 2.6.2.2, or as established by tests agreed by the parties concerned.

2.6.2.4 Not allocated.

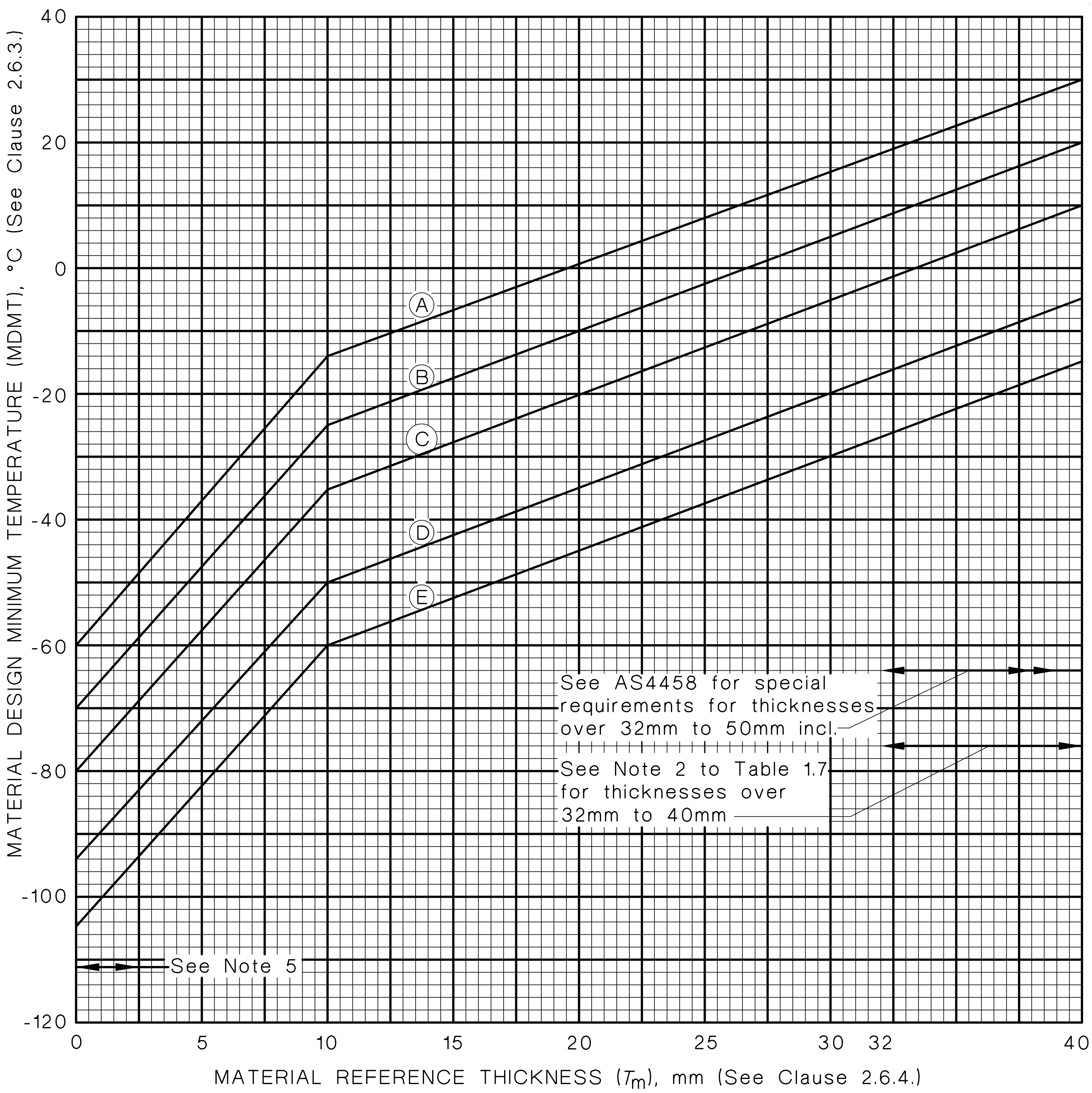


FIGURE 2.6.2(A) WROUGHT CARBON AND CARBON-MANGANESE STEELS—SELECTION OF MATERIAL FOR LOW TEMPERATURE SERVICE—AS WELDED

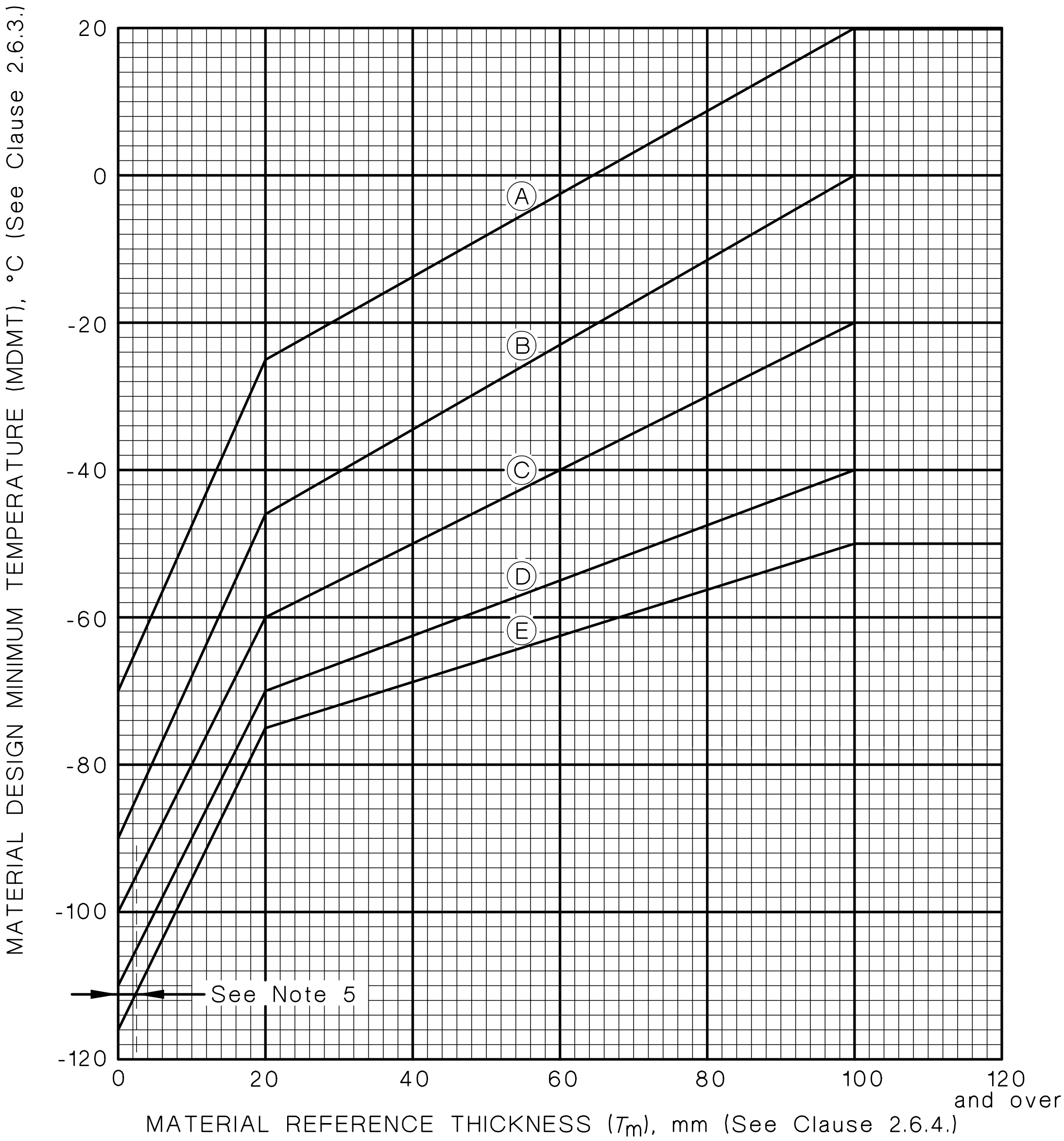


FIGURE 2.6.2(B) WROUGHT CARBON AND CARBON-MANGANESE STEELS—SELECTION OF MATERIAL FOR LOW TEMPERATURE SERVICE —POSTWELD HEAT TREATED

TABLE 2.6.2

EXPLANATORY TABLE FOR CURVES ON FIGURES 2.6.2(A) AND 2.6.2(B)

Curve	Standard impact test temperature °C	Standard impact test value (*J*) Tensile strength, MPa Specified min., $R_m \leq 450$ (Note 8)	Specified min., $R_m > 450 \leq 470$ (Note 9)	Specified min., $R_m > 470$ (Note 10)	Type of steel (permitted by this Standard) (Note 11)
A	No test	—	—	—	All
B	0 (Note 1)	27	31	40 (Note 3)	All
	No test	—	—	(Note 4)	Fine grained C-Mn steel with $T_m \leq 70$ mm (Note 2 and Note 4)
C	−20 (Note 1)	27	31	40 (Note 3)	Fine grained C-Mn steel (Note 2)
D	−40 (Note 1)	27	31	40 (Note 3)	Fine grained C-Mn steel (Note 2)
E	−50 (Note 1)	27	31	40 (Note 3)	Fine grained C-Mn steel (Note 2)

NOTES TO FIGURES 2.6.2(A), 2.6.2(B), AND TABLE 2.6.2:

1 Tested by steelmaker or manufacturer.

2 Steels produced to fine grained practice, i.e.—

(a) normalized steel where the actual Mn% divided by the actual C% ≥4;

(b) controlled rolled;

(c) thermo-mechanically controlled rolled; or

(d) grain refining elements added, e.g. aluminium or titanium (or both) 0.01% minimum. Examples are AS 1548, Types 5 and 7, and AS 1594 grade HU 300/1.

3 For steel with impact test values equal to or greater than 27 J and less than 40 J, material design minimum temperatures 10°C above the curve will apply. Where a Standard does not specify the temperature corresponding to 27 J (or 31 J or 40 J) Charpy V energy, the value specified may be converted to the 27 J (or 31 J or 40 J) temperature on the basis of 1.5 J/°C. This conversion shall be permitted in the range of Charpy V energy 20 J to 50 J. For example, AS 1548 Grade 7-460 giving 47 J at −20°C may be regarded as equivalent to 27 J at −33°C.

4 Applicable only to steel with specified minimum tensile strength equal to or less than 470 MPa.

5 Impact tests are not required for material thinner than 3 mm or where it is impracticable to obtain a 10 mm × 2.5 mm specimen. (See also Clause 2.6.2.3. Material specifications may not require impact tests on Charpy specimens smaller than 10 mm × 5 mm without special negotiation and thus impact tested material thinner than 7 mm may not be readily available.)

6 Values at intermediate test temperatures may be obtained by linear interpolation.

7 See Clause 2.6.5 for impact testing.

8 For these steels, an upper limit on tensile strength is also applicable as follows:

(a) Where the steel specification includes a maximum tensile strength (or a hardness equivalent)—the lesser of 560 MPa and the value in the steel specification.

(b) Where the steel specification does not limit the maximum tensile strength—560 MPa.

9 For these steels, an upper limit on tensile strength is also applicable as follows:

(a) Where the steel specification includes a maximum tensile strength (or a hardness equivalent)—the lesser of 600 MPa and the value in the steel specification.

(b) Where the steel specification does not limit the maximum tensile strength—600 MPa.

10 For these steels, an upper limit on tensile strength is also applicable as follows:

(a) Where the steel specification includes a maximum tensile strength (or a hardness equivalent)—the lesser of 620 MPa and the value in the steel specification.

(b) Where the steel specification does not limit the maximum tensile strength—620 MPa.

11 The maximum permitted carbon content by cast analysis is 0.25 percent; this limit may require restriction of the normally specified carbon content in some steel specifications permitted by this Standard.

TABLE 2.6.3

MATERIAL DESIGN MINIMUM TEMPERATURE (MDMT)

Material		Typical specification or nominal composition		Material design minimum temperature, °C (Note 1)	
Steel group (Note 3)	**General type**	**Standard of specification**	**Grade or type**	**Not impact tested**	**Impact tested (Note 4)**
CARBON AND CARBON-MANGANESE STEEL (all forms excluding weld metal and bolting)					
A1	C, C-Mn (low strength)	AS 1548	7-430, 7-460	See Clauses 2.6.2 and 2.6.3.2	See Clauses 2.6.2 and 2.6.3.2
A2	C, C-Mn (medium strength)	AS 1548	5-490, 7-490		
A3	C, C-Mn (high-yield strength)	AS 1594	XF 400, XF 500		
LOW ALLOY STEEL (all forms, excluding weld metal and bolting) (Note 2)					
B	Cr or Mo < 3/4	—	C -1/2Mo, 1/2Cr -1/2Mo	MDMT for Curve A in Figure 2.6.2 (A) or (B) as appropriate but not lower than 0°C	Test temperature giving $C_v \ge 27$ J where $R_m \le 450$ MPa; 40 J where R_m > 450 < 650 MPa; lateral expansion ≥ 0.38 mm for each specimen where R_m ≥ 650 MPa (Notes 5 and 6)
C	3/4 ≤ Total alloy ≤ 3	—	1Cr -1/2Mo		
D1	Vanadium	—	1/2Cr -1/2Mo -1/4V		
D2	3 ≤ Total alloy ≤ 10		2 1/4 Cr-1Mo		
E	3 1/2 Ni	ASTM A 203	D E	−30 or MDMT for Curve B in Figure 2.6.2 (A) or (B), whichever is less	Test Temperature giving $C_v \ge 18$ J
F	9 Ni	ASTM A 353		Not permitted	Test temperature giving $C_v \ge 20$ J Test temperature giving lateral expansion ≥ 0.38 mm for each specimen (Note 10); and (Note 7) NDTT
G	Quenched and tempered	ASTM A 517, AS 3597	A, B, C, D, E, F, J, P 700 PV		
HIGH ALLOY STEEL (all forms, excluding castings, weld metal and bolting					
H	Martensitic chromium Types 12 Cr and 15 Cr	ASTM A 240	410, 429	MDMT as for Curve A in Figure 2.6.2 (A) or (B) as appropriate but not lower than −30	Test temperature giving lateral expansion ≥ 0.38 mm for each specimen or Test temperature giving $C_v \ge 27$ J where $R_m \le 450$ MPa 40J where R_m > 450 < 650 MPa
J	Ferritic high chromium types 12 Cr-Al or 12 Cr low C	ASTM A 240	405, 410S		
K	Austenitic chromium nickel types (only plate specifications shown):				
	18 Cr-8 Ni	ASTM A 240	304	−255	
	18 Cr-8 Ni (Low C)	ASTM A 240	304L	−255	
	18 Cr-8 Ni-Nb	ASTM A 240	347	−255	
	18 Cr-10 Ni-Ti	ASTM A 240	321	−200 (Note 8)	
	18 Cr-10 Ni-2 Mo	ASTM A 240	316	−200	
	18 Cr-10 Ni-2 Mo (Low C)	ASTM A 240	316L	−200	
	19 Cr-13 Ni-3 Mo	ASTM A 240	317	−200	
	25 Cr-20 Ni	ASTM A 240	310S	−200	
	Selected Austenitic types postweld heat treated below 900°C	ASTM A 240	309, 310, 316 309Cb, 310Cb, 316Cb	Not permitted	
	Any type with C > 0.10%	ASTM A 240	302	−30	
L	High chromium	ASTM A 240	442, 446	Not permitted	
M	Ferritic-austenitic chromium nickel	ASTM A 789	S31803	MDMT as for curve A in Figure 2.6.2 (A) or (B) as appropriate but not lower than −30	

(*continued*)

Material		Typical specification or nominal composition		Material design minimum temperature, °C (Note 1)	
Steel group (Note 3)	**General type**	**Standard of specification**	**Grade or type**	**Not impact tested**	**Impact tested (Note 4)**
HIGH ALLOY STEEL (Castings)					
All types (H to M)		—	—	As for Group H steels	Test temperature giving $C_v \geq 20$ J
CAST IRONS					
	Grey iron	AS 1830	T-150 to T-400	−30	
	Spheroidal graphite	AS 1831	500-7 and 400-12		Note 9
		AS 1831	370-17	MDMT as for Curve A in Figure 2.6.2 (B) but not lower than −30	Test temperature giving $C_v \geq 20$ J
	Malleable iron	AS 1832	All whiteheart and blackheart	−30	Note 9
	Austenitic iron	AS 1833	All spheroidal graphite	−30	Test temperature giving $C_v \geq 20$ J
NON-FERROUS METALS					
All types except Titanium and its alloys		See Tables 3.3.1, (D), (E), (F) and (H)		No Limit	Impact test not required
Titanium and its alloys		ASTM B 265		−60	Test temperature giving $C_v \geq 20$ J

NOTES TO TABLE 2.6.3:

1 These MDMT are applicable with the design strengths given in Table 3.3.1. See Clause 2.6.3.2 for modifications permitted or required.

2 Low alloy steels not listed in or not equivalent to those in the table shall meet the requirements specified for Group B steels.

A3 3 For steel groups, see Table 1.7 and AS/NZS 3992.

4 (a) See Clause 2.6.5 for impact testing.

(b) C_v = Charpy V impact test values; R_m specified minimum tensile strength.

(c) Where Charpy V energy values are quoted, the values are the minimum average values for each set of three 10 mm × 10 mm specimens.

5 See also limits in Notes 8, 9 and 10 to Figures 2.6.2(A) and 2.6.2(B).

6 For variations permitted for different energy values and test temperatures, see Note 3 to Figures 2.6.2(A) and 2.6.2(B).

7 In addition to Charpy V impact test, dropweight tests are required for—

(a) Group F steels ≥ 16 mm thick for use at MOT below −170°C; and

(b) Group G steels ≥ 16 mm thick for use at MOT below −30°C.

8 Impact testing for these high alloy steels is not required below the temperature listed when the calculated average stress used for determining thickness does not exceed 50 MPa.

9 These cast irons may be used below −30°C by agreement of the parties concerned, on the basis of suitable testing or successful past experience.

10 For Group F and Group G steels, the maximum test temperature is to be 0°C.

2.6.2.5 *Use of fracture mechanics* Materials may be used at temperatures lower than otherwise required by this Clause (2.6), provided that suitable fracture mechanics analysis and tests justifying the lower temperatures are carried out.

2.6.3 Minimum temperatures

2.6.3.1 *Minimum operating temperature (MOT)* The MOT shall be the lowest metal temperature of the part under consideration during normal operation including normal process fluctuations and during properly conducted start-up and shutdown. The MOT shall be the lowest of the following:

(a) For vessels thermally insulated externally—the minimum temperature of contacting contents.

(b) For vessels not thermally insulated—the lower of—

(i) the lowest one day mean ambient temperature (LODMAT)* plus 10°C, where the metal can be subjected to this temperature while the shell is under pressure; or

(ii) the minimum temperature of the contacting contents, except that for Groups A1, A2, A3, B, C, D1, D2, and G steels, vessels containing fluids at temperatures governed by atmospheric conditions only and whose vapour pressure reduces with decreasing temperature, the temperature corresponding to the vapour pressure obtained by dividing the vessel design pressure by 2.5 may be used.

(c) If there is evidence to show that because of radiation, adiabatic expansion or other effects, the above will not provide a reliable estimate of temperature, the method to be used in assessing the temperature shall be agreed. Allowance shall be made for any sub-cooling during pressure reduction.

(d) A lower temperature than that determined from Items (a), (b) or (c) where so specified by the purchaser or in an application Standard.

2.6.3.2 *Material design minimum temperature* (*MDMT*) *for carbon and carbon-manganese steel* The MDMT shall be determined as follows:

(a) *General* The required MDMT for use in Figures 2.6.2(A) and 2.6.2(B) shall be the lowest of the following, adjusted where necessary by Items (b) and (c):

(i) The lowest temperature occurring coincidentally with process conditions which result in the following equation—

$$\text{Calculated membrane stress} \geq \frac{2}{3} f \eta$$

where

f = design tensile strength at ambient temperature (see Table 3.3.1), in megapascals

η = efficiency of the welded joint.

(ii) A temperature that is 10°C warmer than the lowest temperature occurring coincidentally with process conditions which result in—

$$\text{Calculated membrane stress} \geq 50 \text{ MPa but } < \frac{2}{3} f \eta$$

* See Appendix K.

(iii) A temperature that is 50°C warmer than the lowest temperature occurring coincidentally with process conditions which result in the calculated stresses at any cross-section less than 50 MPa for average stress and less than 100 MPa for peak stress.

The calculated stresses shall take into account all loadings, such as internal and external pressures, thermal stress and external loads arising from connecting pipes. Where such a vessel will also be subject to a higher pressure at higher temperature, e.g. in a refrigeration system with liquefied gas, the material and design shall be suitable for all expected combinations of operating pressures and temperatures (see Appendix K, for an example).

(b) *Modification for lethal substances* For vessels which contain lethal substances, the required MDMT shall be 15°C colder than the MOT required by Clause 2.6.3.1, but shall not be warmer than 0°C.

(c) *Modification for partial postweld heat treatment* For Class 1 vessels where plates containing nozzles, supports or other welded attachments are postweld heat-treated before they are butt welded to the shell, but the main joints are not postweld heat-treated, the required MDMT obtained from Item (a) for as-welded parts may be adjusted by adding 15°C. The minimum distance from the edge of welds of the attachments to the main welded joints shall be not less than 150 mm.

(d) *Material for vessels subject to shock* All steels (except Group K steels used for transportable vessels) shall have a required MDMT 15°C colder than the MOT required by Clause 2.6.3.1.

2.6.3.3 *MDMT for metals other than carbon and carbon-manganese steels* For metals other than carbon and carbon-manganese steels, the required MDMT shall be as specified in Clause 2.6.2.1.

2.6.4 Material reference thickness The reference thickness (T_m) used in applying Figures 2.6.2(A) and 2.6.2(B) shall be determined as follows depending on the type of component:

(a) *Butt welded components* The reference thickness of each component shall be taken as the actual thickness of the component under consideration at the edge of the weld preparation.

(b) *Weld neck flanges, plate and slip-on (or hubbed) flanges, tubeplates and flat ends* The reference thickness shall be the greater of one-quarter the actual thickness of the flange, tubeplate or flat end, or the thickness of the branch or shell attached thereto (see Figures 2.6.4(a), (b), (c) and (d)).

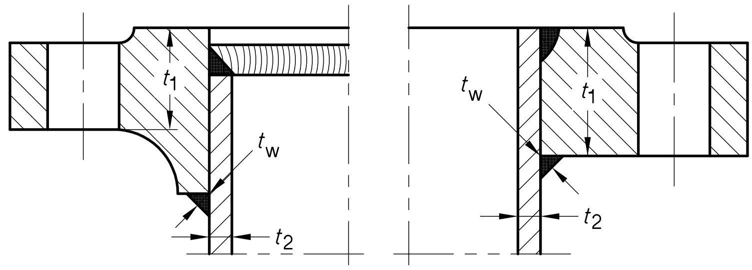
If the distance from the flange, tubeplate or flat end to the butt weld is not less than four times the thickness of the butt weld, the reference thickness for the as-welded condition shall be the thickness at the edge of the weld preparation.

The reference thickness of tubeplates having tubes attached by welding shall be taken as not less than tube thickness.

NOTE: Where the shell to tubeplate joint is stress relieved but the tube/tubeplate joint is as-welded, this may affect the selection of materials for the tubeplate.

(c) *Branches, nozzles and compensating plates* The reference thickness of each component shall be determined separately by considering only the actual thickness of that component. Where butt-welded inserts are used, the reference thickness shall correspond to the thickness at the edge of the weld preparation.

(d) *Tubes* The reference thickness shall be that of the actual thickness of the tube.

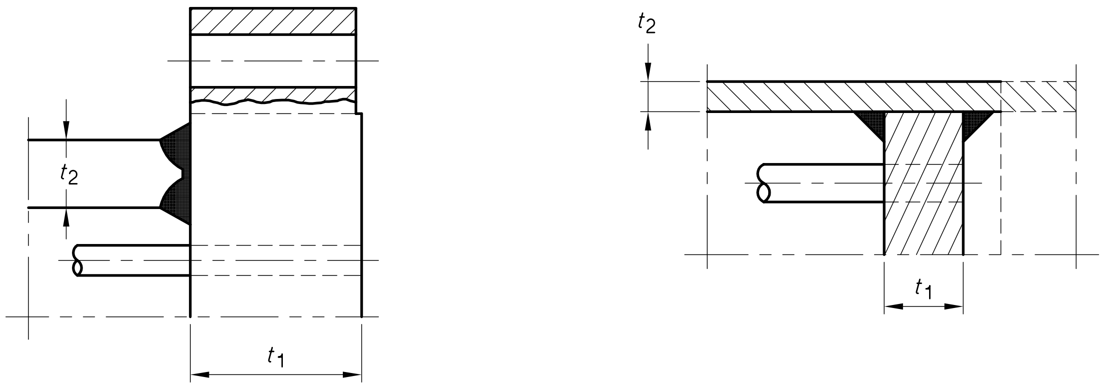


LEGEND:

T_m as welded = greater of t_2 and $0.25\,t_1$ (using Figure 2.6.2(A))

T_m postweld heat treated = greater of t_2 and $0.25\,t_1$ (using Figure 2.6.2(B))

(a) Slip-on and plate flange

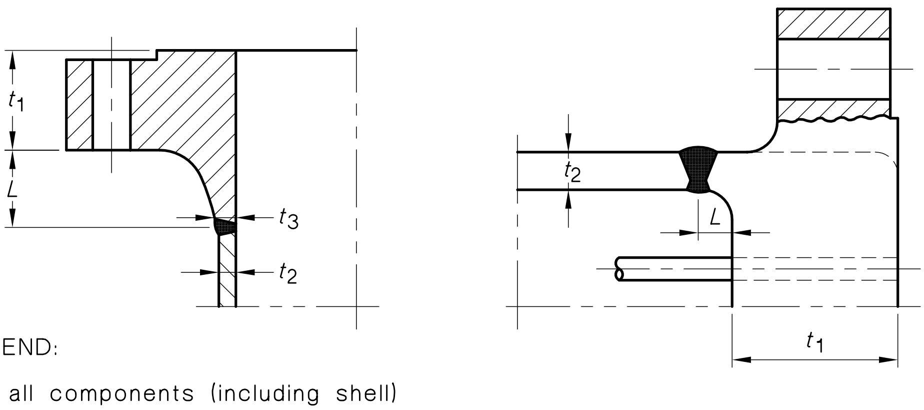


LEGEND:

T_m as welded = greater of t_2 and $0.25\,t_1$ (using Figure 2.6.2(A))

T_m postweld heat treated = greater of t_2 and $0.25\,t_1$ (using Figure 2.6.2(B))

(b) Fixed tube plate, flat end and set-in plate



LEGEND:

For all components (including shell)

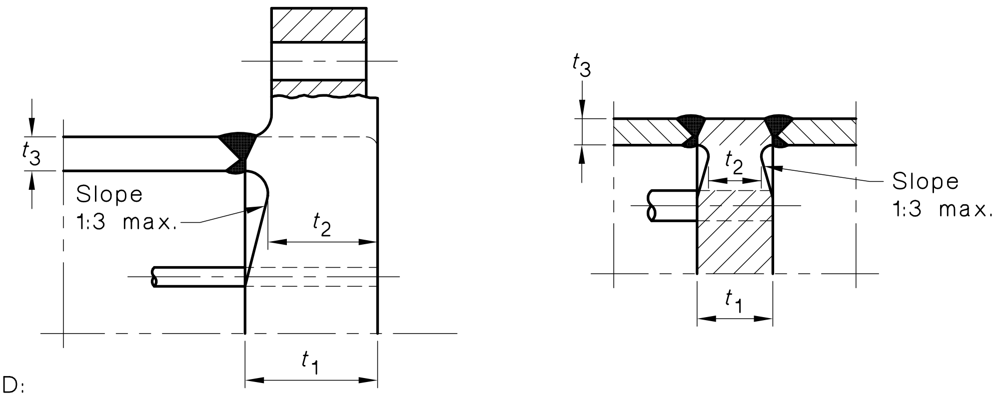
As welded $L < 4t_3$: T_m = greatest of t_2, t_3 and $t_1/4$ (using Figure 2.6.2(A))

$L \geqslant 4t_3$: T_m = greatest of t_2 and t_3 (using Figure 2.6.2(A)) or $0.25\,t_1$ (using Figure 2.6.2(B)) which ever is more onerous)

Postweld heat treated: T_m = greatest of t_2, t_3 and $0.25t_1$ (using Figure 2.6.2(B))

(c) Forged or cast weld neck flange, tubeplate and flat end

FIGURE 2.6.4 (in part) EXAMPLES FOR DETERMINATION OF MATERIAL REFERENCE THICKNESS (T_m)



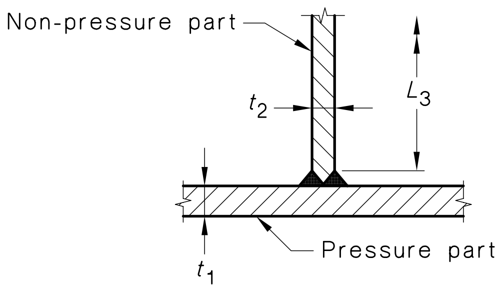
LEGEND:

For all components (including shell)

As welded: T_m greater of $0.25\,t_2$ or t_3 (using Figure 2.6.2(A)); or $0.25\,t_1$ (using Figure 2.6.2(B)) whichever is more onerous

Postweld heat treated: T_m = greater of t_3 and $0.25\,t_1$ (using Figure 2.6.2(B))

(d) Welded tube plate and flat end with stubs



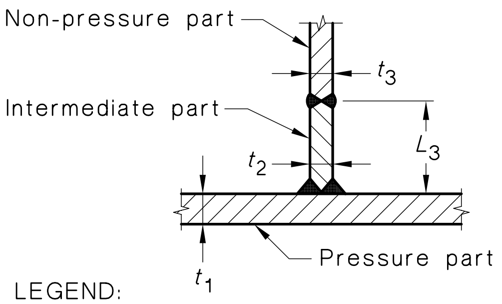
LEGEND:

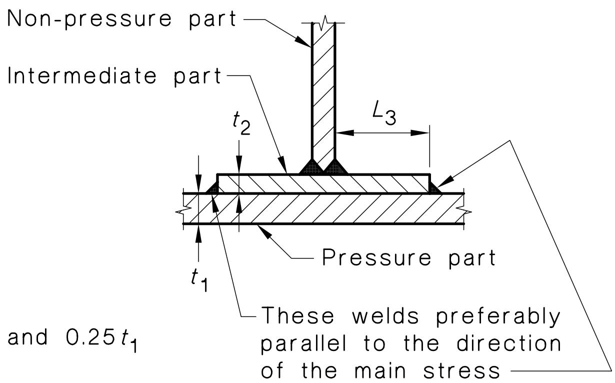
T_m for non-pressure part = greater of t_2 and $0.25\,t_1$

A2 | T_m for pressure part = t_1

L_3 = greater of 50 mm and $2\,t_2$

(e) Non-pressure part





LEGEND:

T_m for intermediate part = greater of t_2 and $0.25\,t_1$

A2 | T_m for pressure part = t_1

L_3 = greater of 50 mm and $2\,t_2$

(f) Non-pressure part with intermediate part

FIGURE 2.6.4 (in part) EXAMPLES FOR DETERMINATION OF MATERIAL REFERENCE THICKNESS (T_m)

(e) *Attachments* Attachments welded directly to a pressure component shall be regarded as part of the pressure component, and the reference thickness shall be the thickness
A2 as shown in Figure 2.6.4. Intermediate attachments, (see Figure 2.6.4(f)) shall be employed where it is required to attach non-critical components to the shell.

(f) *Unwelded items* Unwelded items shall be taken as stress relieved and the reference thickness shall be taken as one-quarter of the thickness of the item.

The thickness above used as a basis for the reference thickness shall be the actual or specified minimum thickness including corrosion and other allowances.

2.6.5 Impact testing

2.6.5.1 *When required* Parent metal of pressure parts and of non-pressure parts directly attached by welding to pressure parts, shall be impact-tested as required by Table 2.6.3.

Impact testing is not required for material other than C and C-Mn steels thinner than 3 mm or where it is impracticable to obtain 10 mm × 2.5 mm Charpy V-notch specimens (see also Clause 2.6.2.3).

For C and C-Mn steels impact testing is not required for 10 mm and thinner material provided that the material design minimum temperature as calculated by Clause 2.6.3.2 is not colder than the temperature shown in Table 2.6.5.1.

TABLE 2.6.5.1

MATERIAL DESIGN MINIMUM TEMPERATURE

Thickness mm	As welded °C	PWHT °C
10	−15	−30
8	−20	−35
6	−25	−40
4	−40	−55
≤ 2	−55	−70

Certified reports of impact tests made by the material manufacturer shall be accepted as evidence that the material complies with the requirements of this Clause provided that—

(a) the test specimens are representative of the material supplied and the material is not subject to heat treatment during or following fabrication, which will materially reduce its impact properties; or

(b) the materials from which the test specimens are removed were heat-treated separately such that they are representative of the material in the finished vessel.

The manufacturer of the vessel may have impact tests made to prove the suitability of a material which the materials manufacturer has not impact-tested provided that the number of tests and the selection of the test specimens shall be as specified in the material Standard.

2.6.5.2 *Test method* Impact testing shall be in accordance with AS 1544.2 except—

(a) lateral expansion tests shall be in accordance with ASTM A 370 (see Table 2.6.3 for use); and

(b) the dropweight test for determining the NDTT shall comply with AS 1663 (see Table 2.6.3 for use).

2.6.5.3 *Test specimens* Test specimens shall be selected and prepared as follows:

(a) *Number of Charpy V specimens* The number and location of Charpy impact test specimens shall be selected to adequately represent the material used in the vessel, and such selection shall be in accordance with a specification appropriate to the product form, e.g.—

(i) plates . . . . AS 1548;

(ii) pipes and tubes . . . . ASTM A 524;

(iii) forgings . . . . ASTM A 350;

(iv) castings . . . . ASTM A 352;

(v) bolting . . . . ASTM A 320; and

(vi) pipe fittings . . . . ASTM A 420.

From Group F and Group G steels, at least three Charpy V specimens (refer to Clause 2.6.5.6(d) for retests and requirements for additional test specimens) shall be made from each plate as heat-treated, or from each heat of bars, pipe, tube, rolled sections, forged parts or castings included in any one heat treatment lot. The specimens for plate shall be oriented transverse to the final direction of rolling; for circular forgings, the specimens shall be oriented tangential to the circumference, and for pipes and tubes the specimens shall be oriented longitudinally.

For wrought material, at least three Charpy specimens shall be cut with the specimen parallel to the principal direction of hot working.

The manufacturer of small components other than bolting, either cast or forged, may certify a lot of more than 20 duplicate parts by reporting the results of one set of impact specimens taken from one such component selected at random, provided that the same specification and heat of material and the same process of production, including heat treatment, were used for all of the lot.

(b) *Dimensions of Charpy V specimens* Standard 10 mm × 10 mm specimens shall be used where the thickness or diameter permits. For material of nominal thickness 20 mm and over, 10 mm × 10 mm specimens shall not include material nearer to the surface than 3 mm. For material of nominal thickness under 20 mm, 10 mm × 10 mm specimens shall be machined so that they do not include material nearer to the surface than 1 mm. If the material is too thin to permit the preparation of 10 mm × 10 mm specimens, the dimension along the base of the notch shall be reduced to the largest possible of 7.5 mm, 5 mm and 2.5 mm.

The base of the notch shall be perpendicular to the original external surface.

(c) *Dropweight test specimens* Dropweight test specimens shall be selected as follows:

(i) For plate thicknesses 16 mm and over, one dropweight test (two specimens) shall be made for each plate as heat-treated.

(ii) For forgings and castings of 16 mm thickness or over, one dropweight test (two specimens) shall be made for each heat in any one treatment lot using the procedure in ASTM A 350 for forgings and in ASTM A 352 for castings.

2.6.5.4 *Impact test requirements* Where impact tests are required by Clause 2.6.5.1, the test results shall comply with the criteria (test method and values) specified in Table 2.6.3 and the following:

(a) *General*
General requirements for impact tests are as follows:

(i) Where Charpy V impact values are specified in Table 2.6.3, the average impact energy values of the three 10 mm × 10 mm Charpy V specimens shall be no less than the values given in Table 2.6.3 to satisfy the MDMT and the values for individual specimens shall be no less than 70 percent of the specified minimum average value.

(ii) Where lateral expansion values are specified in Table 2.6.3, each specimen shall show 0.38 mm minimum lateral expansion on the opposite side of the notch regardless of specimen size.

(iii) When the nil ductility transition temperature (NDTT) is specified in Table 2.6.3, the NDTT shall be equal to or less than required MDMT.

NOTE: The impact energy at a particular temperature is usually appreciably lower for test pieces cut transverse to the grain (i.e. transverse to the direction of principal hot working) than for pieces cut in the direction of the grain. Where test pieces must be cut transverse to the grain, the specified minimum impact energy for longitudinal specimens should be reduced. Where appropriate values are not specified in material specifications, requirements for transverse specimens should be a matter for agreement between the parties concerned.

(b) *Weld neck flanges, plate and slip-on (or hubbed) flanges, tubeplates and flat ends* The minimum impact energy shall comply with the requirements of Clause 2.6.5.4(a) using the appropriate T_m except that in no case shall the impact test requirements be less than those which would be required if they were unwelded.

The minimum impact energy for tubeplates having tubes attached by welding shall be derived in accordance with Clause 2.6.4(b), except that in no case shall the impact requirements for the tubeplates be less than those required for the tubes.

(c) *Attachments* The minimum impact energy for a non-pressure attachment welded directly to a pressure component shall be not less than that required for the pressure component to which it is attached.

2.6.5.5 *Impact test requirements for subsidiary specimens* For subsidiary Charpy V specimens (i.e. less than 10 mm × 10 mm), the energy shall be not less than values given in Table 2.6.3 times the appropriate equivalent energy factor given in Table 2.6.5.5.

TABLE 2.6.5.5

EQUIVALENT ENERGY FACTORS FOR SUBSIDIARY TEST SPECIMENS

Thickness of test specimen, mm	Equivalent energy factor
10 (standard)	1.0
7.5	0.8
5.0	0.7
2.5	0.35

NOTE: For test specimens between the above thicknesses, linear interpolation permitted.

2.6.5.6 *Retests* According to the nature of failure of a test, retests may be performed as follows:

(a) *Failure of one specimen* If the average of the three Charpy impact tests exceeds the specified minimum average energy value specified in Table 2.6.3 but one test piece fails to give the specified minimum individual value, three additional test pieces from the original sample shall be tested. The result shall be added to those previously obtained and a new average calculated. If the average value of the six tests is not less than the specified minimum average, and not more than one result of the six tests is below the specified individual test value, then the product complies with this Clause (2.6.5).

(b) *Failure of average of tests* If the average of the three impact tests fails to attain the specified minimum average energy value or if two of the tests fall below the specified minimum individual value, the material represented shall be deemed not to comply with this Clause (2.6.5).

(c) *Failure due to specimen defect or procedure error* Where failure is the result of a defect peculiar to the specimen or to an error in the test procedure, the result shall be discarded and a further specimen substituted.

(d) *Failure in lateral expansion test for all size specimens* If the value of the lateral expansion for one specimen is below 0.38 mm but not below 0.25 mm, and the average value for the three specimens equals or exceeds 0.38 mm, then a retest of three additional specimens may be made, each of which shall attain values equal to or exceeding 0.38 mm. If the required values are not obtained in the retest or if the values in the initial test are below the minimum required for retest, the material shall be either rejected or submitted to a further heat treatment. After such re-heat treatment, three specimens shall be tested and the lateral expansion for each shall equal or exceed 0.38 mm.

(e) *Failure in the dropweight test* If one of the two test specimens fails to meet the no-break criterion then two more specimens shall be taken and retested. Each of these specimens shall meet the no-break criterion. If this criterion is not met in the retest the material shall be rejected or submitted to a further heat treatment. After such re-heat treatment, two specimens shall be tested and the no-break criterion shall be met.

2.6.6 Not allocated.

2.6.7 Non-metallic materials Non-metallic gaskets, packing and similar parts used for low temperature service shall be suitable for the service at the MOT and allowance shall be made for any hardening or embrittlement.

2.7 MATERIAL FOR HIGH TEMPERATURE SERVICE

2.7.1 General Materials of pressure parts of vessels shall not be used at operating temperatures in excess of the highest design temperature for which strengths are shown in Table 3.3.1 for the given material, except that higher temperatures may be used provided that the material is shown to be suitable for the service conditions and is acceptable to the parties concerned.

2.7.2 Selection of materials for high temperature service In selecting materials for prolonged exposure to high temperatures, consideration shall be given to each of the following factors:

(a) The loss of thickness due to scaling.

(b) The possible graphitization of carbon, carbon-manganese and carbon-silicon steels at temperatures above 425°C and of carbon-molybdenum steel at temperatures above 470°C.

(c) The embrittlement of high alloy steel Type 430 at temperatures above 425°C.

(d) Other exposure effects on materials.

(e) The reliability of elevated temperature test data and the applicability of the design stress basis given in Appendix A.

2.7.3 Valves and similar components The maximum operating temperatures of valves and similar components may be limited by the trim material.

2.7.4 Brazing and soldering materials The operating temperature shall not exceed 95°C for brazing materials and 50°C for soldering materials except higher temperatures may be used when agreed between the parties concerned and qualified by
A3 suitable tests (see AS/NZS 3992).

2.7.5 Steels Steels for vessels for use at temperatures above 50°C may be supplied and used with or without elevated temperature properties being verified or hot-tested by the material manufacturer. See Table 3.3.1 for increased design strengths for verified or hot-tested steel in some grades.

Where steel is to be used at an intermediate design temperature (i.e. requiring interpolation from Table 3.3.1 for design strength) and is ordered hot-tested, the test shall be carried out, and the results shall comply with the values at the nearest higher standard temperature given in the particular material specification.

The use of cladding or lining with chromium-alloy stainless steel with chromium content over 14 percent is not recommended for design temperatures over 425°C.

2.8 NON-DESTRUCTIVE TESTING OF MATERIALS Where increased assurance of material quality is required to assist in economic manufacture, e.g. in tubeplates or major components of Class 1 vessels, non-destructive testing should be carried out on material before fabrication, as required by the manufacturer or by the purchaser (see Appendix E).

Where ultrasonic examination of welded joints is required (see AS 4037), consideration shall be given to the need for ultrasonic examination of the parent material in the vicinity of the area to be welded, to ensure that this portion of the parent material is sufficiently free from defects which would prevent adequate ultrasonic inspection of the joint. This may be done by the use of parent material which has been ultrasonically examined by the material manufacturer or locally by the vessel manufacturer prior to welding. Similarly, attention should be given to plate for applications where there is a high stress gradient through the plate thickness, e.g. at set-on branches.

Where high casting quality factors are required, castings shall meet the requirements of AS 4037.

SECTION 3 DESIGN

3.1 GENERAL DESIGN

3.1.1 Main design requirements The design of vessels and vessel parts subjected to pressure shall comply with the requirements of this Section.

For requirements of designer's quality systems to AS/NZS ISO 9001 and design verification see AS 3920.1.

3.1.2 Design responsibility The designer shall be responsible for the design of the vessel in accordance with this Section and the design conditions which shall be determined by the designer if not specified by the purchaser (see Appendix E).

NOTE: For risk assessment, see Appendix C.

3.1.3 Alternative design methods Where the design of the vessel or of a detail is not dealt with in this Section, or an alternative method is desired, the adequacy of such design shall be demonstrated to the satisfaction of the parties concerned by one or more of the following means:

(a) Successful performance under comparable service conditions of similarly shaped, proportioned and sized components.

(b) Rigorous mathematical analysis, including finite element analysis (see Appendix B).

(c) Proof tests (see Clause 5.12) and experimental stress analysis.

The stress criteria for the analysis in Items (b) and (c) shall be determined in accordance with AS 1210 Supplement 1 using material design tensile strength (f) from Table 3.3.1 of this Standard.

3.1.4 Design against failure

3.1.4.1 *Service conditions considered normal* Compliance with this Standard may be regarded as adequate safeguard against failure of vessels under normal service conditions.

3.1.4.2 *Special service conditions* Where service conditions are not considered normal, this Standard may not provide adequate coverage against failure. Then special consideration shall be given to all feasible modes of failure such as—

(a) high strain or high cycle fatigue;

(b) stress corrosion or corrosion fatigue;

(c) corrosion, including all forms of wastage;

(d) distortion which may cause interference or separation of mating parts;

(e) metal penetration; or

(f) a combination of these.

Appendix D gives guidance on designing for corrosion prevention practice. (See also Clause 3.2 concerning design conditions.)

The design strengths given in Table 3.3.1 of this Standard have been selected to ensure that in the majority of vessels, fatigue cracking is unlikely. However, where extreme severe fatigue conditions exist, it is recommended that further provision be made to avoid fatigue cracking. If further information is required, reference may be made to AS 1210 Supplement 1.

3.2 DESIGN CONDITIONS

3.2.1 Design and calculation pressures

3.2.1.1 *Design pressure of vessel* The design pressure (see Clause 1.8) shall be the pressure specified by the purchaser, the application specification or as otherwise determined in accordance with this Standard. See also Clause 3.2.1.4.

The design pressure shall not be less than the set pressure of the lowest set pressure-relief device.

In selecting the design pressure, a suitable margin, above the maximum operating pressure (see Clause 1.8) should be made to allow for probable surges of pressure during operation and to prevent unnecessary operation of pressure-relief devices. Where pressure relief devices are used, the design pressure is often assumed to be 5 percent to 10 percent above the operating pressure at the most severe condition, but where wide surges in pressure and temperature may occur, this margin may need to be increased. Where bursting discs are used, it is recommended that the design pressure of the vessel be sufficiently above the normal operating pressure to provide a sufficient margin between operating pressure and bursting pressure to prevent premature failure of the bursting disc (refer to AS 1358).

3.2.1.2 *Calculation pressure of a vessel part* A vessel part shall be designed for the most severe conditions of coincident pressure and metal temperature expected in normal operation, excluding the excess pressures developed during the hydrostatic test or during operation of pressure-relief devices. The vessel design shall also be suitable for the test fluid and vessel position during the hydrostatic pressure test. The most severe condition of coincident pressure and temperature shall be that condition which results in the greatest thickness of the part of the vessel under consideration, not including corrosion allowance. The pressure and temperature at this condition, with a suitable margin (see Clause 3.2.1.1), shall be used as the calculation pressure and temperature. For a large or complex vessel, there may be different calculation pressures and temperatures for various parts of the vessel.

In determining the calculation pressure of a part, provision shall be made for pressures due to static head of contained liquids or pressure differentials due to fluid flow. The calculation pressure of any part using the actual thickness minus any corrosion allowance and adjusting for any difference in static head, or pressure differential or in temperature, or any combination of these which may occur under the least favourable conditions, shall at least equal the design pressure of the vessel.

3.2.1.3 *External pressure*

NOTE: Pressure is considered to be external when it acts on the convex surface of a cylindrical or spherical part of the vessel, tending to cause collapse.

For vessels or vessel parts subjected to vacuum conditions or external pressure or different pressures on opposite sides of the part under consideration, the calculation pressure shall be the maximum differential pressure that the vessel part may be subjected to at the most severe condition of temperature and differential pressure considering possible loss of pressure on either side of the part in question. Where relevant, the calculation pressure shall provide for the self-weight of the vessel part which shall be based on actual plate thickness, including corrosion allowance.

For vessels subject internally to vacuum only, the external design pressure shall be 101 kPa or be 25 percent more than the maximum possible external pressure, whichever is smaller. Where the design pressure is less than 101 kPa, the vessel shall be provided with a vacuum relief device or hydraulic seal of an appropriate reliable type. (See Clause 8.10 for setting of vacuum relief devices.)

Where each of the following conditions apply to a vacuum vessel, the calculation pressure may be reduced to two-thirds of the external design pressure (as a means of reducing the nominal factor of safety for the shell, ends and stiffening rings from three to two):

(a) Buckling of the vessel will not cause a safety hazard.

(b) The vessel forms a vacuum jacket on another vessel and buckling of the jacket will not lead to failure of the inner vessel or support structure.

(c) The vessel does not support walkways or operational platforms higher than 2 m above grade.

(d) The vessel is single wall type and the contents are not lethal (see Clause 1.7.1) and is not greater than 5 m in height.

(e) Loading points and lifting lugs are designed and located so as to avoid buckling.

(f) Checks on the circularity and shape of the vessel are carried out and confirm compliance with (AS 4458).

Allowance shall also be made for the vacuum conditions which may arise with certain vessels which are normally under internal pressure, e.g. vessels containing steam or vapour which condenses at low ambient temperatures.

3.2.1.4 *Design pressure for liquefied gas vessels* For vessels subject to pressurization by liquefiable gases, the design pressure shall, in the absence of design requirements in the relevant application Standard, be the greater of the following:

(a) The pressure by the most severe operating conditions, excluding fire or other abnormal circumstances.

(b) The vapour pressure of the liquid content at the maximum service temperature in accordance with Clause 3.2.2.4. Allowance shall be made for the partial pressures of other gases or impurities in the vessel which may increase the total pressure.

NOTE: The design shall also ensure that at the maximum service temperature, the filling ratio is such that the liquid phase on thermal expansion does not completely fill the vessel and the vapour space is not compressed to such an extent that partial pressure of inert gases causes venting through safety valves.

The filling ratio is the ratio of the mass of gas in a vessel to the mass of water the vessel will hold. The maximum filling ratio should be obtained (where given) from relevant application code for a given gase, e.g. AS 1596.

3.2.2 Design and service temperatures

3.2.2.1 *Design temperature for other than clad vessels* The design temperature of other than clad vessels shall be taken as the metal temperature which, with the coincident calculation pressure, results in the greatest thickness of the part under consideration. It shall be taken as not less than the metal temperature reached at the mean wall thickness when the part is at the calculation pressure.

The metal temperature at the mean wall thickness shall be taken as the temperature of the contained or surrounding fluid, as appropriate and shall comply with Table 3.2.2.1, except where calculations, tests, or previous service and experience support the use of another temperature.

For design against brittle fracture, the minimum operating temperature shall be used as a basis. (See Clause 2.6.3.).

Appropriate allowance shall be made for feasible loss of refractory or insulation.

TABLE 3.2.2.1

DESIGN TEMPERATURE FOR HEATED PARTS

Type of heating	Design temperature for heated parts (unless measured or calculated) (see Notes 1 and 2)
1 By gas, steam or liquid	The highest temperature of the heating medium (Note 3)
2 Directly by fire, exhaust gas, or electric power	For protected parts or parts heated primarily by convective heat, the highest temperature of the parts contents plus 20°C For parts not protected from radiation, the highest temperature of the parts contents plus the greater of 50°C and 4 × part thickness (mm) + 15°C, and with a minimum temperature for water of 150°C
3 By indirect electric power i.e. electrode or element in water (Note 4)	The highest temperature of the vessel contents
4 By solar radiation without protection of parts	(a) Direct: 50°C for metals; measure for non-metals (b) Focussed: As measured or calculated

NOTES:

1 Measurement where practicable with embedded and protected thermocouples is recommended. See AS 1228 and ISO 5730 for typical calculation of parts exposed to fire.

2 Provision shall be made for limited heat absorption rates with some fluids and for feasible deviation from ideal temperatures e.g. due to restricted flow in some tubes, loss of baffles or shields, abnormal firing conditions with new fuels and equipment, fouling, excessive firing rates, rapid starts, or poor circulation or mixing.

3 For tubular and plate heat exchangers and similar vessels, a lower temperature determined by heat transfer analysis may be used for the various parts provided suitable provision is made to cater for overheating in the event of loss or restricted flow of cold fluid. See AS 3857 for tube plate design.

4 Assumes pressure retaining parts are completely submerged in liquid and there is no radiation. See Clause 3.32 for special controls to prevent excessive wall temperature due to radiant heating in the event of element exposure with low fluid level.

3.2.2.2 *Design temperature for clad or lined vessels* The design temperature for clad or lined vessels, where design calculations are based on the thickness of the base material exclusive of lining or cladding thickness, shall be taken as that applicable to the base material.

Where design calculations are based on the full thickness of clad plate (see Clause 3.3.1.2), the maximum design temperature shall be the lower of the values allowed for the base material or cladding material referenced in Table 3.3.1.

3.2.2.3 *Temperature fluctuations from normal conditions* Where temperature fluctuations from normal conditions occur, the design temperatures in Clauses 3.2.2.1 and 3.2.2.2 need not be adjusted provided that—

(a) the temperature is in the creep range (i.e. at a temperature where the stress to cause rupture or 1 percent strain in 100 000 h is the stress which determines the design strength);

(b) the average temperature during any one year of operation will not exceed the design temperature;

(c) normal fluctuations in temperature will not cause the operating temperature to exceed the design temperature by more than 15°C; and

(d) for steel components, abnormal fluctuations in temperature will not cause the operating temperature to exceed the design temperature by more than 20°C for a maximum of 400 h per year, or 35°C for a maximum of 80 h per year.

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

Where the excess temperatures are likely to exceed the temperatures in Item (d) for more than 50 percent of the times shown, a temperature recorder shall be fitted.

NOTE: The purchaser is responsible for ensuring that the recorder is fitted and operated to ensure the above requirements are fulfilled.

3.2.2.4 *Maximum service temperature for liquefied gas vessels* The maximum service temperature shall be taken as the greater of the following:

(a) The maximum temperature to which the contents will be subjected by the process under the most severe operating conditions.

(b) The maximum temperature which the liquid contents are likely to attain due to ambient conditions.

NOTE: AS 2872 sets out a method for estimating the temperatures and corresponding pressures of fluids in vessels subject to atmospheric and solar heating in the hottest month of the year in various locations in Australia.

3.2.3 Loadings The loadings to be considered in the design of the vessel shall include the following, where relevant:

(a) Internal or external (or both) design pressures.

(b) Maximum static head of contained fluid under normal operating conditions.

(c) The force due to standard gravity acting on the mass of the vessel and normal contents under operating and test conditions, including conditions of reduced or zero pressure, if applicable.

(d) Superimposed loads, such as other vessels, lining, insulation, operating equipment, platforms, snow, water, ice, and the like.

(e) Wind loads.

NOTE: In calculating the adequacy of design for the hydrostatic test, only 75 percent of the normally applied wind load need be considered to act simultaneously with the other loadings.

See AS 1170.2 (permissible stress method) for wind loads.

For information on dynamic wind loads, refer to BS 4076, Moody, Mahajan, De Ghetto & Long, Freese and Bednar*.

(f) Earthquake loads.

NOTE: Wind and earthquake loads need not be assumed to occur simultaneously.

See AS/NZS 1200 and AS 1170.4 (permissible stress method) for selection of earthquake loads.

(g) For transportable vessels and inertia forces (see Clause 3.26).

(h) Forces caused by the method of support during transit and erection.

(i) Local stresses at lugs, saddles, girders, supports and branches due to the reaction of vessel supports and loads from internal and external structures and connected piping.

(j) Shock loads due to changes in fluid flow, surging of contents, or reaction forces (e.g. relief valve discharge).

---

* See Appendix R.

(k) Moments due to eccentricity of the centre of pressure relative to the neutral axis of the section.

(l) Forces due to temperature conditions, including the effects of differential expansion of parts or attached piping.

(m) Other external or environmental conditions.

Where the vessel is required to be hydrostatically tested in the final installed position as part of periodic inspection or repair, the vessel, supports and foundations shall be designed for full hydrostatic loading unless alternative measures are taken. The design specification should state whether this is a requirements or not. Where the vessel cannot be hydrostatically tested in-situ or special arrangements are required, the name plate or documentation may state this.

3.2.4 Corrosion, (including all forms of wastage)

3.2.4.1 *General* Each vessel or part thereof liable to corrosion (see Clause 1.8) shall have provision made against corrosion for the desired life of the vessel to safeguard against the need for reduction in operating pressure, excessive repairs or replacement.

This provision may consist of—

(a) a suitable increase in thickness of the material over that determined by the design equations to cover general corrosion (this may not be applicable where localized corrosion occurs) (see Clause 3.2.4.2);

(b) linings or wear or impingement plates;

(c) cathodic protection;

(d) chemical treatment of contained fluid;

(e) postweld heat treatment to avoid stress corrosion; or

(f) a combination of these or other suitable methods.

Where corrosion effects are known to be negligible or entirely absent, no provision need be made.

3.2.4.2 *Corrosion allowance* Where provision for corrosion is to be made in accordance with Clause 3.2.4.1(a), the minimum calculated thickness shall be increased by an amount at least equal to the expected loss of wall thickness during the desired life of the vessel. See Appendix D for selection of corrosion allowance.

The dimensional symbols used in all design formulae throughout this Standard represent the dimensions in the corroded condition.

Corrosion may occur on both sides of the wall of some vessels and necessitate an allowance on both sides. Corrosion allowance need not be the same for all parts of the vessel where different rates of attack are expected.

In selecting the corrosion allowance, consideration shall be given to the type of wastage, i.e. general wastage, pitting or knife-like wastage.

Carbon, carbon-manganese and alloy steel vessels used for compressed air service, steam service or water service shall have a minimum of 0.75 mm corrosion allowance on each metal surface in contact with such fluid except that this allowance is not required where seamless cladding or lining, other suitable linings or specially dried air are used.

3.2.4.3 *Dissimilar metal corrosion* Where dissimilar metals are used together in a corrosive environment, control of galvanic action by correct design procedure shall be instituted. This is particularly important with aluminium.

3.2.4.4 *Linings* Vessels may be fully or partially lined with material resistant to corrosion. Such material may be loose, intermittently welded, integrally clad, sprayed or surface welded. Special provisions shall be made for vitreous enamel lining. (See BS 6374, Part 1 to Part 5 for recommended practice in lining vessels.)

Where such linings effectively prevent contact between the corrosive agent and the vessel base material, during the life of the vessel, no corrosion allowance need be provided. Normally, such linings will include metal cladding, applied metal linings, glass lining and thick rubber or plastic linings. Paints, dip galvanizing, electro-deposits and sprayed metals are excluded unless specially agreed upon between the parties concerned.

Where corrosion of the cladding or lining material is expected, the cladding or lining thickness shall be increased by an amount which will provide the required service life of the vessel.

3.2.4.5 *Corrosion data* It is not practicable to give more definite rules than those preceding to safeguard against the effects of corrosion because of its complex nature and the many combinations of corrosive environments and materials. However, additional data are given in Appendix D as a guide.

3.2.5 Low temperature service Vessels made of ferritic steel and with Design Minimum Temperature colder than 0°C shall comply with the following:

(a) Sufficient flexibility shall be provided to cater for differential expansion or contraction.

(b) The vessel should be of simple configuration.

(c) The occurrence of rapid changes in temperature likely to give rise to severe temperature gradients should be avoided. Where this situation nevertheless occurs consideration should be given to special design details. A typical desirable design detail is given in Figure 3.2.5.

(d) Care shall be taken to avoid details which will produce local areas of high stress, e.g. lugs, gussets producing discontinuous stiffening and abrupt structural changes.

(e) Discontinuous stiffeners or continuous stiffeners attached by intermittent welding should not be used.

(f) Doubling plates should preferably be used in attaching vessel supports.

(g) Pipe supports and anchors should preferably be attached to an encircling mechanically separate sleeve.

(h) Screwed connections and socket-welded valves and fittings should as preference, not be used.

(i) Nozzles and complicated structural attachments should be welded to shell plates in the workshop and be considered as a separate sub-assembly which may also be evaluated individually with regard to the desirability of a separate heat treatment.

(j) Non-pressure parts should be attached to pressure parts via intermediate parts which shall be subject to the same restrictions as pressure parts to which they are attached. The requirements of this provision shall apply over a distance of at least $2t_2$ or 50 mm, whichever is the greater (see Figure 2.6.4(f)).

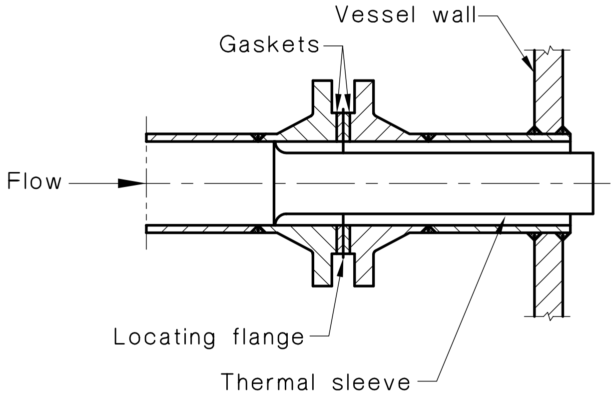


FIGURE 3.2.5 EXAMPLE OF THERMAL SLEEVE TO AVOID SEVERE THERMAL GRADIENTS

3.2.6 Vessel life

3.2.6.1 *General* Vessels complying with this Standard are usually designed and constructed for an undefined but reasonably long, safe period of usefulness (see Preface). However, vessels or components may be designed for an appropriate life against deterioration by time-dependent modes of failure such as corrosion, fatigue, creep or combinations thereof.

For design against corrosion (including all forms of wastage), see Clause 3.2.4. For design against fatigue under severe cyclic stresses (more than already provided for by the design factor of 4), (see AS 1210 Supplement 1). For design against creep for a specific design lifetime, see Clause 3.2.6.2.

3.2.6.2 *Design lifetime in creep (high temperature) range* The design strengths given in Table 3.3.1 for design temperatures in the creep range apply for a nominally indefinite component lifetime. However, each component whose design temperature is such that the applicable design strength is time-dependent may be designed for an appropriate, agreed lifetime, using the basis given in Paragraph A10 of Appendix A and data for different lifetimes in the relevant material specification or in AS 1228 or BS 5500. It is not intended that the same lifetime shall necessarily be adopted for all components. Replaceable components may be designed for shorter lifetimes than the general life expectancy of the vessel.

NOTE: The design lifetime of each component is a matter for agreement between the parties concerned.

No component designed on the basis of time-dependent material properties shall remain in service beyond the agreed design lifetime unless a review is made of its continued fitness for service based on inspection for creep damage and consideration of its temperature/stress history and the latest material data. Subject to satisfactory periodic review, service life may be extended beyond the agreed design lifetime.

In the above review, particular attention shall be paid to geometrical discontinuities and details subject to load or temperature cycling. Consideration shall be given to the installation of suitable equipment to record and provide a time-temperature history and a time-pressure history of the component. Additionally, it is recommended that the dimensional changes due to creep be recorded periodically to assist the review. Metallurgical examination and short-term creep rupture testing may be useful.

NOTE: Documents such as BS PD 6510 and API RP 530 provide examples of procedures followed.

For certain alloy materials, AS 1228 and BS 5500 specify design strength values greater than values determined in accordance with Paragraph A10 of Appendix A. These may be used by agreement between the parties concerned. In such cases, and where so specified in AS 1228 or BS 5500 for some other alloy material, the fitness of a continued service review shall be instituted at two-thirds of the specified design lifetime. Subject to satisfactory periodic review, service life may be continued up to and extended beyond the original design lifetime.

3.2.7 Change in design conditions A vessel or vessel component may be used at pressures or temperatures greater than the original design conditions and greater than permitted in Clause 3.2.2.3 provided that all of the following conditions are met:

(a) Each component so affected complies with the requirements of this Standard.

(b) The time at higher pressure or temperature does not reduce the proposed new design lifetime by more than 5 percent.

(c) Safety valves and other protective devices comply with the requirements of this Standard at the new design conditions.

(d) The parties concerned agree.

3.3 DESIGN STRENGTHS

3.3.1 Design tensile strength (f)

3.3.1.1 *General* The design tensile strengths to be used with the equations in this Standard are given in Table 3.3.1. For exceptions see Clauses 3.3.2 and 3.21. Design tensile strengths for materials not listed in Table 3.3.1 shall be determined in accordance
A2 with Appendix A which gives the basis of design strengths. See also Clause 3.3.9 which allows the use of higher design strengths.

NOTE: It is recognized that bending or local peak stresses in pressure vessels may exceed the strength values given in Table 3.3.1. When such stresses are to be calculated, criteria given in AS 1210 Supplement 1, Appendix S may be followed when dealing with ductile materials (but using the values of f in Table 3.3.1).

To those design strengths the following shall be applied where appropriate:

(a) Welded joint efficiency (see Clause 3.5.1.7).

(b) Brazed joint efficiency (see Clause 3.5.3).

(c) Ligament efficiency (see Clause 3.6).

(d) Casting quality factor to be taken as one of the following:

  (i) Carbon, carbon-manganese, low alloy and high alloy steel castings . . . . 0.80.

  (ii) Non-ferrous and nodular iron castings . . . . 0.90.

  (iii) For Items (i) and (ii), where justified by additional testing to AS 4037 . . 1.0.

  (iv) Iron castings covered in Clause 2.5.3.1 . . . . 1.0.

For some vessels operating under special conditions and as required by the designer, it may be desirable to adopt reduced design strength to—

(e) limit deflection in close fitting assemblies;

(f) allow for abnormal fatigue, corrosion fatigue or stress corrosion conditions (see Clause 3.1.4);

(g) allow for exceptionally long life; or

(h) provide for other design conditions not intended to be covered by the design strength criteria in Appendix A.

The design strengths for bolting material are given in Table 3.21.5.

3.3.1.2 *Design tensile strength for clad and lined material* The following requirements apply:

(a) *Applied corrosion-resistant linings* The thickness of material used for applied lining shall not be included in the computation for the required wall thickness of a lined vessel. The design strength shall be that given for the base material in Table 3.3.1, at the design temperature (see Clause 3.2.2.2).

(b) *Integrally clad plate without credit for full cladding thickness* Except as permitted in Item (c), design calculations shall be based on the total thickness of the clad plates less the specified nominal minimum thickness of cladding. A reasonable excess thickness either of the actual cladding or of the same thickness of corrosion-resistant weld metal may be included in the design calculations as an equal thickness of base material. The design strength value shall be that given for the base material in Table 3.3.1, at the design temperature (see Clause 3.2.2.2).

(c) *Integrally clad plate with credit for cladding thickness* Where clad plate complies with ASTM A 263, A 264 or A 265 and the joints are completed by deposition of corrosion-resisting weld metal over the weld in the base material to restore the cladding, the design calculation may be based on the use of the design strength for the base material listed in Table 3.3.1, using a total thickness equal to—

A3

$$t = t_{base} + t_{clad} \times \frac{f_{clad}}{f_{base}} \quad \ldots 3.3.1$$

where

A3

t_{base} = nominal thickness of base material minus corrosion allowance, in millimetres

t_{clad} = nominal thickness of cladding material minus corrosion allowance, in millimetres

f_{clad} = design tensile strength for the cladding at the design temperature, in megapascals

f_{base} = design tensile strength for the base material at the design temperature, in megapascals

Where f_{clad} is greater than f_{base}, the multiplier f_{clad}/f_{base} shall be taken as equal to unity. Welded vessels in which the cladding is included in the computation of wall thickness shall be of Class 1 or 2A construction (see Table 1.6) when subject to internal pressure.

(d) *Composite tubes* Where tubes are made of composite materials and pressure and other loading conditions permit, the requirements of Clause 3.3.1.2(c) shall apply.

3.3.2 Design tensile strength for low temperature service The design tensile strengths at a minimum operating temperature below 50°C shall not exceed those given in Tables 3.3.1 and 3.21.5 for 50°C except as provided in Clause 3.3.3. The minimum operating temperature at these strengths shall be determined from Clause 2.6.

3.3.3 Reduced design tensile strength for low temperature service Carbon and carbon-manganese steel pipe, plate, forgings, castings and welds may be used at temperatures down to 50°C below those permitted for design strength, in vessels where reduced pressures and reduced stresses occur at low operating temperatures, e.g. with liquefied gases in refrigeration vessels. Under these conditions the design tensile strength shall not exceed 50 MPa. (See Clause 2.6, and Appendix K for an example.)

NOTE: Where a vessel is subject to higher pressure at higher temperature, the design must also satisfy requirements for the higher pressure. Attention is particularly drawn to Clause 3.2.1.2.

3.3.4 Design compressive strength (f_c) The design compressive strength for other than iron castings shall—

(a) not exceed the design tensile strength;

(b) comply with the requirements of Clause 3.7.5 for shells subject to axial compression; and

(c) comply with the requirements of Clause 3.9 for vessels subject to external pressure.

NOTE: Where buckling of components due to loads other than external pressure could occur, an analysis to determine safe working stresses should be undertaken by agreement between the parties concerned.

For iron castings where the design tensile strength is based on a factor of safety of 10 (see Paragraph A8 of Appendix A), the design compressive strength shall not exceed twice the values given in Table 3.3.1(C).

3.3.5 Design shear strength (f_s) Where shear stresses are present alone, the design shear strength shall not exceed 60 percent of the values given in Table 3.3.1, and shall not exceed 80 percent for restricted shear such as dowel bolts, rivets or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction in area.

A3 **3.3.6 Design bearing strength ($f_{bearing}$)** The design bearing strength shall not exceed 160 percent of the values given in Table 3.3.1.

3.3.7 Young modulus (modulus of elasticity) (E) The values for E are given in Table 3.3.7.

A3 **3.3.8 Design bending strength** The primary bending stress (f_b) across a solid section shall be limited to a value such that the total primary stress does not exceed 150 percent of the values given in Table 3.3.1.

NOTES:

1 This recognizes that bending stresses (and design peak stresses) can exceed the design tensile strength values of Table 3.3.1.

2 The equations in this Standard for various parts include provision for the above. However, when such stresses are to be calculated, the appropriate acceptance criteria are specified in Appendix SH of AS 1210 Supplement 1, using the basic stress 'f' listed in this Standard.

3 The provision does not apply to stresses resulting from bending loads across a whole section of vessel.

A2 **3.3.9 Higher design strengths** As a result of the decision to modify the design safety factor from 4.0 to 3.5 on R_m, the design strength currently in this Standard may be amended as given in this Clause (3.3.9).

The use of higher design strengths than those given in Table 3.3.1 is allowed under the following conditions.

These higher design strengths are applicable to all materials and vessels except for the following:

A3 (a) Not applicable.

A2 (b) Flanges (Clause 3.21).

(c) Bolting (Table 3.21.5).

(d) Transportable vessels (Clause 3.26).

A factor of 3.5 may be used with the value R_m to determine the design tensile strength. In this case, the design strength shall be determined from—

(i) Table 3.3.9 for selected materials; or

A2 (ii) as permitted by Appendix A (as amended by Amendment 2:1998).

Table 3.3.1 has not been modified by this Amendment and thus still lists design strengths based on $\frac{R_m}{4}$, however, the use of Appendix A is permitted.

A2

TABLE 3.3.9

HIGHER DESIGN TENSILE STRENGTH (MPa)

CARBON, CARBON-MANGANESE AND LOW ALLOY STEELS

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C																			
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
PLATE, SHEET AND STRIP																									
C, C-Mn	AS 1548	5-490N	All	A2	4,6	140	140	140	140	140	138	134	130	126	110	76	49	33	—	—	—	—	—	—	—
	AS 1548	5-490NH	All	A2	4,6	140	140	140	140	140	140	140	139	135	110	76	49	33	—	—	—	—	—	—	—
	AS 1548	7-430R,N,T	All	A1	4,6	123	123	123	123	123	110	107	105	102	99	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-430RH,NH, TH	All	A1	4,6	123	123	123	123	123	117	114	112	108	105	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-460R,N,T	All	A1	4,6	131	131	131	131	124	110	107	105	102	99	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-460RH,NH, TH	All	A1	4,6	131	131	131	131	131	117	114	112	108	105	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-490R,N,T	All	A2	4,6	140	140	140	140	133	120	117	114	111	108	84	57	39	—	—	—	—	—	—	—
	AS 1548	7-490RH,NH, TH	All	A2	4,6	140	140	140	140	140	128	124	121	118	115	84	57	39	—	—	—	—	—	—	—
	AS/NZS 3678	250	All	A1	7,8	108	108	108	106	99	93	90	86	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	300	All	A1	7,8	113	113	113	113	113	113	109	105	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	350	All	A2	7,8	118	118	118	118	118	118	118	118	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	400	All	A2	7,8	126	126	126	126	126	126	126	126	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA200	≤ 16	A1	7	86	86	86	86	86	86	86	81	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HU250	≤ 16	A1	7	100	100	100	100	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA250	≤ 16	A1	7	100	100	100	100	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HU300	≤ 16	A1	7	114	114	114	114	114	114	114	114	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA300	≤ 16	A1	7	114	114	114	114	114	114	114	114	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA300/1	≤ 16	A1	7	123	123	123	123	123	123	123	121												
	AS/NZS 1594	HA350	≤ 16	A3	7	123	123	123	123	123	123	123	123	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF300	≤ 8	A1	7	126	126	126	126	126	126	123	121	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA400	≤ 16	A3	7	131	131	131	131	131	131	131	131	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF400	≤ 8	A3	7	131	131	131	131	131	131	131	131	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF500	≤ 8	A3	7	163	163	163	163	163	163	163	163	—	—	—	—	—	—	—	—	—	—	—	—
Low alloy Q & T	AS 3597	700 PV	≥ 6 ≤ 65	G	16,24	226	226	226	226	226	226	226	226	—	—	—	—	—	—	—	—	—	—	—	—
			> 65 ≤ 110	G	16,24	206	206	206	206	206	206	206	206	—	—	—	—	—	—	—	—	—	—	—	—
SECTIONS AND BARS																									
C, C-Mn	AS/NZS 3679.1	250	—	A1	8	108	108	108	106	99	93	90	86												
	AS/NZS 3679.1	300	—	A1	8	116	116	116	116	116	116	116	111												
	AS/NZS 3679.1	350	—	A2	8	126	126	126	126	126	126	126	126												
	AS 1442	M1020	—	A1	8	108	108	108	106	99	93	90	86												
		U1021	—	A1	8	108	108	108	106	99	93	90	86												
		1022	—	A1	8	108	108	108	106	99	93	90	86												

NOTE: See end of Table 3.3.1(A) for Notes and Clause 3.3.9 for limitations.

TABLE 3.3.1(A)

DESIGN TENSILE STRENGTH (MPa)
(A) CARBON, CARBON-MANGANESE AND LOW ALLOY STEELS

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5)																			
						Temperature, °C																			
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
PLATE, SHEET AND STRIP																									
C, C-Mn	AS 1548 AS 1548	5-490N 5-490NH	All	A2	4,6	123	123	123	123	123	123	123	123	123	110	76	49	33	—	—	—	—	—	—	—
	AS 1548	7-430R,N,T	All	A1	4,6	108	108	108	108	108	108	108	105	102	99	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-430RH,NH, TH	All	A1	4,6	108	108	108	108	108	108	108	108	108	105	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-460R,N,T	All	A1	4,6	115	115	115	115	115	110	108	105	102	99	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-460RH,NH, TH	All	A1	4,6	115	115	115	115	115	115	115	112	109	105	79	52	35	—	—	—	—	—	—	—
	AS 1548	7-490R,N,T	All	A2	4,6	123	123	123	123	123	120	117	114	111	108	84	57	39	—	—	—	—	—	—	—
	AS 1548	7-490RH,NH, TH	All	A2	4,6	123	123	123	123	123	123	122	121	118	115	84	57	39	—	—	—	—	—	—	—
A2	AS/NZS 3678	250, 250L15	All	A1	7,8	94	94	94	94	94	84	82	79	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	300, 300L15	All	A1	7,8	99	99	99	99	99	88	85	82	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	350, 350L15	All	A2	7,8	104	104	104	104	104	92	89	86	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3678	400, 400L15	All	A2	7,8	110	110	110	110	110	97	94	91	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA200	≤ 8	A1	7	75	75	75	75	75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HU250	≤ 12	A1	7	88	88	88	88	88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA250	≤ 8	A1	7	88	88	88	88	88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HU300	≤ 8	A1	7	100	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA300	≤ 8	A1	7	100	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA300/1	≤ 8	A1	7	108	108	108	108	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA350	≤ 8	A3	7	108	108	108	108	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF300	≤ 8	A1	7	110	110	110	110	110	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	HA400	≤ 8	A3	7	115	115	115	115	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF400	≤ 8	A3	7	115	115	115	115	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 1594	XF500	≤ 8	A3	7	143	143	143	143	143	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Low alloy Q & T	AS 3597	700 PV	≥ 6 ≤ 65	G	16,24	198	198	198	198	198	198	198	198	—	—	—	—	—	—	—	—	—	—	—	—
			> 65 ≤ 110	G	16,24	180	180	180	180	180	180	180	180	—	—	—	—	—	—	—	—	—	—	—	—
A2	ASTM A 517	A,B,C,E,F,J,P	≥ 6 ≤ 63	G	16,24	199	199	199	199	199	199	198	198												
C-½Mo	ASTM A 204	A	All	B	10	113	113	113	113	113	113	113	113	113	112	109	106	97	71	44	—	—	—	—	—
	ASTM A 204	B	All	B	10	121	121	121	121	121	121	121	121	121	121	121	119	100	71	44	—	—	—	—	—
	ASTM A 204	C	All	B	10	130	130	130	130	130	130	130	130	130	130	130	128	102	71	44	—	—	—	—	—
Mn-½Mo	ASTM A 302	A	All	B	—	128	128	128	128	128	128	128	128	128	126	122	118	100	71	44	—	—	—	—	—
	ASTM A 302	B, C, D	All	B	—	137	137	137	137	137	137	137	137	137	135	130	126	102	71	44	—	—	—	—	—

NOTES: See end of this Table 3.3.1(A).

(continued)

TABLE 3.3.1(A) (*continued*)

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C																			
						50	**100**	**150**	**200**	**250**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**	**625**	**650**
PLATE, SHEET AND STRIP (*continued*)																									
1/2Cr-1/2Mo	ASTM A 387	2 Cl 1	All	B	18	95	95	95	95	95	95	95	95	95	95	95	93	89	72	51	—	—	—	—	—
	ASTM A 387	2 Cl 2	All	B	19	121	121	121	121	121	121	121	121	121	121	121	117	104	80	55	—	—	—	—	—
1Cr-1/2Mo	ASTM A 387	12 Cl 1	All	C	18	95	95	95	95	95	95	95	95	95	95	95	93	90	82	63	42	27	18	11	8
	ASTM A 387	12 Cl 2	All	C	19	112	112	112	112	112	112	112	112	112	112	112	109	107	88	63	42	27	18	11	8
	BS 1501	620-27B	All	C	—	104	104	104	104	104	104	104	100	99	97	96	95	94	82	60	35	—	—	—	—
	BS 1501	620-31B	≤ 76	C	—	119	119	119	119	119	119	119	119	119	119	119	119	119	97	60	35	—	—	—	—
	BS 1501	620-31B	> 76 ≤ 155	C	—	112	112	112	112	112	112	112	112	112	112	112	112	112	97	60	35	—	—	—	—
1 1/4Cr-1/2Mo	ASTM A 387	11 Cl 1	All	C	18	103	103	103	103	103	103	103	103	103	103	103	101	96	75	53	38	26	18	12	8
	ASTM A 387	11 Cl 2	All	C	19	130	130	130	130	130	130	130	130	130	130	130	127	103	75	53	38	26	18	12	8
	BS 1501	621B	≤ 76	C	—	119	119	119	119	119	119	119	119	119	119	119	119	119	97	60	35	—	—	—	—
	BS 1501	621B	> 76 ≤ 155	C	—	112	112	112	112	112	112	112	112	112	112	112	112	112	97	60	35	—	—	—	—
2 1/4Cr-1Mo	ASTM A 387	22 Cl 1	All	D2	18	103	103	103	103	103	103	103	103	103	103	103	100	93	82	64	47	36	27	20	11
	ASTM A 387	22 Cl 2	All	D2	19	129	129	126	124	124	123	123	122	119	119	117	113	110	88	63	46	36	27	16	9
	BS 1501	622-31B	≤ 155	D2	—	119	119	119	119	119	119	119	119	119	119	119	117	113	91	67	46	32	—	—	—
	BS 1501	622-45B	≤ 155	D2	—	173	173	173	173	173	173	173	173	173	173	173	160	129	91	67	46	32	—	—	—
5Cr-1/2Mo	ASTM A 387	5 Cl 1	All	D2	18	103	103	100	99	99	99	97	95	94	91	89	84	77	63	47	36	25	18	11	7
	ASTM A 387	5 Cl 2	All	D2	19	129	129	125	124	124	123	121	120	117	114	110	105	82	63	47	36	25	18	11	7
3 1/2Ni	ASTM A 203	D	All	E	—	112	112	112	112	112	112	112	112	106	95	80	65	49	36	24	—	—	—	—	—
	ASTM A 203	E	All	E	—	120	120	120	120	120	120	120	120	113	101	84	67	50	36	24	—	—	—	—	—
	BS 1501	503	≤ 38	E	—	112	112	112	112	112	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9Ni	ASTM A 353	non-welded	All	F	24	173	160	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	ASTM A 353	welded	All	F	22, 24	164	152	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8 & 9Ni	ASTM A 553	1, 11 non-welded	All	F	23, 24	173	160	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	ASTM A 553	1, 11 welded	All	F	22,23,24	164	151	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	BS 1501	509	≤ 51	F	17	173	173	173	173	173	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	BS 1501	510	≤ 51	F	16	173	173	173	173	173	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mo-B	BS 1501	261B	≤ 90	B	20	140	140	140	140	140	140	140	140	140	140	—	—	—	—	—	—	—	—	—	—
Mn-Cr-Ni-V	BS 1501	271B	≤ 25	D1	—	147	147	147	147	147	147	147	147	147	147	147	147	147	100	55	26	—	—	—	—
	BS 1501	271B	> 25 ≤ 76	D1	—	140	140	140	140	140	140	140	140	140	140	140	140	140	100	55	26	—	—	—	—
	BS 1501	271B	> 76 ≤ 155	D1	—	140	140	140	140	140	140	140	140	140	140	140	140	140	100	55	26	—		—	—
Ni-Cr-Mo-V	BS 1501	281B	≤ 25	D1	—	147	147	147	147	147	147	147	147	147	147	147	147	116	74	43	21	—	—	—	—
	BS 1501	281B	> 25 ≤ 155	D1	—	140	140	140	140	140	140	140	140	140	140	140	140	116	74	43	21	—	—	—	—
	BS 1501	282B	≤ 76	D1	—	147	147	147	147	147	147	147	147	147	147	147	147	116	74	—	—	—	—	—	—
	BS 1501	282B	> 76 ≤ 155	D1	—	142	142	142	142	142	142	142	142	142	142	142	142	116	74	—	—	—	—	—	—

NOTES: See end of this Table 3.3.1(A).

(*continued*)

TABLE 3.3.1(A) (*continued*)

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C																			
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
PIPE AND TUBE																									
Carbon	ASTM A 53	A seamless	All	A1	—	83	83	83	83	83	83	83	83	80	73	65	56	47	—	—	—	—	—	—	—
	ASTM A 53	A ERW	All	A1	—	70	70	70	70	70	70	70	70	68	62	55	48	40	—	—	—	—	—	—	—
	ASTM A 106	A	All	A1	—	83	83	83	83	83	83	83	83	80	73	65	56	48	36	23	—	—	—	—	—
A3 C-Mn	ASTM A 53	B seamless	All	A1	—	103	103	103	103	103	103	103	103	98	89	75	62	49	—	—	—	—	—	—	—
	ASTM A 53	B ERW	All	A1	—	88	88	88	88	88	88	88	88	83	75	64	53	41	—	—	—	—	—	—	—
	ASTM A 106	B	All	A1	—	103	103	103	103	103	103	103	103	98	89	75	62	49	36	24	—	—	—	—	—
C,C-Mn & low alloy steel	Pressure equipment types	—	—	All	For design values, use values determined from Appendix A, Paragraph A5; or the values in AS 4041 but not exceeding $\frac{R_m}{4}$																				
CASTINGS																									
Carbon	AS 2074 BS 1504	C7A-1 161-430A	All	A1	—	108	108	108	105	98	93	91	89	88	86	—	—	—	—	—	—	—	—	—	—
	AS 2074 BS 1504	C7A-1E 161-430E	All	A1	—	108	108	108	108	104	99	97	95	93	92	82	53	34	—	—	—	—	—	—	—
	AS 2074 BS 1504	C7A-2 161-480A	All	A2	—	120	120	120	120	113	108	105	103	101	100	—	—	—	—	—	—	—	—	—	—
	AS 2074 BS 1504	C7A-2E 161-480E	All	A2	—	120	120	120	120	120	115	112	109	108	107	82	53	34	—	—	—	—	—	—	—
	AS 2074 BS 1504	C7A-3 161-540A	All	A2	—	135	135	135	135	135	130	—	119	—	100	—	—	—	—	—	—	—	—	—	—
	ASTM A 216	WCA	All	A1	—	103	103	103	103	103	103	103	103	98	89	75	62	49	36	24	—	—	—	—	—
	ASTM A 216	WCB WCC	All	A2	—	120	120	120	120	120	120	120	120	113	101	84	67	50	36	24	—	—	—	—	—
C-Mo	AS 2074	L5A-1	All	B	—	115	115	115	115	115	112	109	106	—	—	—	—	—	—	—	—	—	—	—	
	AS 2074 BS 1504	L5A-2 245A	All	B	—	115	115	115	115	115	113	109	106	105	104	103	103	102	68	40	—	—	—	—	—
	AS 2074 BS 1504	L5A-2E 245E	All	B	—	115	115	115	115	115	115	115	113	112	111	110	109	102	68	40	—	—	—	—	—
	ASTM A 217	WC1	All	B	10	112	112	112	112	112	112	112	112	112	112	109	106	100	71	41	—	—	—	—	—
$1^1/_4$Cr-$^1/_2$Mo	AS 2074 BS 1504	L5B 621	All	C	—	120	120	120	120	120	120	120	119	116	114	112	110	108	97	60	35	—	—	—	—

NOTES: See end of this Table 3.3.1(A).

(*continued*)

TABLE 3.3.1(A) (*continued*)

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C 50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
CASTINGS (*continued*)																									
Cr-Mo-V	AS 2074	L5G	All	D1	—	135	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS 2074 BS 1504	L5H 660	All	D1	—	128	128	128	128	128	128	128	—	118	—	112	—	90	—	—	—	—	—	—	—
2¼Cr-Mo	AS 2074 BS 1504 AS 2074 BS 1504	L5C 622A L5C-E 622E	All	D2	—	135	135	135	135	135	135	135	135	135	135	135	135	124	91	83	46	—	—	—	—
3Cr-Mo	AS 2074 BS 1504	L5D 623	All	D2	—	155	155	155	155	155	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5Cr-Mo	AS 2074 BS 1504 AS 2074 BS 1504	L5E 625A L5E-E 625E	All	D2	—	155	155	155	155	155	155	155	155	155	155	155	155	—	—	—	—	—	—	—	—
9Cr-1Mo	AS 2074 BS 1504	H2A 629	All	D2	—	155	155	155	155	155	155	155	155	—	144	—	123	—	87	—	55	—	21	—	—
	ASTM A 217	C12	All	D2	13	155	154	150	149	149	148	146	144	141	136	132	126	119	90	60	43	30	21	14	10
3½Ni	AS 2074 BS 1504	L3A 503	All	E	—	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	ASTM A 352	LC3	All	E	—	121	121	121	121	121	121	121	121	—	—	—	—	—	—	—	—	—	—	—	—
FORGINGS																									
Carbon	ASTM A 181	Cl 60	All	A1	11.21	103	103	103	103	103	103	103	103	98	89	75	62	49	36	24	—	—	—	—	—
	ASTM A 181	Cl 70	All	A1	11.21	120	120	120	120	120	120	120	120	113	101	84	67	50	36	24	—	—	—	—	—
A3	ASTM A 105		All	A2	11.21	120	120	120	120	120	120	120	120	113	101	84	67	50	36	24	—	—	—	—	—
	ASTM A 266	1	All	A1	—	103	103	103	103	103	103	103	103	98	89	75	62	49	36	24	—	—	—	—	—
A2	ASTM A 266	2, 4	All	A2	—	120	120	120	120	120	120	120	120	113	101	84	67	50	36	24	—	—	—	—	—
	ASTM A 266	3	All	A2	—	128	128	128	128	128	128	128	128	121	108	88	70	50	36	24	—	—	—	—	—
	ASTM A 350	LF1	All	A1	—	104	104	104	104	104	104	104	103	98	89	76	57	39	25	15	—	—	—	—	—
	ASTM A 350	LF2	All	A2	—	121	121	121	121	121	121	121	120	113	101	84	58	39	25	15	—	—	—	—	—

NOTES: See end of this Table 3.3.1(A).

(*continued*)

TABLE 3.3.1(A) (*continued*)

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C 50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
FORGINGS (*continued*)																									
C-Mn	BS 1503	221-430		A1	—	108	108	108	108	108	100	98	96	94	93	84	57	39	—	—	—	—	—	—	—
	BS 1503	221-430E		A1	—	108	108	108	108	108	107	104	102	100	99	84	57	39	—	—	—	—	—	—	—
	BS 1503	221-490		A2	—	123	123	123	123	123	120	117	114	112	111	84	57	39	—	—	—	—	—	—	—
	BS 1503	221-490E		A2	—	123	123	123	123	123	123	123	122	120	118	84	57	39	—	—	—	—	—	—	—
	BS 1503	223-430		A1	—	108	108	108	108	108	107	103	100	97	94	84	57	39	—	—	—	—	—	—	—
	BS 1503	223-430E		A1	—	108	108	108	108	108	108	108	107	103	100	84	57	39	—	—	—	—	—	—	—
	BS 1503	223-490		A2	—	123	123	123	123	123	123	123	123	119	115	84	57	39	—	—	—	—	—	—	—
	BS 1503	223-490E		A2	—	123	123	123	123	123	123	123	123	123	123	84	57	39	—	—	—	—	—	—	—
	BS 1503	224-430		A1	—	108	108	108	108	108	101	97	94	92	90	84	57	39	—	—	—	—	—	—	—
	BS 1503	224-430E		A1	—	108	108	108	108	108	108	104	101	98	96	84	57	39	—	—	—	—	—	—	—
	BS 1503	224-490		A2	—	123	123	123	123	123	121	117	114	111	108	84	57	39	—	—	—	—	—	—	—
	BS 1503	224-490E		A2	—	123	123	123	123	123	123	123	121	118	115	84	57	39	—	—	—	—	—	—	—
C-1/2Mo	ASTM A 182	F1		B	14	121	121	121	121	121	121	121	121	121	121	121	119	103	70	41	—	—	—	—	—
	ASTM A 336	F1		B	10, 14	121	121	121	121	121	121	121	121	121	121	121	119	103	70	41	—	—	—	—	—
	BS 1503	245		B	—	105	105	105	105	105	105	104	103	102	101	100	100	98	97	62	—	—	—	—	—
1Cr-1/2Mo	ASTM A 182	F12		C	—	121	121	121	121	121	121	121	121	121	121	121	118	114	90	58	37	25	16	9	7
	ASTM A 336	F12		C	—	121	121	121	121	121	121	121	121	121	121	121	118	114	90	58	37	25	16	9	7
	ASTM A 182	F12b		C	—	103	103	103	103	103	103	103	103	103	103	102	99	93	82	63	43	29	17	10	7
	BS 1503	620-440		C	—	110	110	110	110	110	110	110	106	104	101	100	98	96	94	60	35	—	—	—	—
	BS 1503	620-440E	All	C	—	110	110	110	110	110	110	110	110	110	108	107	105	103	100	60	35	—	—	—	—
	BS 1503	620-540		C	—	135	135	135	135	135	135	135	135	135	135	135	135	135	102	60	35	—	—	—	—
	BS 1503	620-540E		C	—	135	135	135	135	135	135	135	135	135	135	135	135	135	102	60	35	—	—	—	—
11/4Cr-1/2Mo	ASTM A 182	F11		C	—	121	121	121	121	121	121	121	121	121	121	121	118	114	89	59	40	27	18	14	8
	BS 1503	621-460		C	—	115	115	115	115	115	115	115	115	115	115	114	112	108	97	60	35	—	—	—	—
	BS 1503	621-460E		C	—	115	115	115	115	115	115	115	115	115	115	115	115	115	97	60	35	—	—	—	—
21/4Cr-1Mo	ASTM A 336	F22		D2	19	129	129	126	124	124	123	123	122	120	119	117	113	112	89	61	46	37	27	16	9
	ASTM A 336	F22a		D2	—	103	103	103	103	103	103	103	103	103	103	103	100	93	82	64	47	36	27	20	11
	BS 1503	622-490		D2	—	123	123	123	123	123	123	123	123	123	123	123	123	119	91	67	46	32	—	—	—
	BS 1503	622-490E		D2	—	123	123	123	123	123	123	123	123	123	123	123	123	123	91	67	46	32	—	—	—
	BS 1503	622-560		D2	—	140	140	140	140	140	140	140	140	140	140	140	140	119	91	67	46	32	—	—	—
	BS 1503	622-560E		D2	—	140	140	140	140	140	140	140	140	140	140	140	140	123	91	67	46	32	—	—	—
5Cr-1/2Mo	ASTM A 182	F5		D2	—	121	120	117	116	116	115	113	112	110	106	102	99	81	61	47	35	26	18	13	9
	ASTM A 336	F5		D2	—	103	103	100	99	99	99	97	95	94	91	89	84	78	63	46	35	26	18	13	9
	ASTM A 182	F5a		D2	—	155	154	150	149	149	148	146	144	140	137	133	104	80	62	46	35	26	18	13	9
	ASTM A 336	F5a		D2	—	138	138	134	132	132	131	130	128	125	121	118	102	81	62	46	33	26	18	13	9
	BS 1503	625-520		D2	—	130	130	130	130	130	130	130	130	130	130	130	130	110	75	50	33	—	—	—	—
	BS 1503	625-590		D2	—	148	148	148	148	148	148	148	148	148	148	148	148	110	75	50	33	—	—	—	—
31/2Ni	ASTM A 350	LF3		E	—	121	121	121	121	121	121	121	121	—	—	—	—	—	—	—	—	—	—	—	—
	BS 1503	503-490		E	—	123	123	123	123	123	123	123	123	—	—	—	—	—	—	—	—	—	—	—	—

NOTES: See end of this Table 3.3.1(A).

(*continued*)

TABLE 3.3.1(A) (*continued*)

Type	Specification	Grades (Note 2)	Thickness mm (Note 3)	Steel group	Notes	Design tensile strength, MPa (Notes 1, 5) Temperature, °C																			
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
FORGINGS (*continued*)																									
Cr-Mo-V	BS 1503	660-460	All	D1	—	115	115	115	115	115	115	115	115	115	115	115	115	115	113	83	56	35	—	—	—
	BS 1503	660-460E		D1	—	115	115	115	115	115	115	115	115	115	115	115	115	115	115	83	56	35	—	—	—
SECTION AND BARS (Note 12)																									
C, C-Mn	AS/NZS 3679.1	250	—	A1	8	94	94	94	94	94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A2	AS/NZS 3679.1	300	—	A1	8	99	99	99	99	99	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS/NZS 3679.1	350	—	A2	8	110	110	110	110	110	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS 1442	M1020	—	A1	8	94	94	94	94	94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS 1442	U1021	—	A1	8	94	94	94	94	94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	AS 1442	1022	—	A1	8	94	94	94	94	94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

NOTES TO TABLE 3.3.1(A)

1 Design strengths at intermediate temperatures may be obtained by linear interpolation. Joint efficiencies and casting quality factors are to be applied where applicable. See Clause 3.3.1

2 Hot-tested or verified steel is shown with suffix 'H' for Australian Standards and 'B' for British Standards (except BS 1504). Where design strengths are listed for hot-tested or verified grades only, design strengths for non-hot-tested or non-verified grades may be determined from Appendix A.

3 For thickness greater than shown, design strengths are to be based on Appendix A.

4 For A designation AS 1548 steel plate, the following criteria are to apply:

(a) 'A' designation Type 5 plate shall not be used where the plate is to be in the non-normalized condition in the completed vessel.

(b) 'A' designation Type 7 plate must be used in the normalized condition in the completed vessel. However, provided the manufacturer's test certificate shows that plates comply with both 'R' and 'A' designations, they can be used in the non-normalized condition in the completed vessel.

5 For design strengths at temperatures below 50°C, see Clause 3.3.2.

6 For impact-tested steels in all grades, design strengths are equal to those listed for non-hot-tested or non-verified steels of the same grade. The design strengths for a steel designated both to L0, L20, etc, and H are equal to those listed for the 'H' designation.

7 Hot forming above 650°C, or normalizing of AS 1594 and AS 3678 steels is not to be performed unless the specified properties of the material are verified by tests on a specimen subject to a simulated heat treatment equivalent to that to which the vessel is subjected.

8 Thickness to satisfy requirements of Clause 2.3.3; see also Clause 2.3.4.

9 —

10 Upon prolonged exposure to temperatures above 470°C, the carbide phase of carbon-molybdenum steel may be converted to graphite.

11 Upon prolonged exposure to temperatures above 425°C, the carbide phase of carbon steel may be converted to graphite.

12 Design strengths for bolting are given in Table 3.21.5.

13 These stresses apply to normalized and drawn material only.

14 Atmospheric scaling at temperatures above 495°C should be taken into account.

15 —

16 Quenched and tempered.

17 Double normalized and tempered.

18 Annealed.

19 Normalized and tempered.

20 Special consideration by parities concerned should be given to appropriate steel group to be used for determining postweld heat treatment and non-destructive examination requirements.

21 Only Silicon-Aluminium fully killed steel shall be used above 450°C.

22 The minimum tensile strength of the reduced tensile test specimen is to be no less than 655 MPa (see Clause 5.2.11).

23 ASTM A 553 Grade II is not to be used for minimum allowable temperature below −170°C.

24 The design strength values listed are for a material which has been heat-treated to enhance its properties.

TABLE 3.3.1(B)
DESIGN TENSILE STRENGTH (MPa)
(B) HIGH ALLOY STEEL

	ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8) Temperature, °C																									
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
	PLATE																														
	A 240	302	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	110	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	302	18Cr-8Ni	K	—	129	106	97	90	85	80	78	78	76	74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	304	18Cr-8Ni	K	1,10,13	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
	A 240	304	18Cr-8Ni	K	10,13	129	106	97	90	85	80	78	77	76	74	76	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 240	304L	18Cr-8Ni	K	1	108	108	105	102	100	98	96	94	93	92	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	304L	18Cr-8Ni	K	—	107	91	83	76	72	68	66	65	65	63	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	309S	23Cr-12Ni	K	1,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	79	66	54	42	33	26	20	16	13	10	7	6
	A 240	309S	23Cr-12Ni	K	10	129	115	110	103	98	94	92	90	87	86	84	82	81	79	74	66	54	42	33	26	20	16	13	10	7	6
	A 240	310S	25Cr-20Ni	K	1,2,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	80	72	65	57	49	41	33	26	18	13	9	6
	A 240	310S	25Cr-20Ni	K	2,10	129	115	110	103	98	94	92	90	87	86	84	82	81	80	77	72	65	57	49	41	33	26	18	13	9	6
	A 240	310S	25Cr-20Ni	K	1,3,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	82	65	42	32	24	17	10	6	4	3	2	1
	A 240	310S	25Cr-20Ni	K	3,10	129	115	110	103	98	94	92	90	87	86	84	82	81	78	73	60	43	32	24	17	10	6	4	3	2	1
	A 240	316	16Cr-12Ni-2Mo	K	1,10,13	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
	A 240	316	16Cr-12Ni-2Mo	K	10,13	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
	A 240	316L	16Cr-12Ni-2Mo	K	1	108	108	108	107	101	95	92	91	89	87	86	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	316L	16Cr-12Ni-2Mo	K	—	108	90	82	75	70	66	64	63	62	61	59	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	317	18Cr-13Ni-3Mo	K	1,10,13	129	129	127	125	125	119	117	115	112	111	110	107	107	106	106	104	96	81	65	50	38	30	23	18	13	9
	A 240	317	18Cr-13Ni-3Mo	K	10,13	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
	A 240	317L	18Cr-13NI-3Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	317L	18Cr-13NI-3Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 240	321	18Cr-10Ni-Ti	K	1,10,13	129	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
	A 240	321	18Cr-10Ni-Ti	K	10,13	129	108	98	90	84	80	78	77	76	75	74	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
	A 240	347	18Cr-10Ni-Cb	K	1,10,13	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
	A 240	347	18Cr-10Ni-Cb	K	10,13	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
	A 240	348	18Cr-10Ni-Cb	K	1,10,13	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
	A 240	348	18Cr-10Ni-Cb	K	10,13	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
	A 240	405	12Cr-A1	J	9	103	98	95	92	90	86	85	85	83	81	77	73	68	63	44	—	—	—	—	—	—	—	—	—	—	—
	A 240	410	13Cr	H	—	112	106	103	100	96	94	93	91	90	87	83	79	74	66	52	38	27	18	12	7	—	—	—	—	—	—
	A 240	410S	13Cr	J	—	103	98	95	92	90	86	85	85	83	81	77	72	68	62	51	38	26	18	12	7	—	—	—	—	—	—
	A 240	429	15Cr	H	9	112	106	103	100	96	94	93	91	90	87	83	79	74	68	54	38	28	21	16	12	—	—	—	—	—	—
	A 240	430	17Cr	J	9	112	106	103	100	96	94	93	91	90	87	83	79	74	68	54	38	28	21	16	12	—	—	—	—	—	—
	A 240	S31803	22Cr-5Ni-3Mo	M	7	155	155	150	145	142	140	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A2	A 240	S32304	23Cr-4Ni-Mo-Cu	M	7	149	146	145	137	131	127																				
	PIPE AND TUBE (SEAMLESS)																														
	A 213	TP304	18Cr-8Ni	K	1,10	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
	A 213	TP304	18Cr-8Ni	K	10	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 213	TP304H	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
	A 213	TP304H	18Cr-8Ni	K	—	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 213	TP304L	18Cr-8Ni	K	1	108	108	105	102	100	98	96	94	93	92	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 213	TP304L	18Cr-8Ni	K	—	107	91	83	76	72	68	66	65	65	63	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 213	TP310S	25Cr-20Ni	K	1,2,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	80	72	65	57	49	41	33	26	18	13	9	6
A2	A 213	TP310S	25Cr-20Ni	K	2,10	129	115	110	103	98	94	92	90	87	86	84	82	81	80	73	72	65	57	49	41	33	26	18	13	9	6
	A 213	TP310S	25Cr-20Ni	K	1,3,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	82	65	42	32	24	17	10	6	4	3	2	1
	A 213	TP310S	25Cr-20Ni	K	3,10	129	115	110	103	98	94	92	90	87	86	84	82	81	78	73	60	43	32	24	17	10	6	4	3	2	1
	A 213	TP316	16Cr-12Ni-2Mo	K	1,10	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
	A 213	TP316	16Cr-12Ni-2Mo	K	10	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8

NOTES: See end of this Table 3.3.1(B).

(*continued*)

TABLE 3.3.1(B) (*continued*)

ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8) — Temperature, °C 50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
PIPE AND TUBE (SEAMLESS) (*continued*)																														
A 213	TP316H	16Cr-12Ni-2Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	107	106	105	104	96	81	65	50	38	30	23	18	13	9
A 213	TP316H	16Cr-12Ni2Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 213	TP316L	16Cr-12Ni-2Mo	K	1	108	108	108	107	101	95	92	91	89	87	86	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 213	TP316L	16Cr-12Ni-2Mo	K	—	108	90	82	75	70	66	64	63	62	61	59	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 213	TP321	18Cr-10Ni-Ti	K	1,10	129	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
A 213	TP321	18Cr-10Ni-Ti	K	10	129	108	98	90	84	80	78	77	76	75	74	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 213	TP321H	18Cr-10Ni-Ti	K	1	129	126	119	118	118	115	112	111	109	108	107	106	106	106	102	90	75	59	46	37	28	23	18	14	12	8
A 213	TP321H	18Cr-10Ni-Ti	K	—	129	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
A 213	TP347	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 213	TP347	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 213	TP347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	102	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 213	TP347H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 213	TP348	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 213	TP348	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 213	TP348H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 213	TP348H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 268	TP405	12Cr-Al	J	—	103	98	95	92	90	86	85	85	83	81	77	73	68	63	44	—	—	—	—	—	—	—	—	—	—	—
A 268	TP410	13Cr	H	—	103	98	95	92	90	86	85	85	83	81	77	72	68	62	51	38	26	18	12	—	—	—	—	—	—	—
A 268	TP430	16Cr	J	9	103	98	95	92	90	86	85	85	83	81	77	73	68	62	52	38	27	21	16	12	—	—	—	—	—	—
A 268	TP446	27Cr	L	10	120	114	111	108	104	101	100	98	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 312	TP304	18Cr-8Ni	K	1,10	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 312	TP304	18Cr-8Ni	K	10	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 312	TP304H	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 312	TP304H	18Cr-8Ni	K	—	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 312	TP304L	18Cr-8Ni	K	1	108	108	105	102	100	98	96	94	93	92	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 312	TP304L	18Cr-8Ni	K	—	107	91	83	76	72	68	66	65	65	63	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A2 A 312	TP309S	23Cr-12Ni	K	1,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	79	66	54	42	33	26	20	16	13	10	7	6
A 312	TP309S	23Cr-12Ni	K	10	129	115	110	103	98	94	92	90	87	86	84	82	81	79	74	66	54	42	33	26	20	16	13	10	7	6
A 312	TP310S	25Cr-20Ni	K	1,2,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	80	72	65	57	49	41	33	26	18	13	9	6
A 312	TP310S	25Cr-20Ni	K	2,10	129	115	110	103	98	94	92	90	87	86	84	82	81	80	77	72	65	57	49	41	33	26	18	13	9	6
A 312	TP310S	25Cr-20Ni	K	1,3,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	82	65	42	32	24	17	10	6	4	3	2	1
A 312	TP310S	25Cr-20Ni	K	3,10	129	115	110	103	98	94	92	90	87	86	84	82	81	78	73	60	43	32	24	17	10	6	4	3	2	1
A 312	TP316	16Cr-12Ni-2Mo	K	1,10	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 312	TP316	16Cr-12Ni-2Mo	K	10	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 312	TP316H	16Cr-12Ni-2Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 312	TP316H	16Cr-12Ni-2Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 312	TP316L	16Cr-12Ni-2Mo	K	1	108	108	108	107	101	95	92	91	89	87	86	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 312	TP316L	16Cr-12Ni-2Mo	K	—	108	90	82	75	70	66	64	63	62	61	59	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 312	TP317	18Cr-13Ni-3Mo	K	1,10	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 312	TP317	18Cr-13Ni-3Mo	K	10	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 312	TP321	18Cr-10Ni-Ti	K	1,10	129	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
A 312	TP321	18Cr-10Ni-Ti	K	10	129	108	98	90	84	80	78	77	76	75	74	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 312	TP321H	18Cr-10Ni-Ti	K	1	129	126	119	118	118	115	112	111	109	108	107	106	106	106	102	90	75	59	46	37	28	23	18	14	12	8
A 312	TP321H	18Cr-10Ni-TI	K	—	129	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
A 312	TP347	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 312	TP347	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 312	TP347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9

NOTES: See end of this Table 3.3.1(B). (*continued*)

TABLE 3.3.1(B) (*continued*)

ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
					Design tensile strength, MPa (Notes 5, 8) — Temperature, °C																									
PIPE AND TUBES (SEAMLESS) (*continued*)																														
A 312	TP347H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 312	TP348	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 312	TP348	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 312	TP348H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 312	TP348H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 376	TP304	18Cr-8Ni	K	1,10	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 376	TP304	18Cr-8Ni	K	10	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 376	TP304H	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 376	TP304H	18Cr-8Ni	K	—	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 376	TP316	16Cr-12Ni-2Mo	K	1,10	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 376	TP316	16Cr-12Ni-2Mo	K	10	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 376	TP316H	16Cr-12Ni-2Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 376	TP316H	16Cr-12Ni-2Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 376	TP321	18Cr-10Ni-Ti	K	1,10	129	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
A 376	TP321	18Cr-10Ni-Ti	K	10	129	108	98	90	84	80	78	77	76	75	74	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 376	TP321H	18Cr-10Ni-Ti	K	1	129	126	119	118	118	115	112	111	109	108	107	106	106	106	102	90	75	59	46	37	28	23	18	14	12	8
A 376	TP321H	18Cr-10Ni-Ti	K	—	129	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
A 376	TP347	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 376	TP347	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 376	TP347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 376	TP347H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 376	TP348	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 376	TP348	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 430	FP304	18Cr-8Ni	K	1,10,13	121	114	107	104	102	102	102	102	102	101	101	100	98	97	95	89	78	64	51	42	32	27	21	17	14	10
A 430	FP304	18Cr-8Ni	K	10,13	121	107	97	90	85	80	78	78	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 430	FP304H	18Cr-8Ni	K	1	121	114	107	104	102	102	102	102	102	101	101	100	98	97	95	89	78	64	51	42	32	27	21	17	14	10
A 430	FP430H	18Cr-8Ni	K	—	121	107	97	90	85	80	78	78	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 430	FP316	16Cr-12Ni-2Mo	K	1,10,13	121	120	118	116	116	116	116	115	112	111	110	108	108	107	105	101	94	82	65	50	38	30	23	19	14	8
A 430	FP316	16Cr-12Ni-2Mo	K	10,13	121	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	13	9
A 430	FP316H	16Cr-12Ni-2Mo	K	1	121	120	118	116	116	116	116	115	112	111	110	108	108	107	105	101	94	82	65	50	38	30	23	19	14	8
A 430	FP316H	16Cr-12Ni-2Mo	K	—	121	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	13	9
A 430	FP321	18Cr-10Ni-Ti	K	1,10,13	121	118	112	110	110	110	110	110	109	108	106	106	105	105	102	83	58	44	33	25	18	13	8	6	4	2
A 430	FP321	18Cr-10Ni-Ti	K	10,13	121	108	98	90	84	80	78	77	76	75	75	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 430	FP321H	18Cr-10Ni-Ti	K	1	121	117	111	110	110	110	110	110	109	108	107	106	106	106	101	90	74	58	46	37	28	23	18	14	12	8
A 430	FP321H	18Cr-10Ni-Ti	K	—	121	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
A 430	FP347	18Cr-10Ni-Cb	K	1,10,13	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 430	FP347	18Cr-10Ni-Cb	K	10,13	129	117	110	104	98	94	92	90	89	88	88	87	87	86	86	86	77	57	40	30	23	16	11	9	7	5
A 430	FP347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	10	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 430	FP347H	18Cr-10Ni-Cb	K	—	129	118	110	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 452	TP304H	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 452	TP304H	18Cr-8Ni	K	—	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 452	TP316H	16Cr-12Ni-2Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 452	TP316H	16Cr-12Ni-2Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 452	TP347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	—	—	—	—	—	—	—	—	—	—	—
A 452	TP347H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	—	—	—	—	—	—	—	—	—	—	—
A2 A 790	S32750	25Cr-7Ni-4Mo-N	M	7	202	198	188	182	180	179																				

NOTES: See end of this Table 3.3.1(B).

(*continued*)

TABLE 3.3.1(B) (*continued*)

	ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8) Temperature, °C																									
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
	PIPE AND TUBE (WELDED)																														
	A 249	TP304	18Cr-8Ni	K	1,4,10	110	103	97	95	93	93	93	93	93	91	89	88	87	85	83	78	67	54	44	36	28	23	18	15	12	8
	A 249	TP304	18Cr-8Ni	K	4,10	110	90	83	76	73	68	67	66	65	63	62	61	60	59	58	57	55	51	44	36	28	23	18	15	12	8
	A 249	TP304H	18Cr-8Ni	K	1,4	110	103	97	95	93	93	93	93	93	91	89	88	87	85	83	78	67	54	44	36	28	23	18	15	12	8
	A 249	TP304H	18Cr-8Ni	K	4	110	90	83	76	73	68	67	66	65	63	62	61	60	59	58	57	55	51	44	36	28	23	18	15	12	8
	A 249	TP304L	18Cr-8Ni	K	1,4	92	92	90	86	85	83	82	80	79	78	77	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 249	TP304L	18Cr-8Ni	K	4	92	77	70	65	61	58	57	56	55	54	53	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A2	A 249	TP309S	23Cr-12Ni	K	1,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	77	67	56	46	36	28	22	17	14	11	9	6	5
	A 249	TP309S	23Cr-12Ni	K	4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	67	63	56	46	36	28	22	17	14	11	9	6	5
	A 249	TP310S	25Cr-20Ni	K	1,2,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	76	69	61	55	48	41	35	28	21	15	11	7	4
	A 249	TP310S	25Cr-20Ni	K	2,4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	68	65	61	55	48	41	35	28	21	15	11	7	4
	A 249	TP310S	25Cr-20Ni	K	1,3,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	76	70	55	36	27	20	14	8	5	3	2	2	1
	A 249	TP310S	25Cr-20Ni	K	3,4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	67	63	51	36	27	20	14	8	5	3	2	2	1
	A 249	TP316	16Cr-12Ni-2Mo	K	1,4,10	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	82	70	56	43	32	25	19	15	12	8
	A 249	TP316	16Cr-12Ni-Mo	K	4,10	110	94	85	79	74	71	69	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 249	TP316H	16Cr-12Ni-2Mo	K	1,4	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	82	70	56	43	32	25	19	15	12	8
	A 249	TP316H	16Cr-12Ni-2Mo	K	4	110	94	85	79	74	71	69	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 249	TP316L	16Cr-12Ni-2Mo	K	1,4	92	92	92	91	86	81	79	77	75	74	73	71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 249	TP316L	16Cr-12Ni-2Mo	K	4	92	77	70	64	59	56	55	54	52	50	50	49	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 249	TP317	18Cr-13Ni-Mo	K	1,4,10	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	82	70	56	43	32	25	19	15	12	8
	A 249	TP317	18Cr-13Ni-3Mo	K	4,10	110	94	85	79	74	71	69	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 249	TP321	18Cr-10Ni-Ti	K	1,4,10	110	107	101	101	101	97	95	94	93	92	91	90	90	89	87	71	50	38	28	21	15	11	8	6	4	1
	A 249	TP321	18CR-10Ni-Ti	K	4,10	110	91	83	76	71	68	66	65	64	63	63	63	62	62	62	59	50	38	29	21	15	11	8	6	4	1
	A 249	TP321H	18Cr-10Ni-Ti	K	1,4	110	107	101	101	101	97	95	94	93	92	91	91	90	90	86	77	64	50	39	31	24	19	16	12	10	6
	A 249	TP321H	18Cr-10Ni-Ti	K	4	110	91	83	76	71	68	66	65	64	63	63	63	62	62	62	61	57	49	39	31	24	19	16	12	10	7
	A 249	TP347	18Cr-10Ni-Cb	K	1,4,10	110	104	96	91	88	86	86	86	86	86	86	86	86	86	84	78	66	49	34	26	17	14	10	8	6	5
	A 249	TP347	18Cr-10Ni-Cb	K	4,10	110	100	94	89	84	80	78	77	76	75	75	75	74	74	73	73	66	49	34	26	19	14	10	8	6	5
	A 249	TP347H	18Cr-10Ni-Cb	K	1,4	110	104	96	91	88	86	86	86	86	86	86	86	86	86	85	84	82	74	59	46	35	27	20	16	13	8
	A 249	TP347H	18Cr-10Ni-Cb	K	4	110	100	94	89	84	80	78	77	76	75	75	75	74	74	74	74	73	70	59	46	35	27	20	16	13	8
	A 249	TP348	18Cr-10Ni-Cb	K	1,4,10	110	104	96	91	88	86	86	86	86	86	86	86	86	86	84	78	66	49	34	26	19	14	10	8	6	5
	A 249	TP348	18Cr-10Ni-Cb	K	4,10	110	100	94	89	84	80	78	77	76	75	75	75	74	74	73	73	66	49	34	26	19	14	10	8	6	5
	A 249	TP348H	18Cr-10Ni-Cb	K	1,4	110	104	96	91	88	86	86	86	86	86	86	86	86	86	85	84	82	74	59	46	35	27	20	16	13	8
	A 249	TP348H	18Cr-10Ni-Cb	K	4	110	100	94	89	84	80	78	77	76	75	75	75	74	74	74	74	73	70	59	46	35	27	20	16	13	8
	A 268	TP405	12Cr-Al	J	4,14	88	84	81	78	76	74	73	72	71	68	65	61	58	53	37	—	—	—	—	—	—	—	—	—	—	—
	A 268	TP410	13Cr	H	4,14	88	84	81	78	76	74	73	72	71	68	65	61	58	52	43	32	22	15	10	5	—	—	—	—	—	—
	A 268	TP429	15Cr	H	4,14	88	83	81	78	76	73	72	71	70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 268	TP430	17Cr	J	4,14	88	84	81	78	76	74	73	72	71	68	65	61	58	53	44	32	23	17	13	10	—	—	—	—	—	—
	A 312	TP304	18Cr-8Ni	K	1,4,10	110	103	97	95	93	93	93	93	93	91	89	88	87	85	83	78	67	54	44	36	28	23	18	15	12	8
	A 312	TP304	18Cr-8Ni	K	4,10	110	90	83	76	73	68	67	66	65	63	62	61	60	59	58	57	55	51	44	36	28	23	18	15	12	8
	A 312	TP304H	18Cr-Ni	K	1,4	110	103	97	95	93	93	93	93	93	91	89	88	87	85	83	78	67	54	44	36	28	23	18	15	12	8
	A 312	TP304H	18Cr-8Ni	K	4	110	90	83	76	73	68	67	66	65	63	62	62	60	59	58	57	55	51	44	36	28	23	18	15	12	8
	A 312	TP304L	18Cr-8Ni	K	1,4	92	92	90	86	85	83	82	80	79	78	77	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 312	TP304L	18Cr-8Ni	K	4	91	77	70	65	61	58	57	56	55	54	53	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A2	A 312	TP309S	23Cr-12Ni	K	1,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	77	67	56	46	36	28	22	17	14	11	9	6	5
	A 312	TP309S	23Cr-12Ni	K	4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	67	63	56	46	36	28	22	17	14	11	9	6	5
	A 312	TP310S	25Cr-20Ni	K	1,2,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	76	69	61	55	48	41	35	28	21	15	11	7	4
	A 312	TP310S	25Cr-20Ni	K	2,4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	68	65	61	55	48	41	35	28	21	15	11	7	4
	A 312	TP310S	25Cr-20Ni	K	1,3,4,10	110	100	97	93	91	90	89	89	89	88	88	86	83	76	70	55	36	27	20	14	8	5	3	2	2	1

NOTES: See end of this Table 3.3.1(B).

(*continued*)

TABLE 3.3.1(B) (*continued*)

	ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8)																									
						Temperature, °C																									
						50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
	PIPE AND TUBE (WELDED) *continued*																														
A2	A 312	TP310S	25Cr-20Ni	K	3,4,10	110	98	93	88	84	80	78	76	74	73	72	70	69	67	63	51	36	27	20	14	8	5	3	2	2	1
	A 312	TP316	16Cr-12Ni-2Mo	K	1,4,10	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	82	70	56	43	32	25	19	15	12	8
	A 312	TP316	16Cr-12Ni-2Mo	K	4,10	110	94	85	79	74	71	69	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 312	TP316H	16Cr-12Ni-2Mo	K	1,4	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	72	70	56	43	32	25	19	15	12	8
	A 312	TP316H	16Cr-12Ni-2Mo	K	4	110	94	85	79	74	71	99	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 312	TP316L	16Cr-12Ni-2Mo	K	1,4	92	92	92	91	86	81	79	77	75	74	73	71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 312	TP316L	16Cr-12Ni-2Mo	K	4	92	77	70	64	59	56	55	54	52	50	50	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 312	TP317	18Cr-13Ni-3Mo	K	1,4,10	110	110	108	106	106	102	99	98	96	94	93	93	91	91	90	88	82	70	56	43	32	25	19	15	12	8
	A 312	TP317	18Cr-13Ni-3Mo	K	4,10	110	94	85	79	74	71	69	67	66	66	65	64	64	63	62	62	61	60	53	43	32	25	19	15	12	8
	A 312	TP321	18Cr-10Ni-Ti	K	1,4,10	110	107	101	101	101	97	95	94	93	92	91	90	90	89	87	71	50	38	28	21	15	11	8	6	4	1
	A 312	TP321	18Cr-10Ni-Ti	K	4,10	110	91	83	76	71	68	66	65	64	63	63	63	62	62	62	59	50	38	28	21	15	11	8	6	4	1
	A 312	TP321H	18Cr-10Ni-Ti	K	1,4	110	107	101	101	101	97	95	94	93	92	91	91	90	90	86	77	64	50	39	31	24	19	16	12	10	6
	A 312	TP321H	18Cr-10Ni-Ti	K	4	110	91	83	76	71	68	66	65	64	63	63	63	62	62	62	61	57	49	39	31	24	19	16	12	10	7
	A 312	TP347	18Cr-10Ni-Cb	K	1,4,10	110	104	96	91	88	86	86	86	86	86	86	86	86	86	84	78	66	49	34	26	19	14	10	8	6	5
	A 312	TP347	18Cr-10Ni-Cb	K	4,10	110	100	94	89	84	80	78	77	76	75	75	75	74	74	73	73	66	49	34	26	19	14	10	8	6	5
	A 312	TP347H	18Cr-10Ni-Cb	K	1,4	110	104	96	91	88	86	86	86	86	86	86	86	86	86	85	84	82	74	59	46	35	27	20	16	13	8
	A 312	TP347H	18Cr-10Ni-Cb	K	4	110	100	94	89	84	80	78	77	76	75	75	75	74	74	74	74	73	70	59	46	35	27	20	16	13	8
	A 312	TP348	18Cr-10Ni-Cb	K	1,4,10	110	104	96	91	88	86	86	86	86	86	86	86	86	86	84	78	66	49	34	26	19	14	10	8	6	5
	A 312	TP348	18Cr-10Ni-Cb	K	4,10	110	100	94	89	84	80	78	77	76	75	75	75	74	74	73	73	66	49	34	26	19	14	10	8	6	5
	A 312	TP348H	18Cr-10Ni-Cb	K	1,4	110	104	96	91	88	86	86	86	86	86	86	86	86	86	85	84	82	74	59	46	35	27	20	16	13	8
	A 312	TP348H	18Cr-10Ni-Cb	K	4	110	100	94	89	84	80	78	77	76	75	75	75	75	74	74	74	73	70	59	46	35	27	20	16	13	8
A2	A 790	S32750	25Cr-7Ni-4Mo-N	M	4,7	172	168	160	155	153	152																				
	FORGINGS																														
	A 182	F304	18Cr-8Ni	K	1,10	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
	A 182	F304	18Cr-8Ni	K	10	129	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 182	F304	18Cr-8Ni	K	1,10,12	121	114	107	104	102	102	102	102	102	101	101	100	98	97	95	89	78	64	51	42	32	27	21	17	14	10
	A 182	F304	18Cr-8Ni	K	10,12	121	107	98	90	85	80	78	78	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 182	F304H	18Cr-8Ni	K	1	129	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
	A 182	F304H	18Cr-8Ni	K	—	129	107	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 182	F304H	18Cr-8Ni	K	1,12	121	114	107	104	102	102	102	102	102	101	101	100	98	97	95	89	78	64	51	42	32	27	21	17	14	10
	A 182	F304H	18Cr-8Ni	K	12	121	107	97	90	85	80	78	78	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
	A 182	F304L	18Cr-8Ni	K	1	108	105	98	94	93	92	92	91	90	90	89	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 182	F304L	18Cr-8Ni	K	—	107	91	83	76	72	68	66	65	65	63	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	A 182	F310	25Cr-20Ni	K	1,2,10	129	118	113	110	107	106	106	105	104	103	103	101	98	90	80	72	65	57	49	41	33	26	18	13	9	6
	A 182	F310	25Cr-20Ni	K	2,10	129	115	110	103	98	94	92	90	87	86	84	82	81	80	77	72	65	57	49	41	33	26	18	13	9	6
	A 182	F310	25Cr-20Ni	K	1,3,10	129	118	113	110	107	107	106	105	105	104	103	101	98	90	82	65	42	32	24	17	10	6	4	3	2	1
	A 182	F310	25Cr-20Ni	K	3,10	129	115	110	103	98	94	92	90	87	86	84	82	81	78	73	60	43	32	24	17	10	6	4	3	2	1
	A 182	F321	18Cr-10Ni-Ti	K	1,10	129	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
	A 182	F321	18Cr-10Ni-Ti	K	10	129	108	98	90	84	80	78	77	76	75	75	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
	A 182	F321	18Cr-10Ni-Ti	K	1,10,12	121	118	112	110	110	110	110	110	109	108	106	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
	A 182	F321	18Cr-10Ni-Ti	K	10,12	121	108	98	90	84	80	78	77	76	75	75	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
	A 182	F321H	18Cr-10Ni-Ti	K	1	129	126	119	118	118	115	112	111	109	108	107	106	106	106	102	90	75	59	46	37	28	23	18	14	12	8
	A 182	F321H	18Cr-10Ni-Ti	K	—	129	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
	A 182	F321H	18Cr-10Ni-Ti	K	1,12	121	117	111	110	110	110	110	110	109	108	107	106	106	106	101	90	74	58	46	37	28	23	18	14	12	8
	A 182	F321H	18Cr-10Ni-Ti	K	12	121	108	98	90	84	80	78	77	76	75	75	74	73	73	73	72	67	58	46	37	28	23	18	14	12	8
	A 182	F347	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
	A 182	F347	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6

NOTES: See end of this Table 3.3.1(B).

(*continued*)

TABLE 3.3.1(B) (*continued*)

ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8) Temperature, °C 50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
FORGINGS (*continued*)																														
A 182	F347	18Cr-10Ni-Cb	K	1,10,12	121	114	105	100	96	95	95	95	95	95	95	95	95	94	93	89	77	57	40	30	23	16	11	9	7	6
A 182	F347	18Cr-10Ni-Cb	K	10,12	121	114	105	100	96	94	92	90	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 182	F347H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 182	F347H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 182	F347H	18Cr-10Ni-Cb	K	1,12	121	114	105	100	96	95	95	95	95	95	95	95	95	94	94	92	90	84	70	54	41	32	24	29	15	9
A 182	F347H	18Cr-10Ni-Cb	K	12	121	114	105	100	96	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 182	F348	18Cr-10Ni-Cb	K	1,10	129	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 182	F348	18Cr-10Ni-Cb	K	10	129	118	111	104	98	93	92	91	89	88	88	88	88	87	87	86	77	57	40	30	23	16	11	9	7	6
A 182	F348	18Cr-10Ni-Cb	K	1,10,12	121	114	105	100	96	95	95	95	95	95	95	95	95	94	93	89	77	57	40	30	23	16	11	9	7	6
A 182	F348	18Cr-10Ni-Cb	K	10,12	121	114	105	100	96	94	92	90	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 182	F348H	18Cr-10Ni-Cb	K	1	129	122	113	107	103	102	101	101	101	101	101	101	101	101	100	99	96	86	70	54	41	32	24	19	15	9
A 182	F348H	18Cr-10Ni-Cb	K	—	129	118	111	104	98	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 182	F348H	18Cr-10Ni-Cb	K	1,12	121	114	105	100	96	95	95	95	95	95	95	95	95	94	94	92	90	84	70	54	41	32	24	19	15	9
A 182	F348H	18Cr-10Ni-Cb	K	12	121	114	105	100	96	93	92	91	89	88	88	88	87	87	87	87	86	82	70	54	41	32	24	19	15	9
A 182	F316	16Cr-12Ni-2Mo	K	1,10	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 182	F316	16Cr-12Ni-2Mo	K	10	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 182	F316	16Cr-12Ni-2Mo	K	1,10,12	121	120	118	116	116	116	116	115	112	111	110	108	108	107	105	101	94	82	65	50	38	30	23	19	14	8
A 182	F316	16Cr-12Ni-2Mo	K	10,12	121	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	13	9
A 182	F316H	16Cr-12Ni-2Mo	K	1	129	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 182	F316H	16Cr-12Ni-2Mo	K	—	129	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 182	F316H	16Cr-12Ni-2Mo	K	1,12	121	120	118	116	116	116	116	115	112	111	110	108	108	107	105	101	94	82	65	50	38	30	23	19	14	8
A 182	F316H	16Cr-12Ni-2Mo	K	12	121	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	13	9
A 182	F316L	16Cr-12Ni-2Mo	K	1	108	108	108	107	101	95	92	91	89	87	86	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 182	F316L	16Cr-12Ni-2Mo	K	—	108	90	82	75	70	66	64	63	62	61	59	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 336	F304	18Cr-8Ni	K	1,10,13	121	113	107	104	102	102	102	102	102	101	101	100	98	97	95	89	78	64	51	42	32	27	21	17	14	10
A 336	F304	18Cr-8Ni	K	10,13	121	106	97	90	85	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 336	F321	18Cr-10Ni-Ti	K	1,10,13	121	118	112	110	110	110	110	110	109	108	106	106	105	105	102	83	58	44	33	25	18	13	8	6	4	2
A 336	F321	18Cr-10Ni-Ti	K	10,13	121	108	98	90	84	80	78	77	76	75	75	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 336	F347	18Cr-10Ni-Cb	K	1,10,13	121	114	105	100	96	95	95	95	95	95	95	95	95	94	93	89	77	57	40	30	23	16	11	9	7	6
A 336	F347	18Cr-10Ni-Cb	K	10,13	121	114	105	100	96	94	92	90	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 336	F316	16Cr-12Ni-2Mo	K	1,10,13	121	120	118	116	116	116	116	115	112	111	110	108	108	107	105	101	94	82	65	50	38	30	23	19	14	8
A 336	F316	16Cr-12Ni-2Mo	K	10,13	121	110	100	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	50	38	30	23	18	13	9
A2 A 336	F310	25Cr-20Ni	K	1,2,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	80	72	64	57	49	41	33	26	18	13	9	6
A 336	F310	25Cr-20Ni	K	2,10	129	115	110	103	98	94	92	90	87	86	84	82	81	80	77	72	64	57	49	41	33	26	18	13	9	6
A 336	F310	25Cr-20Ni	K	1,3,10	129	118	113	110	107	106	105	105	104	103	103	101	98	90	82	65	43	32	24	17	10	6	4	3	2	1
A 336	F310	25Cr-20Ni	K	3,10	129	115	110	103	98	94	92	90	87	86	84	82	81	78	73	60	43	32	24	17	10	6	4	3	2	1
CASTINGS (*continued*)																														
A 351	CF3	18Cr-8Ni	K	1	121	113	105	104	102	102	102	102	102	101	101	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF3	18Cr-8Ni	K	—	121	106	96	87	84	80	78	77	76	74	73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF3A	18Cr-8Ni	K	1	134	124	116	114	113	112	112	111	99	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF3A	18Cr-8Ni	K	—	134	124	113	105	99	95	90	85	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF3M	18Cr-9Ni-2½Mo	K	1,11	121	120	118	116	116	116	116	114	112	110	109	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF3M	18Cr-9Ni-2½Mo	K	11	121	110	101	92	86	83	81	79	78	77	76	75	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 351	CF8	18Cr-8Ni	K	1,10	121	112	104	103	102	102	102	102	102	101	101	100	98	95	88	76	60	49	40	33	27	23	20	17	15	13
A 351	CF8	18Cr-8Ni	K	10	121	106	96	89	84	80	78	77	76	74	73	70	69	68	66	64	59	49	38	31	23	18	14	10	8	—

NOTES: See end of this Table 3.3.1(B).

(*continued*)

TABLE 3.3.1(B) (*continued*)

ASTM material spec.	Type or grade	Nominal composition	Steel group	Notes	Design tensile strength, MPa (Notes 5, 8)																									
					Temperature, °C																									
					50	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
CASTINGS (*continued*)																														
A 351	CF8M	18Cr-9Ni-2½Mo	K	1,11	121	120	118	116	116	116	116	114	112	110	109	108	107	106	106	94	75	58	46	37	30	24	20	17	14	12
A 351	CF8M	18Cr-9Ni-2½Mo	K	11	121	110	101	92	86	83	81	79	78	77	76	75	75	74	74	72	68	63	53	41	37	29	22	18	15	10
A 351	CF8C	18Cr-10Ni-Cb	K	1,10	121	113	105	100	96	95	95	95	95	95	95	95	95	94	92	92	85	68	52	34	25	20	15	12	10	8
A 351	CF8C	18Cr-10Ni-Cb	K	10	121	113	105	100	96	94	92	90	89	88	88	87	87	87	84	80	76	69	52	34	25	20	15	12	10	7
A 351	CH8	125Cr-12Ni	K	1,10	112	102	98	95	93	92	92	91	90	90	90	89	87	84	77	67	54	42	33	26	20	16	13	10	7	6
A 351	CH8	125Cr-12Ni	K	10	112	102	98	95	92	88	86	84	82	81	79	77	75	75	72	65	54	42	33	26	20	16	13	10	7	6
A2 A 351	CH20	25Cr-12Ni	K	1,10	121	110	105	102	100	99	98	98	97	97	96	95	93	89	79	66	54	42	33	26	20	16	13	10	7	6
A 351	CH20	25Cr-12Ni	K	10	121	110	105	102	98	94	92	90	87	86	84	82	81	79	74	66	54	42	33	26	20	16	13	10	7	6
A 351	CK20	25Cr-20Ni	K	1,10	112	102	98	95	93	92	92	91	90	90	90	89	87	84	79	72	65	57	49	41	33	26	18	13	9	6
A 351	CK20	25Cr-20Ni	K	10	112	102	98	95	92	88	86	84	82	81	79	77	76	74	72	70	65	57	49	41	33	26	18	13	9	6
BARS																														
A 479	302	18Cr-8Ni	K	1	130	122	114	112	110	110	110	110	110	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	302	18Cr-8Ni	K	—	130	106	97	90	85	80	78	78	76	74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	304	18Cr-8Ni	K	1,10,13	130	122	114	112	110	110	110	110	109	107	105	103	102	100	98	91	79	64	51	42	32	27	21	17	14	10
A 479	304	18Cr-8Ni	K	10,13	130	106	97	90	84	80	78	77	76	74	73	72	71	69	68	67	64	60	52	42	32	27	21	17	14	10
A 479	304L	18Cr-8Ni	K	1	108	108	105	102	100	98	96	94	93	92	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	304L	18Cr-8Ni	K	—	107	91	83	76	72	68	66	65	65	63	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	310S	25Cr-20Ni	K	1,2,10	130	118	113	110	107	106	105	105	104	103	103	101	98	90	80	72	65	57	49	41	33	26	18	13	9	6
A 479	310S	25Cr-20Ni	K	2,10	130	115	110	103	98	94	92	90	87	86	84	82	81	80	77	72	65	57	49	41	33	26	18	13	9	6
A 479	310S	25Cr-20Ni	K	1,3,10	130	118	113	110	107	106	105	105	104	103	103	101	98	90	82	65	42	32	24	17	10	6	4	3	2	1
A 479	310S	25Cr-20Ni	K	3,10	130	115	110	103	98	94	92	90	87	86	84	82	81	78	73	66	43	32	24	17	10	6	4	3	2	1
A 479	316	18Cr-12Ni-2Mo	K	1,10,13	130	129	127	125	125	119	117	115	112	111	110	109	107	106	106	104	96	81	65	50	38	30	23	18	13	9
A 479	316	18Cr-12Ni-2Mo	K	10,13	130	110	101	93	87	82	81	80	78	77	76	75	75	74	73	73	72	70	63	51	38	30	23	18	14	8
A 479	316L	18Cr-12Ni-2Mo	K	1	108	108	108	107	101	95	92	91	89	87	86	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	316L	18Cr-12Ni-2Mo	K	—	108	90	82	75	70	66	64	63	62	61	59	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A 479	321	18Cr-10Ni-Ti	K	1,10,13	130	126	119	118	118	115	112	111	109	108	107	106	106	105	102	83	58	44	33	25	18	13	8	6	4	2
A 479	321	18Cr-10Ni-Ti	K	10,13	130	108	98	90	84	80	78	77	76	75	74	74	73	73	73	69	58	44	33	25	18	13	8	6	4	2
A 479	347	18Cr-10Ni-Cb	K	1,10,13	130	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 479	347	18Cr-10Ni-Cb	K	10,13	130	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 479	348	18Cr-10Ni-Cb	K	1,10,13	130	122	113	107	103	102	101	101	101	101	101	101	101	101	99	92	77	57	40	30	23	16	11	9	7	6
A 479	348	18Cr-10Ni-Cb	K	10,13	130	118	111	104	98	93	92	91	89	88	88	88	87	87	87	86	77	57	40	30	23	16	11	9	7	6
A 479	405	12Cr-A1	J	9	103	98	95	92	90	86	85	85	83	81	77	73	68	63	44	—	—	—	—	—	—	—	—	—	—	—
A 479	410	13Cr	H	—	112	106	103	100	97	93	92	91	90	87	83	78	73	65	52	—	—	—	—	—	—	—	—	—	—	—
A 479	430	17Cr	J	9	121	114	111	107	104	101	100	98	97	94	89	84	78	69	54	—	—	—	—	—	—	—	—	—	—	—

NOTES:

1 Due to the relatively low yield strength of these materials, these higher design strength values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher design strength values exceed 62.5 percent but do not exceed 90 percent of the yield strength at temperature. Use of these design strengths may result in dimensional changes due to permanent strain. These design strength values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage of malfunction.

2 These design strength values at temperatures of 575°C and above should be used only when assurance is provided that the steel has a predominant grain size not finer than ANSI/ASTM E 112, No 6.

3 These design values are to be considered basic values to be used when no effort is made to control or check the grain size of the steel.

4 The design strength values are the basic values multiplied by a joint efficiency factor of 0.85.

5 The design strength values in this Table may be interpolated to determine values for intermediate temperatures.

6 To these values a quality factor as specified in Clause 3.3.1.1(d) is to be applied for castings.

7 This steel may be expected to develop embrittlement after service at moderately elevated temperatures. It is not recommended for extended service above 300°C.

8 For design strengths at temperatures below 50°C, see Clause 3.3.2.

9 This steel may be expected to develop embrittlement at room temperature after service at temperatures above 425°C. Consequently, its use at higher temperatures is not recommended unless due caution is observed.

10 At temperatures above 550°C, these design strength values apply only when the carbon content is 0.04 percent or higher.

11 For temperatures above 425°C, the design strength values apply only when the carbon content is 0.04 percent or higher.

12 Theses design strength values are applicable to forgings over 125 mm in thickness.

13 For temperatures above 550°C, these design strength values may be used only if the material is heat-treated by heating it to a minimum temperature of 1040°C and quenching in water or rapidly cooling by other means.

14 Filler metal is not to be used in the manufacture of welded pipe or tubing.

TABLE 3.3.1(C)

DESIGN TENSILE STRENGTH (MPa)
(C) IRON CASTINGS

Material			Maximum allowable design pressure MPa	Notes	Design tensile strength, MPa								
					Temperature, °C								
Type	Specification	Grade			≤ 250	300	350	375	400	425	450	475	500
Grey iron	AS 1830	T-150	(Note 3)	1,2,6	15	—	—	—	—	—	—	—	—
		T-180	(Note 3)	1,2,6	18	—	—	—	—	—	—	—	—
		T-220	(Note 3)	1,2,6	22	—	—	—	—	—	—	—	—
		T-260	(Note 3)	1,2,6	26	—	—	—	—	—	—	—	—
		T-300	(Note 3)	1,2,6	30	—	—	—	—	—	—	—	—
		T-350	(Note 3)	1,2,6	35	—	—	—	—	—	—	—	—
		T-400	(Note 3)	1,2,6	40	—	—	—	—	—	—	—	—
Spheroidal graphite iron	AS 1831	370-17	(Note 4)	1,2,5	93	93	93	93	—	—	—	—	—
		400-12	(Note 3)	1,2	100	—	—	—	—	—	—	—	—
		500-7	(Note 3)	1,2	95	—	—	—	—	—	—	—	—
Whiteheart malleable iron	AS 1832	W 350-4	(Note 3)	1,2,7	55	—	—	—	—	—	—	—	—
		W 400-5	(Note 3)	1,2,7	72	—	—	—	—	—	—	—	—
A1 Blackheart malleable iron	AS 1832	B 300-6	(Note 3)	1,2	52	—	—	—	—	—	—	—	—
		B 350-10	(Note 3)	1,2	78	—	—	—	—	—	—	—	—
Spheroidal graphite austenitic iron	AS 1833	S-Ni Mn 13 7	(Note 4)	1,2,5	78	78	78	78	—	—	—	—	—
		S-Ni Cr 20 2	(Note 3)	1,2	37	37	—	—	—	—	—	—	—
		S-Ni Cr 20 3	(Note 3)	1,2	39	39	—	—	—	—	—	—	—
		S-Ni Si Cr 20 5 2	(Note 3)	1,2	37	37	—	—	—	—	—	—	—
		S-Ni 22	(Note 4)	1,2,5	74	74	74	74	—	—	—	—	—
		S-Ni Mn 23 4	(Note 4)	1,2,5	88	88	88	88	—	—	—	—	—
		S-Ni Cr 30 1	(Note 3)	1,2	37	37	—	—	—	—	—	—	—
		S-Ni Cr 30 3	(Note 3)	1,2	37	37	—	—	—	—	—	—	—
		S-Ni Si Cr 30 5 5	(Note 3)	1,2	39	39	—	—	—	—	—	—	—
		S-Ni 35	(Note 4)	1,2,5	74	74	74	74	—	—	—	—	—
		S-Ni Cr 35 3	(Note 3)	1,2	37	37	—	—	—	—	—	—	—

NOTES:

1 See Clause 3.3.3 for design strength at lower temperatures.

2 —

3 Pressure limits are 1.8 MPa for steam, water, oil, air and refrigerants.

4 Pressure limits are 7 MPa for steam, water, oil, air and refrigerants.

5 To these design strength values a casting quality factor as specified in Clause 3.3.1.1(d) is to be applied.

6 Higher design strength may be used for thickness not exceeding 41 mm; such design strengths being in proportion to the minimum tensile strength for the actual as-cast thickness.

7 Design strength values are for 9 mm diameter test bar; values should be reduced by—

7 MPa for 12 mm diameter test bar
9 MPa for 15 mm diameter test bar } (grade W 400-5)

3 MPa for 12 mm diameter test bar
6 MPa for 15 mm diameter test bar } (grade W 350-4)

TABLE 3.3.1(D)

DESIGN TENSILE STRENGTH (MPa)
(D) COPPER AND COPPER ALLOYS

A2

Common name	Product form	Specification	Alloy or UNS No.	Condition or temper	Size or thickness mm	Notes	Design tensile strength, MPa (Notes 1 & 2) Temperature, °C 50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
PLATE, SHEET AND STRIP																						
Copper - ETP (tough pitch)	Plate, sheet and strip	ASTM B152M	C11000	Annealed	<60	—	46	39	37	36	35	28	22	—	—	—	—	—	—	—	—	—
Copper- OF (oxygen free)	Plate, sheet and strip	ASTM B152M	C10200	Annealed	<60	—	44	40	38	36	35	28	22	—	—	—	—	—	—	—	—	—
Copper - DHP phosphorus deoxidized	Plate, sheet and strip	ASTM B152M	C12200	Annealed	<60	—	46	39	37	35	34	28	22	—	—	—	—	—	—	—	—	—
Admiralty brass	Plate, and sheet	ASTM B171M	C44300	Annealed	≤100	—	69	69	69	69	69	68	30	14	—	—	—	—	—	—	—	—
Naval brass	Plate and sheet	ASTM B171M	C46400	Annealed	≤80 >80 ≤150	—	86 83	86 83	86 83	86 83	85 82	47 47	20 20	— —	— —	— —	— —	— —	— —	— —	— —	— —
90/10 Copper-nickel	Plate and sheet	ASTM B171M	C70600	Annealed	≤140	—	69	66	65	64	62	60	59	57	56	52	45	—	—	—	—	—
70/30 Copper-nickel	Plate and sheet	ASTM B171M	C71500	Annealed	≤60 >60 ≤140	—	86 78	75 67	72 65	72 64	72 64	72 64	72 64	72 64	72 64	72 64	72 64	72 64	72 64	72 64	— —	— —
Aluminium bronze	Plate	ASTM B171M	C61400	Annealed	≤50 >50 ≤140	—	121 112	121 112	121 112	121 112	121 112	121 112	118 110	115 107	112 103	— —	— —	— —	— —	— —	— —	— —
Aluminium-nickel bronze	Plate	ASTM B171M	C63000	Annealed	≤50 >50 ≤100 >100 ≤140	—	155 147 137	155 147 136	155 147 135	155 147 133	155 145 132	155 143 130	155 140 129	152 138 127	149 136 123	127 123 116	98 98 98	75 75 75	55 55 55	39 39 39	— — —	— — —
Silicon bronze	Plate and sheet	ASTM B96M	C65500	Annealed	All	3	83	83	82	80	68	37	—	—	—	—	—	—	—	—	—	—
PIPE AND TUBE																						
A3 Copper-Phosphorus-deoxidized	Tube	AS 1569	C12200	Anneald Hard drawn	All	—	39 78	34 78	33 78	33 78	32 76	28 71	22 37	— —	— —	— —	— —	— —	— —	— —	— —	— —
Copper-OF	Tube	ASTM B75M	C10200	Annealed Light drawn Hard drawn	All All All	— 4, 6 4, 5	39 62 78	34 62 78	33 62 78	33 62 78	32 60 76	28 59 71	22 57 37	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —
Copper-DHP	Tube	ASTM B75M	C12200																			
A3 70/30 Brass-Arsenical	Tube	AS 1569	C26130	Annealed	All	—	69	69	69	69	69	53	27	13	—	—	—	—	—	—	—	—
A3 Admiralty brass	Tube	ASTM B111M AS 1569	C44300	Annealed	All	—	69	69	69	69	69	69	30	14	—	—	—	—	—	—	—	—

(*continued*)

TABLE 3.3.1(D) (*continued*)

Common name	Product form	Specification	Alloy or UNS No.	Condition or temper	Size or thickness mm	Notes	Design tensile strength, MPa (Notes 1 & 2) Temperature, °C															
							50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
PIPE AND TUBE (*continued*)																						
Aluminium brass	Tube	ASTM B111M AS 1569	C68700	Annealed	All	—	82	82	82	82	80	47	25	15	—	—	—	—	—	—	—	—
90/10 Copper-nickel	Tube	AS 1569 ASTM B111M	C70610 C70600	Annealed	All	—	69	66	65	64	62	60	59	57	56	52	45	—	—	—	—	—
70/30 Copper-nickel	Tube	AS 1569 ASTM B111M	C71500	Annealed Drawn stress relieved	All All	—	82 124	79 124	77 124	76 124	74 124	73 122	71 120	70 117	69 115	68 113	67 111	66 110	65 110	64 109	— 102	— 59
ROD, BAR AND SECTION																						
Copper-tough pitch, high conductivity	Rod and bar	AS 1567	110	Annealed	All	—	46	46	44	43	34	27	19	—	—	—	—	—	—	—	—	—
Phosphorus deoxidized	Rod and bar	AS 1567	122																			
CASTING																						
Leaded gunmetal (85/5/5/5)	All castings	AS 1565	C83600	As cast	All	7, 8	48	48	48	48	48	48	46	42	36	—	—	—	—	—	—	—
Leaded tin bronze (80/10/10)	All castings	AS 1565	C93700	As cast	All	7, 8	42	42	42	40	38	37	36	—	—	—	—	—	—	—	—	—
Aluminium bronze	All castings	AS 1565	C95210	As cast	All	7, 8	108	108	103	100	98	98	98	90	81	65	51	—	—	—	—	—

NOTES:

1 Design strengths at intermediate temperatures may be obtained by linear interpolation. Joint efficiencies are to be applied where necessary. See Clause 3.3.1.

2 For minimum allowable operating temperature, see Clause 3.3.2.

3 Copper-silicon alloys are not always suitable when exposed to certain media and high temperatures, particularly steam above 100°C. The user should satisfy himself that the alloy selected is satisfactory.

4 If welded, the allowable stress values for the annealed condition shall be used.

5 Use Figure NFC-4 of ASME II, Part D, Subpart 3 up to and including 177°C. Use the 600°F curve of Figure NFC-3 of ASME II, Part D, Subpart 3 above 177°C up to and including 204°C. Maximum temperature for external pressure not to exceed 204°C.

6 Use Figure NFC-3 of ANSI/ASME BPV-IID, Subpart 3 for temperatures above 149°C up to and including 204°C.

7 A casting factor is to be applied to these design strengths, see Clause 3.3.1.1(e).

8 No welding permitted.

TABLE 3.3.1(E)

DESIGN TENSILE STRENGTH (MPa)
(E) ALUMINIUM AND ALUMINIUM ALLOYS

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6)						
						Temperature, °C						
						50	75	100	125	150	175	200
Plate and sheet AS 1734 (Equivalent to ASTM B 209)	1080A	99.8Al	O	≥1.3 ≤6	—	13	12	11	9	8	7	6
			H14	≥1.3 ≤6	3	23	22	19	17	15	12	8
	(—)		H112	≥6 ≤50	3	14	14	12	10	9	8	7
	1050 (1060)	99.5Al	O	≥1.3 ≤6	—	14	13	11	10	9	8	7
			H12	≥1.3 ≤6	3	20	19	18	16	14	12	8
			H14	≥1.3 ≤12	3	25	23	20	18	16	13	8
			H112	≥6 ≤25	3	16	15	13	11	10	8	7
	1100 & 1200 (1100)	99Al	O	≥1.3 ≤75	—	16	16	16	15	12	9	7
			H12	≥1.3 ≤50	3	24	24	24	22	19	14	8
			H14	≥1.3 ≤25	3	28	28	27	24	19	14	8
			H112	≥6 ≤12	3	22	22	20	18	16	11	7
				>12 ≤50	3	21	20	19	17	15	11	7
				>50 ≤75	3	18	18	18	16	12	9	7
	3003 (3003)	Al-1.25Mn	O	≥1.3 ≤75	—	23	23	22	20	17	13	10
			H12	≥1.3 ≤50	3	29	29	29	27	25	21	17
			H14	≥1.3 ≤25	3	34	34	34	33	29	22	17
			H112	≥6 ≤12	3	29	29	29	27	25	21	17
				>12 ≤50	3	26	26	25	21	17	13	10
				>50 ≤75	3	25	25	24	21	17	13	10
	Alclad 3003 (Alclad 3003)	Al-(Al-1.25Mn)	O	≥0.15 <12	8	20	20	20	18	15	11	9
				≥12 ≤75	9	23	23	22	18	15	11	9
			H12	≥0.15 <50	3, 8, 9	26	26	26	25	23	19	15
				≥0.15 <25	3, 8, 9	31	31	31	30	27	19	15
			H14	≥6 <12	3, 8	26	26	26	25	23	19	15
				≥12 <50	3, 10	24	24	23	20	15	11	9
			H112	>50 ≤75	3, 10	23	23	22	20	15	11	9

NOTES: See end of this Table 3.3.1(E).

(*continued*)

A2

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6) Temperature, °C 50	75	100	125	150	175	200
AS 1734	3004 (3004)	—	O	≥0.15 ≤75	—	38	38	38	38	35	27	18
			H32	≥1.3 ≤50	3	49	49	49	48	40	27	18
			H34	≥1.3 ≤25	3	56	56	56	54	40	27	18
			H112	≥6 ≤75	3	40	40	40	40	35	27	18
	Alclad 3004 (Alclad 3004)	—	O	≥1.3 ≤75	8, 9	35	35	35	34	31	24	16
			H32	≥1.3 ≤50	3, 8, 9	44	44	44	43	36	24	16
			H34	≥1.3 ≤25	3, 8, 9	50	50	50	48	36	24	16
			H112	≥6 ≤75	3, 8, 9	36	36	36	36	32	24	16
	3203 (—)	Al-1.25Mn	O	≥1.3 ≤25	—	23	23	22	20	17	13	10
			H12	≥1.3 ≤25	3	29	29	29	27	25	21	17
			H14	≥1.3 ≤12	3	35	34	34	33	29	22	17
			H112	≥6 ≤12	3	29	29	29	27	25	21	17
				>12 ≤50	3	26	26	25	21	17	13	10
				>50 ≤75	3	25	25	24	21	17	13	10
	5052 (5052)	Al-2.5Mg	O	≥1.3 ≤75	—	43	43	43	42	38	29	17
			H32	≥1.3 ≤50	3	53	53	53	51	41	29	17
			H34	≥1.3 ≤25	3	59	59	59	57	41	29	17
			H112	≥6 ≤12	3	48	48	48	48	41	29	17
				>12 ≤75	3	43	43	43	42	41	29	17
	5083 (5083)	Al-4.5Mg 0.75Mn	O	≥1.3 ≤40	—	69						
				>40 ≤75	3	67						
			H112	≥6 ≤40	3	69						
				>40 ≤75	3	67						
			H321	≥5 ≤40	3	76	} to 65°C max.					
				>40 ≤75	3	71						
			H323	≥1.3 ≤6	3	77						
			H343	≥1.3 ≤6	3	86						

NOTES: See end of this Table 3.3.1(E).

(*continued*)

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6)						
						Temperature, °C						
						50	75	100	125	150	175	200
AS 1734	5086 (5086)	Al-4Mg-0.5Mn	O H32 H34 H112 H116	≥1.3 ≤50 ≥1.3 ≤50 ≥1.3 ≤25 ≥4.8 ≤6 >6 ≤50 >50 ≤75 ≥1.3 ≤50	— 3 3 3 3 — 3, 12	60 69 76 62 60 59 70	} to 65°C max.					
	5154A (5154)	Al-3.5Mg	O H32 H34 H112	≥1.3 ≤75 ≥1.3 ≤50 ≥1.3 ≤25 ≥6 <12 ≥12 ≤75	12 3, 12 3, 12 3, 12 3, 12	51 63 68 56 51	} to 65°C max.					
	5251 (5254)	Al-2Mg	O H32 H34	≥0.8 ≤75 ≥1.3 ≤50 ≥1.3 ≤25	— 3 3	42 50 58	42 50 58	41 49 57	40 43 52	36 37 47	31 31 42	25 25 27
	6061 (6061)	Al-Mg-Si-Cu-Cr	T4 T4 welded T6 T6 welded T451 T451 welded T651 T651 welded	≥1.3 ≤6 ≥1.3 ≤6 ≥1.3 ≤6 ≥1.3 ≤6 ≥6 ≤75 ≥6 ≤75 ≥6 ≤100 >100 ≤150 ≥6 ≤150	3, 7 5 3, 7 5 4, 7 5, 7 4, 7 4, 7 5, 7	52 41 72 41 52 42 73 63 42	52 41 72 41 52 42 73 63 42	52 41 71 41 52 42 72 62 42	50 40 67 40 51 41 68 59 41	47 38 58 38 48 38 58 51 38	44 32 45 32 44 32 45 40 32	30 25 30 25 33 26 33 30 26

NOTES: See end of this Table 3.3.1(E).

(*continued*)

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6) Temperature, °C						
						50	75	100	125	150	175	200
AS 1734	Alclad 6061 (Alclad 6061)	Al-Al-Mg-Si-Cu-Cr	T4	≥1.3 <6	4, 7, 8	47	47	47	46	43	40	30
			T4 welded	≥1.3 <6	5, 7	42	42	42	41	38	32	26
			T6	≥1.3 <6	4, 7, 8	66	66	65	61	52	41	30
			T6 welded	≥1.3 <6	5, 7, 9	42	42	42	41	38	32	26
			T451	≥6 ≤75	4, 7, 9	47	47	47	46	43	40	30
			T451 welded	≥6 ≤75	7	42	42	42	41	38	32	26
			T651	≥6 ≤100	4, 7, 9	66	66	65	61	52	41	30
				>100 ≤150	4, 7, 9	63	63	62	59	51	40	30
			T651 welded	≥6 ≤150	7	42	42	42	41	38	32	26
PIPES AND TUBES												
ASTM B 210	3003	Al-1.25Mn	O	≥0.3 ≤12.7	—	23	23	22	20	17	13	10
			H12	≥0.3 ≤12.7	3	29	29	29	27	25	21	17
			H14	≥0.3 ≤12.7	3	34	34	34	33	29	22	17
			H18	≥0.3 ≤12.7	3	46	46	45	43	36	24	18
			H112	≥0.3 ≤12.7	3	23	23	22	20	17	13	10
			H113	≥0.3 ≤12.7	3	24	24	23	20	17	13	10
	Alclad 3003	Al-Al-1.25Mn	O	≥0.3 ≤12.7	6	21	21	20	18	15	11	8
			H14	≥0.3 ≤12.7	3, 8	31	31	30	29	26	19	15
			H18	≥0.3 ≤12.7	3, 8	42	42	40	38	33	21	16
			H112	≥0.3 ≤12.7	3, 8	21	21	20	18	15	11	8
			H113	≥0.3 ≤12.7	3, 8	21	21	20	18	15	11	9
	5052	Al-2.5Mg	O	≥0.5 ≤11.4	—	43	43	43	42	38	29	17
			H32	≥0.5 ≤11.4	3	53	53	53	51	41	29	17
			H34	≥0.5 ≤11.4	3	59	59	59	57	41	29	17
	5154	Al-3.5Mg	O	≥0.46 ≤11.4	12	52	52	52	51	44		
			H34	≥0.46 ≤11.4	3, 12	68	68	68	63	45		

NOTES: See end of this Table 3.3.1(E).

(*continued*)

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6)						
						Temperature, °C						
						50	75	100	125	150	175	200
ASTM B 210 (*continued*)	6061	Al-4.5Mg-Cu-Cr	T4 T6 T4 welded T6 welded	≥0.6 ≤12.7 ≥0.6 ≤12.7 ≥0.6 ≤12.7 ≥0.6 ≤12.7	3 3 — —	52 72 41 41	52 72 41 41	52 71 41 41	50 67 40 40	47 58 38 38	44 45 32 32	31 31 25 25
	6063	Al-Mg-Si	T6 T6 welded	≥0.6 ≤12.7 ≥0.6 ≤12.7	3 —	56 29	56 29	53 29	50 28	37 27	24 21	14 14
ASTM B 234	3003	Al-1.25Mn	H14 H25	≥0.3 ≤5 ≥0.3 ≤5	4 4	35 38	35 38	35 38	34 36	30 30	21 21	17 17
	Alclad 3003	Al- Al-1.25Mn	H14 H25	≥0.3 ≤5 ≥0.3 ≤5	4 8	31 35	31 35	31 34	30 32	27 27	19 19	15 15
	5052	Al-2.5Mg	H32 H34	≥0.3 ≤5 ≥0.3 ≤5	4 4	54 59	54 59	54 59	51 57	43 43	29 29	19 19
	5454	—	H32 H34	≥0.3 ≤6 ≥0.3 ≤6	4 4	63 68	63 68	60 64	50 50	38 38	29 29	22 22
	6061	Al-4.5Mg-Cu-Cr	T4 T6 T4 welded T6 welded	≥0.6 ≤6 ≥0.6 ≤6 ≥0.6 ≤6 ≥0.6 ≤6	4 4 5 5	52 73 42 42	52 73 42 42	52 72 42 42	51 68 41 41	48 58 38 38	44 45 32 32	33 33 26 26
ASTM B 241	1100	99 Al	O H112	— —	— 3	14 14	14 14	14 14	14 14	12 12	10 10	7 7
	3003	Al-1.25Mn	O H18 H112	— <25 —	— 4 3	24 47 24	24 47 24	23 46 23	20 43 20	17 37 17	13 25 13	10 19 10
	Alclad 3003	Al- Al-1.25Mn	O H112	— —	8 3, 8	21 21	21 21	20 20	18 18	15 15	11 11	9 9
	5052	Al-2.5Mg	O	—	—	44	44	44	43	39	29	18

NOTES: See end of this Table 3.3.1(E). (*continued*)

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6)						
						Temperature, °C						
						50	75	100	125	150	175	200
ASTM B 241 (*continued*)	5083	Al -4.5Mg-0.75Mn	O	≤125	12	68	to 65°C max.					
			H111	≤125	3, 12	70						
			H112	≤125	3, 12	68						
	5086	Al -4Mg-0.5Mn	O	≤125	12	61	to 65°C max.					
			H111	≤125	3, 12	63						
			H112	≤125	—	61						
	5454	—	O	≤125	—	54	54	54	50	38	29	22
			H111	≤125	3	58	58	57	50	38	29	22
			H112	≤125	3	54	54	54	50	38	29	22
	6061	Al-4.5Mg-Cu-Cr	T4	—	4, 7	45	45	45	44	42	41	33
			T6	—	4, 7	66	66	66	62	55	45	33
			T4 welded	—	5, 7	42	42	42	41	38	32	26
			T4 welded	—	5	42	42	42	41	38	32	26
	6063	Al-Mg-Si	T1	≤12.7	2, 9	29	29	29	29	29	24	16
				>12.7 ≤25	2, 8	28	28	28	28	28	24	16
			T5	≤12.7	4	38	38	37	35	32	24	16
				>12.7 ≤25	4	37	36	35	34	30	24	16
			T6	≤25	4	52	52	51	46	34	24	16
			T5 welded	≤25	5	30	30	30	29	27	21	15
			T6 welded	≤25	5	30	30	30	29	27	21	15
FORGINGS												
ASTM B 247	2014 Die	Al-Cu-Mn-Si-Mg	T4	≤102	4	95	94	90	85	78	49	30
			T6	≤51	4	110	110	108	99	78	49	30
				>51 ≤102	4	109	109	107	99	78	49	30
	3003 Die	Al-1.25Mn	H112	≤102	—	24	24	23	20	16	13	10
			H112 welded	≤102	—	24	24	23	20	16	13	10

NOTES: See end of this Table 3.3.1(E).

(*continued*)

TABLE 3.3.1(E) (*continued*)

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6)						
						Temperature, °C						
						50	75	100	125	150	175	200
ASTM B 247 (*continued*)	5083	Al-4.5Mg-0.75Mn	H111 H112 H111 welded H112 welded	≤102 ≤102 ≤102 ≤102 ≤102	4 — 4 5, 12 5, 12	68 66 68 66 66	} to 65°C max.					
	6061 Die	Al-Mg-Si-Cu-Cr	T6	≤102	4	66	66	65	62	54	45	33
	6061 Hand	Al-Mg-Si-Cu-Cr	T6	≤102 >102 ≤204	— —	64 61	64 61	63 60	60 57	53 51	44 43	33 33
	6061		T6 welded	≤204	—	42	42	41	40	38	32	25
ROD, BAR AND SHAPES												
ASTM B 211	2024	—	T4	≥3 ≤163 >163 ≤200	4 4	108 101	108 101	105 98	92 86	71 67	47 44	34 31
	6061	Al-Mg-Si-Cu-Cr	T6 T651 T6 welded T651 welded	≥3 ≤200 ≥3 ≤200 ≥3 ≤200 ≥3 ≤200	4, 7 4, 7 5, 7, 11 5, 7, 11	73 73 42 42	73 73 42 42	72 72 42 42	68 68 41 41	58 58 38 38	45 45 32 32	33 33 26 26
ASTM B 221	1100	99 Al	O H112	— —	— 3	14 14	14 14	14 14	14 14	12 12	10 10	7 7
	2024	—	T3	<6 ≥6 <20 ≥20 <40 ≥40	4, 7 4, 7 4, 7 4, 7	100 105 114 118	100 105 114 118	97 102 110 115	85 89 96 101	65 69 74 78	43 45 49 51	31 33 35 37
	3003	Al-1.25Mn	O H112	— —	11 3, 11	24 24	24 24	23 23	20 20	17 17	13 13	10 10
	5083	Al-4.5Mg-0.75Mn	O H111 H112	≤125 ≤125 ≤125	11, 12 3, 12 3, 11, 12	68 70 68	} to 65°C max.					

NOTES: See end of this Table 3.3.1(E).

(*continued*)

TABLE 3.3.1(E) (*continued*)

A2

Specification	Grade (Note 13)	Type	Temper	Thickness, mm or test bar type	Notes	Design tensile strength, MPa (Notes 1, 2, 6) Temperature, °C 50	75	100	125	150	175	200
ASTM B 221 (*continued*)	5086	Al-4Mg-0.5Mn	O	≤125	4, 11, 12	61	} to 65°C max.					
	5154A	—	O	—	12	52	52	52	51	46		
			H112	—	3, 11, 12	52	52	52	51	46		
	5454	—	O	≤125	11	54	54	53	50	38	29	22
			H111	≤125	3	58	58	56	50	38	29	22
			H112	≤125	3, 11	54	54	53	50	38	29	22
	6061	Al-Mg-Si-Cu-Cr	T4	—	4, 7	45	45	45	44	42	41	32
			T6	—	4, 7	66	66	66	62	55	45	33
			T4 welded	—	5, 7	42	42	42	41	38	32	26
			T6 welded	—	5, 7 11	42	42	42	41	38	32	26
	6063	Al-Mg-Si	T1	≤12	4	29	29	29	29	29	24	16
				≥12 ≤25	4	28	28	28	28	28	24	16
			T5	≤12	4	38	38	38	37	32	24	16
				≥12 ≤25	4	37	36	35	34	30	24	16
			T6	≤25	4	52	52	50	45	34	24	16
			T5 welded	≤25	5	29	29	29	29	27	21	15
			T6 welded	≤25	11	29	29	29	29	27	21	15
ASTM B 308	6061	Al-Mg-Si-Cu-Cr	T6	—	4	65	64	62	58	50	40	30
			T6 welded	—	5, 11	42	41	39	37	35	30	23
CASTINGS												
AS 1874	BB401 CC401 EA401	Al-12Si	F1	Sand cast	4, 6	27	23	22	21	19	17	15
				Permanent mould	4, 6	31	26	25	24	21	19	18
	AA601 AC601	Al-7Si 0.35Mg	T6	Sand cast	4, 6	52	52	52	43	—	—	—

NOTES:

1 Design strengths at intermediate temperatures may be obtained by linear interpolation.

2 For minimum temperatures, see Clause 3.3.2.

3 Welded construction design strength values for 'O' temper or 'welded' are to be used.

4 Design strength values given are not applicable where welding or thermal cutting is used.

5 Transverse tensile specimen is required to qualify welding procedure.

6 Joint efficiencies and casting factors are to be applied where applicable (see Clause 3.3.1).

7 For stress relieved tempers (T351/etc) design strength for materials in the basic temper shall be used.

8 Design strengths are 90 percent of those for corresponding core material.

9 The tension test specimen from plate 12.5 mm and thicker is machined from the core and does not include the cladding alloy; therefore the allowable stress values for thicknesses less than 12.5 mm shall be used.

10 The tension test specimen from plate 12.5 mm and thicker is machined from the core and does not include the cladding alloys; therefore the allowable stress values shown are 90% of those for the core materials of the same thickness.

11 Material in the form of barstock is permitted only for stiffening rings subject to external pressure.

12 An assessment for resistance to stress corrosion cracking in the operating environment is recommended. The material supplier should be consulted where relevant. Also refer ANSI/ASME BPV-VIII-1 Part UNF, NF-13(b).

13 Approximate grades in the ASTM Standards are shown in brackets. Unified numbering system alloy designations are those listed but prefixed by A9.

TABLE 3.3.1(F)

DESIGN TENSILE STRENGTH (MPa)
(F) NICKEL AND HIGH NICKEL ALLOYS

ASTM Spec No.	Type/ Grade/ UNS No.	Nominal composition	Condition	Size mm	Notes	Design tensile strength, MPa (Note 6) Temperature, °C																									
						40	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Plate, sheet & strip																															
B 127	N04400	67Ni-30Cu	Annealed	—	—	128	112	106	102	101	101	101	101	101	100	99	80	60	—	—	—	—	—	—	—	—	—	—	—	—	—
			Hot rolled	—	—	129	129	129	129	129	129	129	128	124	118	100	63	34	—	—	—	—	—	—	—	—	—	—	—	—	—
B 162	N02200	Ni	Annealed	—	—	69	69	69	69	69	69	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Hot rolled	—	4	92	92	92	92	87	81	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N02201	Ni Low C	Hot rolled Annealed	—	—	55	53	52	52	52	52	52	52	51	50	50	42	33	27	23	19	16	13	10	8	—	—	—	—	—	—
B 168	N06600	72Ni-15Cr-8Fe	Annealed	—	—	138	138	138	138	138	138	138	136	135	134	132	130	118	87	58	40	27	19	15	14	—	—	—	—	—	—
			Annealed	—	1	138	138	138	138	138	138	138	138	138	138	138	138	120	86	58	40	27	19	15	14	—	—	—	—	—	—
			Hot rolled	—	4	146	146	146	146	146	146	146	146	146	145	141	140	136	136	117	86	63	46	39	38	—	—	—	—	—	—
			Hot rolled	—	1, 4	146	146	146	146	146	146	146	146	146	146	146	146	146	146	123	84	63	46	39	38	—	—	—	—	—	—
B 333	N10665	65Ni-28Mo-2Fe	Annealed		—	199	199	199	193	183	179	176	174	172	170	169	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Annealed		1	199	199	199	199	199	199	199	199	199	199	198	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B 409	N08800	33Ni-42Fe-21Cr	Annealed	—	—	129	129	123	119	116	113	112	111	109	108	107	106	105	103	102	101	98	85	64	45	30	16	11	9	7	7
			Annealed	—	1	129	129	129	129	129	129	129	128	128	128	128	126	126	124	122	122	109	84	65	45	30	16	11	9	7	7
B 424	N08825	42Ni-21.5Cr-5Mo-2.3Cr	Annealed	—	—	146	146	141	133	127	124	122	121	119	119	118	117	116	115	115	—	—	—	—	—	—	—	—	—	—	—
				—	1	146	146	146	146	146	146	146	145	145	144	144	142	142	140	137	—	—	—	—	—	—	—	—	—	—	—
B 443	N06625	60Ni-22Cr-9Mo-3.5Cb	Gr 1 Ann.	—	—	192	192	192	187	183	178	177	175	174	173	172	170	168	167	165	164	159	139	88	—	—	—	—	—	—	—
B 575	N10276	54Ni-16Mo-15Cr	Annealed		—	174	173	160	149	141	133	130	127	124	121	119	117	116	115	115	115	111	100	83	68	55	—	—	—	—	—
			Sol. ann.		1	174	174	174	170	167	165	163	162	161	160	159	158	156	155	150	139	121	100	83	68	55	—	—	—	—	—
	N06022	55Ni-21Cr-13.5Mo	Sol. ann.	—	—	167	174	171	159	150	103	139	136	134	132	130	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
				—	1	174	174	173	167	163	159	158	157	156	155	155	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B 625	N08904	44Fe-25Ni-21Cr-Mo	Annealed	—	—	123	114	104	96	89	84	82	80	78	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N08925	25Ni-20Cr-6Mo-Cu-N	Annealed	—	—	152	151	146	138	129	123	120	118	118	118	118	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Annealed	—	1	152	151	146	141	136	132	130	128	127	125	122	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B 709	N08028	31Ni-21Fe-29Cr-Mo	Annealed	—	—	126	125	111	106	95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

NOTES: See end of this Table 3.3.1(F).

(continued)

TABLE 3.3.1(F) (*continued*)

ASTM Spec No.	Type/ Grade/ UNS No.	Nominal composition	Condition	Size mm	Notes	Design tensile strength, MPa (Note 6) Temperature, °C																									
						40	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Pipe and tube																															
For design values, use values determined from Appendix A, or the values in AS 4041 but not exceeding $\frac{R_m}{4}$																															
Bars, rods																															
B 160	N02200	Ni	Annealed	All	—	69	69	69	69	69	69	69	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Hot rolled	All	—	69	69	69	69	66	60	56	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N02201	Ni-Low C	Hot rolled Annealed	All	—	46	44	43	43	43	43	43	43	43	41	41	40	35	28	23	19	15	13	10	8	—	—	—	—	—	—
B 164	N04400	67Ni-30Cu	Hot fin.	All except hex >54	—	138	138	138	138	138	138	138	137	131	127	102	66	35	—	—	—	—	—	—	—	—	—	—	—	—	—
				Hex >54	—	129	129	129	124	123	121	119	117	117	115	101	67	35	—	—	—	—	—	—	—	—	—	—	—	—	—
			Stress rel.	& ≥101.6	—	138	138	138	138	138	138	138	137	131	120	101	67	35	—	—	—	—	—	—	—	—	—	—	—	—	—
			Stress rel.	rnd >304	—	129	129	129	129	129	129	129	128	123	118	101	67	35	—	—	—	—	—	—	—	—	—	—	—	—	—
			Annealed	—	—	115	101	95	92	91	91	91	91	91	91	89	79	61	—	—	—	—	—	—	—	—	—	—	—	—	—
B 166	N06600	Ni-Cr-Fe	Annealed	All	—	138	138	138	138	138	138	137	136	135	133	132	129	117	89	58	40	27	19	15	14	—	—	—	—	—	—
			Annealed	All	1	138	138	138	138	138	138	138	138	138	138	138	138	120	88	58	40	27	19	15	14	—	—	—	—	—	—
			Hot fin.	All	—	146	146	146	146	146	146	146	146	145	144	141	139	136	133	119	87	63	46	39	38	—	—	—	—	—	—
			Hot fin.	All	1	146	146	146	146	146	146	146	146	146	146	146	146	146	146	127	85	63	46	39	38	—	—	—	—	—	—
B 408	N08800	33Ni-42Fe-21Cr	Annealed	All	—	129	128	123	119	115	113	112	111	109	108	107	106	104	103	102	101	97	85	65	45	30	16	11	9	7	6
			Annealed	All	1	129	129	129	129	129	129	129	128	128	127	127	126	125	124	122	120	110	84	65	45	30	16	11	9	7	6
B 425	N08825	42Ni-21.5Cr-5Mo-2.3Cu	Annealed	All	—	146	146	140	133	127	123	122	121	119	118	118	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Annealed	All	1	146	146	146	146	146	146	146	145	144	144	143	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B 446	N06625	60Ni-22Cr-9Mo-3.5Cb	Gr 1 Ann.	≤ 102	7, 8	192	192	192	187	183	178	177	175	174	173	172	170	168	167	166	165	164	159	139	88	—	—	—	—	—	—
			Gr 2 Ann.	> 102	8	192	192	192	187	183	178	177	175	174	173	172	170	168	167	166	165	164	159	139	88	—	—	—	—	—	—
B 574	N06022	55Ni-21Cr-13.5Mo	Sol. ann.	—	—	174	174	171	159	150	142	139	136	134	132	130	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
				—	1	174	174	173	167	163	159	158	157	156	155	155	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N10276	54Ni-16Mo-15Cr	Annealed	—	—	174	173	160	149	141	133	130	127	124	121	119	117	116	115	115	115	111	100	83	68	55	—	—	—	—	—
			Sol. ann.	—	1	174	174	174	170	167	165	163	162	161	160	159	158	156	155	153	142	121	100	83	68	55	—	—	—	—	—
B 649	N08904	44Fe-25Ni-21Cr-Mo	Annealed	All	—	123	114	104	96	89	84	82	80	78	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N08925	25Ni-20Cr-6Mo-Cu-N	Annealed	—	—	151	151	145	137	129	123	120	118	118	118	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Annealed	—	1	151	151	146	141	136	132	130	128	127	125	122	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

NOTES: See end of this Table 3.3.1(F).

(*continued*)

TABLE 3.3.1(F) (*continued*)

ASTM Spec No.	Type/ Grade/ UNS No.	Nominal composition	Condition	Size mm	Notes	Design tensile strength, MPa (Note 6) Temperature, °C 40	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Forgings																															
B 564	N04400	67Ni-30Cu	Annealed	—	—	115	101	95	92	91	91	91	91	91	91	89	79	61	—	—	—	—	—	—	—	—	—	—	—	—	—
	N06600	72Ni-15Cr-8Fe	Annealed	—	—	139	139	139	139	139	139	139	138	136	135	133	131	116	87	60	41	28	20	15	13	—	—	—	—	—	—
	N06625	60Ni-22Cr-9Mo-3.5Cb	Gr 1 Ann. Gr 2 Ann.	≤ 102 > 102	7, 8 8	192 192	192 192	192 192	187 187	183 183	178 178	177 177	175 175	174 174	173 173	172 172	170 170	168 168	167 167	166 166	165 165	164 164	159 159	139 139	88 88	— —	— —	— —	— —	— —	— —
	N08800	33Ni-42Fe-21Cr	Annealed Annealed	— —	— 1	130 130	130 130	125 130	120 130	117 130	114 130	113 130	112 130	111 130	109 129	108 129	107 128	106 127	104 126	103 124	102 121	98 109	85 85	65 65	45 45	30 30	16 16	12 12	9 9	7 7	6 6

NOTES

1 Due to the relatively low yield strength of these materials, these higher design strength values were established at temperatures where the short time tensile properties govern to permit the used of these alloys where slightly greater deformation is acceptable. These higher design strength values exceed 62.5 percent but do not exceed 90 percent of the yield strength at temperature. Use of these design strengths may result in dimensional changes due to permanent strain. These design strength values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

2 —

3 —

4 For plate only.

5 —

6 The design strength values in this Table may be interpolated to determine values for intermediate temperatures.

7 The minimum tensile strength of reduced tension specimens shall not be less than 767 MPa.

8 Alloy N06625 in the annealed condition is subject to severe loss of impact strength at room temperatures after exposure in the range of 538°C to 760°C.

TABLE 3.3.1(G)

DESIGN TENSILE STRENGTH (MPa)
(G) TITANIUM AND TITANIUM ALLOYS

ASTM Material specification	Nominal composition	Condition	Alloy designation UNS No.	Design tensile strength, MPa (See Note)					
				Temperature, °C					
				40	100	150	200	250	300
Plate, sheet and strip									
B 265	Ti	Grade 1 As manufactured	R50250	61	49	40	34	29	23
		Grade 2 Annealed	R50400	86	73	62	54	47	41
		Grade 7 As manufactured	R52400	86	73	62	54	47	41
		Grade 12 Annealed	R53400	122	112	99	88	81	76
Pipe and tube									
For design values use the values determined from Appendix A, or the values in AS 4041 but not exceeding $R_m/4$									
Forgings									
B 381	Ti	Grade F2 Annealed	R50400	86	73	62	54	47	41
		Grade F7 Annealed	R52400	86	73	62	54	47	41
Bar and billet									
B 348	Ti	Grade 2 Annealed	R50400	86	73	62	54	47	41
		Grade 7 Annealed	R52400	86	73	62	54	47	41

NOTE: Design strengths at intermediate temperatures may be obtained by linear interpolation.

TABLE 3.3.1(H)

DESIGN TENSILE STRENGTH (MPa)
(H) ZIRCONIUM AND ZIRCONIUM ALLOYS

ASTM Material specification	Type or nominal composition	Condition	Alloy designation UNS No.	Notes	Design tensile strength, MPa (Note 1)								
					Temperature, °C								
					40	100	150	200	250	300	325	350	370
Plate, sheet and strip													
B 551	99-2Zr	Annealed	R60702	—	90	75	65	49	44	42	40	37	33
Pipe and tube													
B 523	99-2Zr	Annealed	R60702	—	90	75	65	49	44	42	40	37	33
		Annealed	R60702	2, 3	77	64	55	42	37	36	34	31	—
B 658	99-2Zr	Annealed	R60702	—	90	75	65	49	44	42	40	37	33
Bar													
B 550	99-2Zr	Annealed	R60702	—	90	75	65	49	44	42	40	37	33

NOTES:

1 Design strength at intermediate temperatures may be obtained by linear interpolation

2 A factor of 0.85 has been applied in arriving at the design tensile strength values in tension for this material. Divide tabulated values by 0.85 for design tensile strength in longitudinal direction.

3 Filler metal shall not be used in the manufacture of welded pipe or tube.

TABLE 3.3.7
YOUNG MODULUS (MODULUS OF ELASTICITY) (*E*)

Material		Young modulus, GPa														
		Temperature, °C														
Type or grade	**Nominal composition**	**−200**	**−150**	**−100**	**−50**	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
Carbon and low alloy steels	C ≤ .3%C	217	213	210	207	204	201	198	195	192	189	186	179	171	162	150
	C > .3%C	215	212	209	206	203	200	197	194	191	187	184	178	170	161	149
	C-.5Mo, Mn-.5Mo, Mn-.25Mo, Mn-V	215	211	208	205	202	199	196	193	190	187	184	178	170	160	150
	.5Ni-.5Mo-V, .5Ni-.5Cr-.25Mo-V, .75Ni-.5Mo-Cr-V, .75Ni-1Mo-.75Cr, .75Ni-.5Cu-Mo, 1Ni-.4Cr-.5Mo, .75Cr-.5Ni-Cu, .75Cr-.75Ni-Cu-Al, 2Ni-1Cu, 2.5Ni, 3.5Ni.	204	201	198	196	193	190	187	184	181	178	175	171	167	163	159
	.5Cr-.5Mo, 1Cr-.5Mo, 1.25Cr-.5Mo(+Si), 2Cr-.5Mo	218	215	212	210	207	204	200	196	193	190	187	183	179	174	170
	2.25Cr-1Mo, 3Cr-1Mo	225	222	218	215	212	209	206	203	199	196	192	188	184	179	175
	5Cr-.5Mo(+Si, +Ti), 7Cr-.5Mo, 9Cr-Mo	—	—	—	219	215	211	207	204	201	198	194	190	190	176	168
Stainless steels																
405, 410, 429, 430	12Cr-Al, 13Cr, 15Cr, 17Cr	215	213	210	206	202	199	196	192	189	185	181	178	174	166	156
304 316, 317 321 347 and 348 309, 310	18Cr-8Ni 16Cr-12Ni-2Mo, 18Cr-13Ni-3Mo 18Cr-10Ni-Ti 18Cr-10Ni-Nb 23Cr-12Ni, 25Cr-12Ni,25Cr-20Ni	209	206	203	200	197	194	190	186	183	179	175	172	169	164	161
S31803, 2304	22Cr-.5Ni-.3Mo, 23Cr-4Ni	—	—	—	205	200	195	190	185	180	175	170	165	160	—	—
N08904	25Ni-20Cr-4.5Mo-1.5Cu	—	—	—	200	196	193	189	185	181	167	172	168	165	—	—
N08028	31Ni-27Cr-3.5Mo-1.0Cu	—	—	—	204	201	198	195	192	189	185	180	175	170	—	—
Aluminium alloys																
3003, 3004, 6061, 6063		77	75	73	72	70	68	66	63	60	—	—	—	—	—	—
5052, 5054		78	76	75	73	71	69	67	65	62	—	—	—	—	—	—
5083, 5086		79	77	76	74	72	70	68	65	62	—	—	—	—	—	—

(*continued*)

TABLE 3.3.7 (*continued*)

Material		Young modulus, GPa														
		Temperature, °C														
Type or grade	**Nominal composition**	**−200**	**−150**	**−100**	**−50**	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
Copper and copper alloys																
C21000	Copper >95%	124	123	121	117	114	111	108	105	102	99	95	92	89	86	83
C22000, C24000	Brasses: 10 and 20Zn	124	123	121	120	118	116	114	111	109	106	103	101	98	97	94
C26000, C28000	30 and 40Zn	110	108	107	106	104	101	99	97	95	93	91	89	86	83	80
C70610	Cu-Ni: 10Ni	131	130	128	126	125	123	121	119	116	112	110	107	104	101	98
C71630	20 and 30Ni	161	159	157	152	148	144	140	137	133	129	124	120	116	112	108
C64250	Bronze	116	114	112	110	107	104	102	99	96	93	89	86	84	81	78
Nickel and nickel alloys																
200, 201	Ni and Low C Ni	222	218	215	211	208	205	202	199	197	194	192	189	186	182	179
330	Ni-44Fe-18Cr-1Si	207	204	201	197	194	191	188	185	183	181	179	177	174	170	167
400 and 405	Ni-32Cu	192	189	186	184	181	178	175	173	171	168	166	164	161	158	155
600	Ni-15.5Cr-8Fe	229	226	222	219	215	211	208	206	204	201	199	196	192	189	185
800 and 800H	Ni-46Fe-21Cr	210	207	204	200	197	194	191	189	187	185	183	180	177	174	170
825	Ni-30Fe-21Cr-3Mo-2Cu	207	204	201	197	194	191	188	185	183	181	179	177	174	170	167
B	Ni-28Mo-5Fe	230	226	223	219	215	212	209	206	204	201	199	197	193	189	185
C-4	Ni-16Cr-16Mo	220	217	214	209	206	203	200	197	195	193	191	188	185	181	177
C276	Ni-15.5Cr-16Mo-5.5Fe-4W	220	217	214	209	206	203	200	197	195	193	191	188	185	181	177
Titanium and titanium alloys																
1, 2, 3 and 7		—	—	—	110	108	106	103	100	97	93	88	84	80	—	—
Zirconium and zirconium alloy 702	Zr	—	—	—	101	100	98	95	92	86	80	74	68	—	—	—
705 and 706	Zr-2.5Nb	—	—	—	103	102	100	93	86	80	75	71	67	—	—	—

NOTES:

1 These values are recommended for calculation purposes. It is not implied that materials are suitable for all temperatures shown.

2 Data based on ASME Sect V111.1, with additions from the ASM Metals Handbook.

3 Values at intermediate temperatures may be obtained by linear interpolation.

4 Values at temperatures beyond those listed are to be used by agreement between parties concerned.

3.4 THICKNESS OF VESSEL WALL

3.4.1 Minimum calculated thickness The thickness obtained by the Clauses in this Section is that required to withstand the calculation pressure and where necessary shall be varied in accordance with Clause 3.4.2 and with provision made for any other design loadings given in Clause 3.2.3.

The dimensional symbols used in all design equations in this Section 3 represents dimensions in the corroded condition unless noted.

The nominal thickness so determined shall indicate the minimum class of construction required in accordance with Table 1.7; however, a higher class of construction may be used and appropriate credit taken. (See Clause 1.7 for other factors which require a higher vessel class.)

3.4.2 Thickness allowances The actual thickness at any part of the completed vessel shall be no less than the minimum calculated thickness increased by the following allowances:

(a) Additional thickness for corrosion (see Clause 3.2.4).

(b) Additional thickness over that for pressure and corrosion considerations, sufficient to give necessary rigidity to permit handling and transport of the vessel and to maintain A2 its shape at atmospheric or reduced pressure (see Clause 3.2.3).

NOTE: The minimum calculated thickness plus allowances (Items (a) and (b)) is referred to as the design thickness, which shall be not less than that required by Table 3.4.3.

When ordering material for fabrication of the vessel further allowances shall be made to the design thickness to provide for the following:

(i) Except for plate material, additional thickness to allow for mill under tolerance on the material (see appropriate material specification).

(ii) For plate material, a thickness allowance to cater for mill under-tolerance on the material (see appropriate material specification). The ordered thickness minus the maximum specified mill under-tolerance shall be at least the greater of—

(A) 0.94 of the design thickness (see Note above); and

A2 (B) the design thickness minus 0.3 mm.

(iii) Additional thickness to allow for reduction in thickness during fabrication operations, such as forming, machining and dressing of welds.

Vessels made of plate complying with these provisions may be used at the design pressure appropriate to the above design thickness.

3.4.3 Minimum nominal thickness of pressure parts Notwithstanding the requirements of Clauses 3.4.1 and 3.4.2, the minimum nominal thickness of a pressure part shall comply with Table 3.4.3.

TABLE 3.4.3

MINIMUM NOMINAL THICKNESS OF ANY PRESSURE PART

Vessels constructed of metal	Outside diameter of vessel part (D_o)	Minimum nominal thickness for type of manufacture (see Notes 1 and 2)		
		Forged; metal and submerged-arc welded; GMAW welded	Brazed; GTAW welded; and heat exchanger tubes	Cast
	mm	mm	mm	mm
All except as noted below (see Note 3)	≤225 >225 ≤1000 >1000	2.0 2.3 2.4	$0.10\sqrt{D_o}$ 1.5 2.4	4 8 10
Lethal contents	Twice the above values			
Transportable vessels	See Clause 3.26			
Vessel branches	See Clause 3.19.10.2			

NOTES:

1 Values are based primarily on limits of proven manufacture, assembly and ability to withstand handling, dispatch, installation and use.

2 Minimum thickness equals the total thickness for integrally clad vessels and the base thickness for applied linings.

3 Minimum thicknesses for group F and G steel parts are 5 and 6 mm respectively.

3.5 WELDED AND BRAZED JOINTS

3.5.1 Welded joints

3.5.1.1 *Types of welded joints* For the purposes of this Standard, welded joints are classified as one of the following, according to their position as indicated in Figure 3.5.1.1 for typical joint types:

(a) *Type A, longitudinal* These are longitudinal welded joints in main cylindrical shells, transitions in diameter, or in branches; or joints in positions requiring equivalent welds. This includes circumferential or any other welded joints within spherical shells, within formed or flat ends, or welds connecting spherical ends to main shells or within flat plates forming integral parts of pressure vessels.

(b) *Type B, circumferential* These are circumferential welded joints within main cylindrical shells, within transitions in diameter, or within branches; or circumferential welded joints connecting formed ends (other than spherical) or connecting transitions to main shells.

(c) *Type C, corner* These are peripheral welded joints with the weld located at a corner of a pressure-retaining part as in the joints connecting flanges, tube plates, or flat ends to main shells, to formed ends, to transitions in diameter, or to branches.

(d) *Type D, branch* These are welded joints connecting branches to main shells, to spheres, to transitions in diameter, or to ends.

In addition to the types of welded joints defined in AS 2812, butt joints are defined as—

(i) *double-welded butt joints*, i.e. butt joints welded from both sides; and

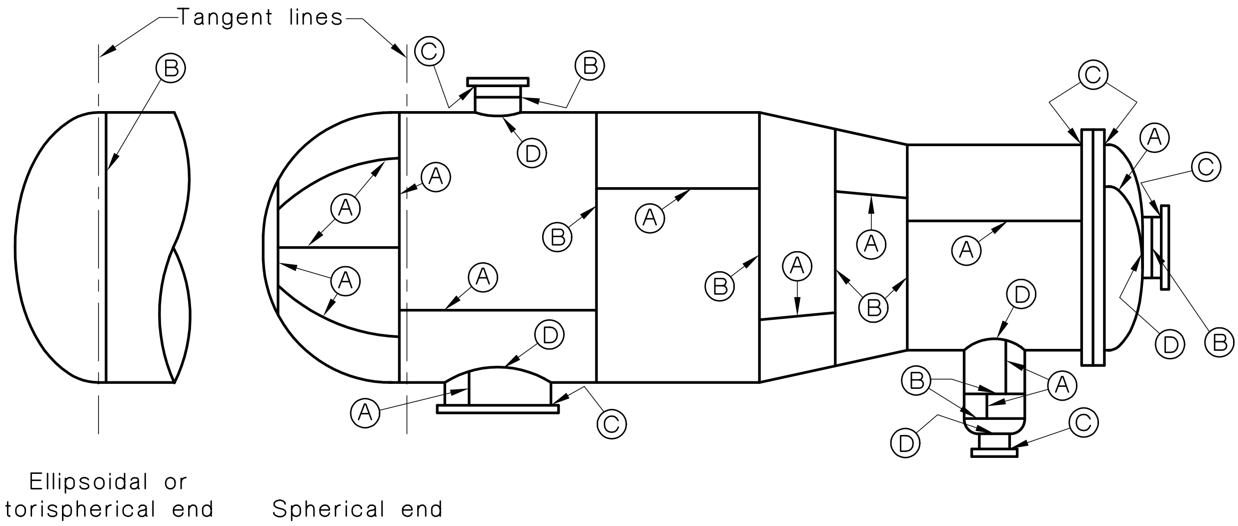
(ii) *single-welded butt joints*, i.e. butt joints welded from one side.

The following welded butt joints may be considered as double-welded butt joints:

(A) A single-welded butt joint where a backing strip is used and is subsequently removed and inspection shows complete penetration and fusion to the far side.

(B) A single-welded butt joint using a process and procedure so that subsequent inspection shows complete penetration and fusion to the far side, including welds using temporary backing bars.

(C) Electroslag, electrogas, flash butt, resistance, and similar welds.



NOTE: For explanation of points A to D, see Clause 3.5.1.1

FIGURE 3.5.1.1 WELDED JOINT TYPES—BASED ON LOCATION

3.5.1.2 *Number of joints* The number of welded joints in a vessel shall be the minimum practicable number.

3.5.1.3 *Location of joints* Welded joints should be located:

(a) To avoid disturbances to the flow of force or sudden changes in stiffness or areas of severe stress concentration particularly in vessels subject to fluctuating or impact loads. See also Clause 3.18.5.3 concerning openings.

(b) Clear of areas of severe corrosion;

(c) To avoid more than two welded joints meeting at a point;

(d) So that distance between the toes of attachment welds, the toes of large fillet welds of branches or nozzles or undressed main welds is not less than the smaller of 40 mm or three times the shell thickness.

(e) To provide reasonable access for welding equipment and welder and for visual, radiographic or ultrasonic examination of the root side of butt welds.

(f) So that the joint is readily visible in service (after removal of insulation, if necessary) and is clear of supports.

A3 AS 4458 specifies additional requirements for the location of welded joints which shall be complied with for compliance with this Standard (AS 1210).

3.5.1.4 *Design of welded joints*

3.5.1.4.1 *General* The types of welded joints shall be adequate to transfer all expected loads between parts joined.

Edge preparation of welds shall enable sound welds and complete fusion and penetration to be obtained consistently with the particular welding procedure.

3.5.1.4.2 *Butt welds* The throat thickness (excluding any weld reinforcement or weld metal extending outside the projection of the parent material) of longitudinal and circumferential type butt welds in shells, ends or branches, shall be at least equal to the thickness of the thinner of the parts joined.

3.5.1.4.3 *Fillet welds* Fillet welded circumferential type joints are not permitted, except as described in Figure 3.5.1.5(A) and Clause 3.5.1.7, where the dimensions shall develop the strength required for the appropriate joint efficiency (see Clause 3.5.1.7).

A3 The allowable load on fillet welds at branch connections shall be in accordance with Clause 3.19.3.5.

The allowable load on other fillet welds shall be based on the minimum throat area of the weld and using a design strength not more than 75 percent of the design strength, *f*, for the weaker material in the joint.

The minimum design throat area shall be taken as the design throat thickness allowing for the reduction in the throat thickness made necessary by any root gap, multiplied by the effective weld length which equals the length measured on the centreline of the throat. No fillet weld shall have an effective weld length less than 50 mm or six times the leg length, whichever is less.

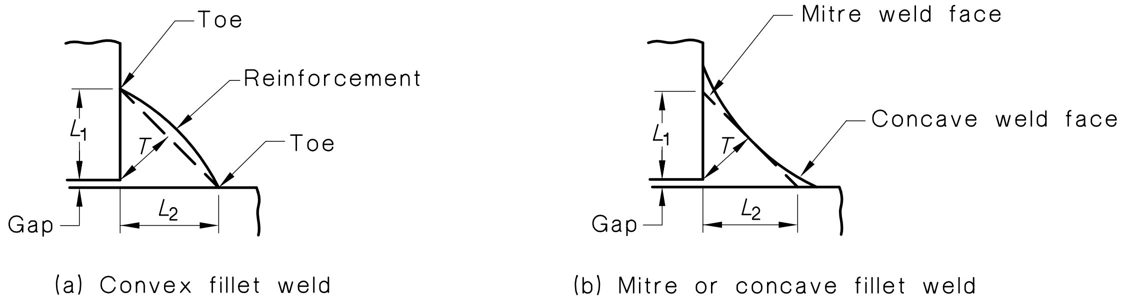
The shape of fillet welds shall be in accordance with Figure 3.5.1.4.

For fillet welds in corner or branch welded joints, and other joints subjected to bending stresses, see Clause 3.5.1.4.5.

The plates of fillet welded lap joints shall be lapped at least four times the thickness of the thinner plate, except for lap-welded dished ends (see Clause 3.12.6).

3.5.1.4.4 *Plugwelds and slotwelds* Plugwelds and slotwelds shall be used only where other methods of welding attachment are not possible to achieve the required joint efficiency of lap joints, and in reinforcements around openings and in non-pressure structural attachments. Except for stayed surfaces (see Clause 3.16), plugwelds or slotwelds shall not be considered to take more than 30 percent of the total load to be transmitted.

Where holes or slots in one or more of the parts forming the joint are manually welded, the hole or slot shall not be filled with weld metal, nor partially filled in such a manner as to form a direct weld metal connection between opposite sides of the hole. The diameter of the hole or width of the slot shall be no less than 2.5 times the thickness of the plate in which the hole is made. The ends of slots shall be semicircular or rounded with a radius no less than 1.25 times the plate thickness.



LEGEND:

L_1 = Effective leg length on vertical face
L_2 = Effective leg length on horizontal face
T = Design throat thickness ($0.71L_1$ for equal leg fillet)
Gap = 1.5 mm or $L_1/8$, whichever is less
Reinforcement: minimum = 0
Reinforcement: maximum = 1.5 mm + $L_1/8$, or 4mm, whichever is less

FIGURE 3.5.1.4 FILLET WELD SHAPE AND DIMENSIONS

Where automatic or semi-automatic processes are used for making plug welds, a hole smaller than required for manual welding may be adopted and the plug hole completely filled with weld metal, provided that the manufacturer proves by procedure tests that complete fusion and penetration can be obtained consistently and the quality of the welding complies with requirements of this Standard.

The distance from the edge of the plate or member and the edge of the hole or slot shall be no less than twice the thickness of the plate or member.

The strength of ligaments between plugwelds and slotwelds shall be no less than 50 percent of the solid plate. The strength of plugwelds and slotwelds shall be calculated in accordance with Clause 3.5.1.4.3.

3.5.1.4.5 *Welded joints subject to bending stresses* If welded joints are subjected to bending stresses then fillet welds shall be added where necessary to reduce stress concentration.

Corner or T-joints may be made with fillet welds only, provided that the plates forming the joint are properly supported independently of such welds; except where specific weld details are permitted in other Clauses of this Standard and AS 4458. However, independent supports are not required for joints such as lugs for platforms, ladders and other attachments.

3.5.1.4.6 *Welded joints with backing strip* For limitations see Table 3.5.1.7.

3.5.1.4.7 *Corner and branch welded joints* For design of these joints see Clauses 3.15 and 3.19, respectively.

3.5.1.4.8 *Stud welds* Stud welds shall not be used for connecting pressure-retaining parts.

3.5.1.5 *Acceptable joint preparation* Some acceptable types of joint preparation for joints within shells and ends are given in Figure 3.5.1.5(A) to (E), inclusive. For acceptable types of joints for attachments of flat ends, branches, and the like, see appropriate clauses for these components.

Where pressure welding processes are used, butt type joints only are permitted.

Where joint preparations other than shown in this Standard are required, these shall be
A3 proven by qualification of the welding procedure in accordance with AS/NZS 3992.

3.5.1.6 *Application of welded joints* The application of various types of welded joints longitudinal and circumferential type joints shall be in accordance with Table 3.5.1.7.

Butt-welded joints using backing strips retained in service or single-welded lap joints shall not be used where excessive corrosion or fatigue due to fluctuating or impact loads are likely to occur.

For Group G steels, welded joint Types A or B shall be double-welded butt joints or other butt joints with equivalent quality, and for joint Type C shall be full penetration welds extending through the entire section at the joint without retained backing strip.

For Group F steels, welded joint Types A, B and C shall be double-welded butt joints or other joints with equivalent quality except that for circumferential welds a single welded butt joint with retained backing strip may be used.

3.5.1.7 *Welded joint efficiency,* η The maximum allowable joint efficiency of welded joints shall be in accordance with Table 3.5.1.7.

TABLE 3.5.1.7

WELDED JOINT EFFICIENCIES (See Note 5)

Type of joint	Permissible joint location (See Figure 3.5.1.1)	Joint limitations (Notes 3 & 6)	Radiographic or ultrasonic examination (Note 1)	Maximum welded joint efficiency for vessel (Note 4)			
				Class 1	Class 2A	Class 2B	Class 3
Double-welded butt joint, or other butt joint with equivalent quality (welds using backing strips which remain in service are excluded)	A,B,C,D	None	Full Spot None	1.0 — —	— 0.85 —	— — 0.80	— — 0.70
Single-welded butt joint with backing strip which remains in service	A,B,C,D	Circumferential joints—no limit except $t \leq 16$ mm for joggled joint (See Figure 3.5.1.5(A)(d) Longitudinal joints-limited to $t \leq 16$ mm	Full Spot None	0.90 — —	— 0.80 —	— — 0.75	— — 0.65
Single-welded butt joint without use of backing strip	B,C	Circumferential joints only in Class 2 and Class 3 vessels with $t \leq 16$ mm and 610 mm max. inside diameter	None	—	0.70	0.65	0.6
Double full fillet-welded lap joint. Figure 3.5.1.5(A)(p) & 3.12.6(g)	A,B,C	Circumferential joints in Class 3 vessels only. Longitudinal joints in Class 3 vessels only with $t \leq 10$ mm	None	—	—	—	0.55
Single full fillet lap joint with plug welds conforming to Figure 3.5.1.5(A)(q)	B	Circumferential joints only in Class 3 vessels for the attachment of dished ends to shells 610 mm max. inside diameter (Note 2)	None	—	—	—	0.50
Single full fillet-welded lap joint without plug welds conforming to Figure 3.12.6(h), (j) and (l)	B	Circumferential joints only in Class 3 vessels for the attachment of— (a) ends convex to pressure, to shells with fillet weld on inside of shell with $t \leq 16$ mm (b) ends concave to pressure, to shells with $t \leq 8$ mm thickness 610 mm max inside diameter with fillet weld on end flange only	None	—	—	—	0.45
Welded joints in pipes and tubes	A,B	For longitudinal welds in high alloy steel pipes, the joint efficiencies have been included in the design strength listed in Table 3.3.1(B). For carbon, carbon-manganese and alloy steel pipes, the joint efficiencies for longitudinal welds as specified in AS 4041 shall be used.					

NOTES:

1 The examination listed is for Type A and B joints. See AS 4037 for examination of all types of joints.

2 See Clause 3.23 for exceptions for some jacketed vessels.

3 See Clause 3.5.1.6 for requirements for specific materials.

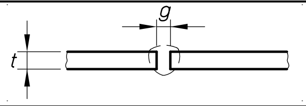
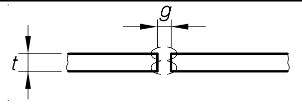
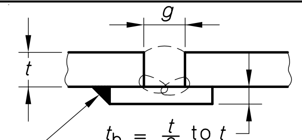
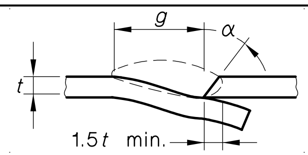
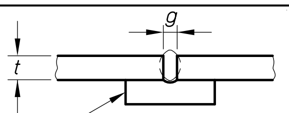
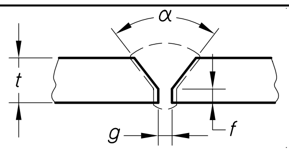
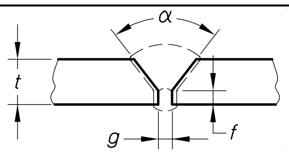
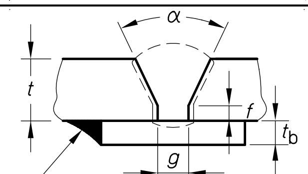
4 These efficiencies apply to longitudinal and circumferential type welds (see Clause 3.5.1.1).

5 A welded joint efficiency of 1.0 shall be applicable for design purposes for—

(a) seamless products, such as seamless pipes and forgings; and

(b) longitudinal and circumferential type butt welds and fillet welds attaching ends, on vessels subject to vacuum only.

6 t = nominal thickness of shell.

Figure	Joint type (Note 1)	Joint form (sectional view) (Note 2)	Recommended thickness t, mm	Dimensions of joint: Gap g, mm	Bevel angle α	Root face f, mm	Application and Notes (See also joint limits in Table 3.5.1.7)
a	Single-welded square butt joint		1.5 3 max.	0–1.5 0–2.5	— —	— —	Circumferential joints but not recommended
b	Double-welded square butt joint		1.5 3 5 max.*	0–1.5 0–2.5 0–3	— — —	— — —	Circumferential and longitudinal joints *To 10 mm with deep penetration welding procedures
c	Single-welded square butt joint with backing strip		3 5 6 max.	3–6 5–8 6–10	— — —	— — —	Figure (c) may also be used for longitudinal joints where one side is inaccessible for welding Circumferential joints where one side is inaccessible for welding, and corrosion or fatigue is not important Close fit of backing strip, joggle and backing bar is essential Where backing strip or joggle is machined out after welding this weld is suitable for longitudinal joints provided the root is suitably examined
d	Single-welded joggled butt		16 max.	t–2.5t	0–30°	—	
e	Single-welded square butt joint with backing bar		≤ 5	t/2 max	—	—	
f	Single-welded single V butt joint (Note 3)		3–10; over 10	1.5–3 1.5–5	60°–70° 60°–70°	0–1.5 0–3	Circumferential joints where one side is inaccessible for welding, and corrosion or fatigue is not important. Larger angles may be used for vertical welds
g	Double-welded single V butt joint (Note 3)		All	0–3	60°–70°	0–3	Circumferential and longitudinal joints. Second side grooved to sound metal before welding second side. The V should be located on the inside of small diameter vessels
h	Single-welded single V butt joint with backing strip (Note 3)						Circumferential and longitudinal joints where one side is inaccessible for welding and corrosion or fatigue is not important. Longitudinal joints are limited to 16 mm max. Where the backing strip is machined out after welding, this weld is suitable for all longitudinal welds provided the root is suitably examined

t, mm	Min gap for α 45°	30°	15°	f	t_b
5	5	6	8	0–1.5	2.5–5
6	5	6	8	0–1.5	3–6
10	6	8	10	0–1.5	3–8
12	8	10	11	0–3	3–10
Over 12	10	10	11	0–3	3–t/2
Over 25	11	11	12	0–5	5–t/2

NOTES:

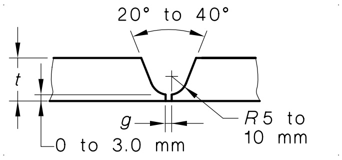
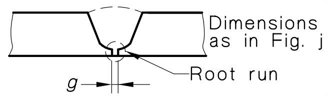
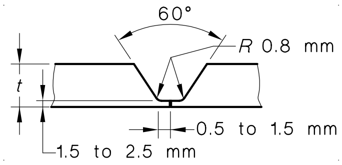
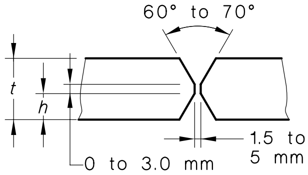
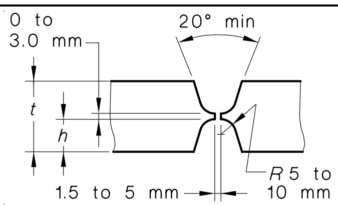
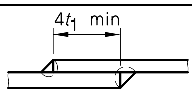
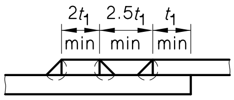
1 For austenitic steels, (f) and (g) are recommended.

2 The use of minimum angle should be associated with the maximum gap and conversely the minimum gap should be associated with the maximum angle.

3 Alternatively, in lieu of (f), (g) or (h), single bevel preparation in accordance with Figure 3.19.3(D) may be used.

FIGURE 3.5.1.5(A) (in part) SOME TYPICAL WELD PREPARATIONS—CARBON, CARBON-MANGANESE, ALLOY AND AUSTENITIC CHROMIUM-NICKEL STEELS—MANUAL AND GAS METAL ARC WELDING PROCESSES

(Suitable for all positions of welding, but downhand preferred)

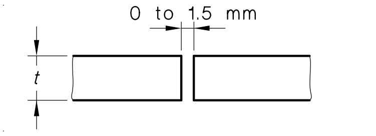
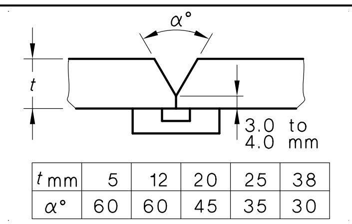
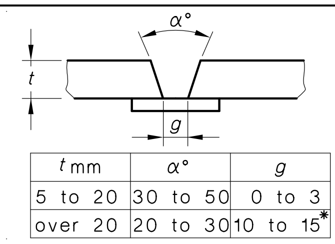
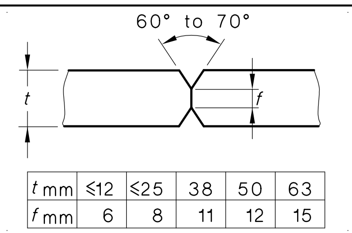
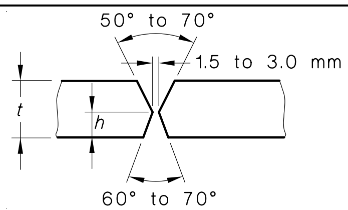
Figure	Joint type (Note 1)	Joint form (sectional view) (Note 2)	Recommended thickness *t*, mm	Application and Notes (See also joint limits in Table 3.5.1.7)
j	Single-welded single U butt joint		15 max.	Circumferential welds, where one side is inaccessible for welding g = 0−3 mm
k	Double-welded single U butt joint		Over 15 to 25	Longitudinal and circumferential welds g = 0−5 mm
l	Single-welded single U butt joint (GTAW root)		20 max.	Circumferential welds where inside is inaccessible for welding. Root run is to be made by GTAW process with inert gas backing
m	Double-welded double V but joint		15−38	Longitudinal and circumferential welds h may vary from $\frac{t}{2}$ to $\frac{t}{3}$
n	Double-welded double U butt joint		over 25	Longitudinal and circumferential welds h may vary from $\frac{t}{2}$ to $\frac{t}{3}$
p	Double full fillet lap joint		10 max. 12 max.	Longitudinal welds in Class 3 vessels Circumferential welds in Class 3 vessels t_1 = thickness of thinner plate
q	Single full fillet lap joint with plug welds		12 max.	Circumferential welds in Class 3 vessels for attachment of ends to shells 610 mm max. inside diameter t_1 = thickness of thinner plate Plug welds are to be proportioned to take 30 percent of total load

NOTES:

1 For austenitic steels, (j) to (n) are recommended.

2 The use of minimum angle should be associated with maximum radius or gap; conversely the minimum radius or gap should be associated with the maximum angle.

FIGURE 3.5.1.5(A) (in part) SOME TYPICAL WELD PREPARATIONS—CARBON, CARBON-MANGANESE, ALLOY AND AUSTENITIC CHROMIUM STEELS—MANUAL AND GAS METAL ARC WELDING PROCESSES

Figure	Joint type	Joint form (sectional view) (see Note)	Recommended thickness *t* mm	Application and Notes (see also joint limits in Table 3.5.1.7)
a	Single-welded square butt joint (with temporary backing)		1.5 to 8	Temporary backing bar required
b	Double-welded square butt joint		3 to 12	Second side need not be cut back to sound metal if the root runs penetrate each other
c	Single-welded single V butt joint (with temporary backing)		5 to 38	Longitudinal and circumferential welds. Temporary backing bar may be copper or flux covered.
d	Single-welded single V joint (with backing strip)		5 and over	Welded in several layers with backing strip. Where the backing strip is retained after welding (see Clause 3.5.1.6) and same limits as in Figure 3.5.1(A)(h) apply) *To 25 mm only where contraction assists in imparting shape required
e	Double-welded double V butt joint		10 and over	Longitudinal and circumferential welds. Second side need not be cut back to sound metal if the root runs penetrate each other Root-face may be off-centre Gap: 0 to 1.5 mm
f	Double-welded double V butt joint (manual backing)		10 and over	Manual metal arc weld may be laid and cut back before submerged arc welding. *h* = 5 mm for *t* <12 mm = 6 mm min. for *t* ≥12 mm

NOTE: The use of minimum angle should be associated with maximum gap; conversely the minimum gap should be associated with the maximum angle.

FIGURE 3.5.1.5(B) SOME TYPICAL WELD PREPARATIONS—CARBON, CARBON-MANGANESE, ALLOY AND AUSTENITIC CHROMIUM STEELS—SUBMERGED ARC PROCESS

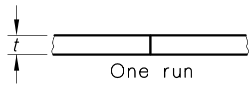
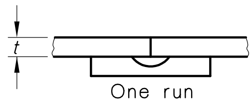
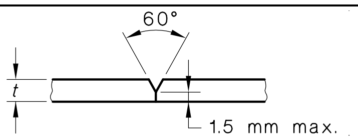
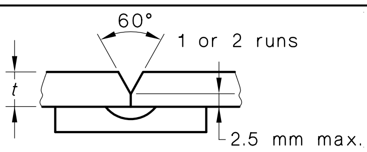
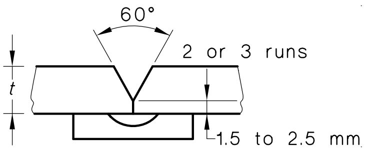
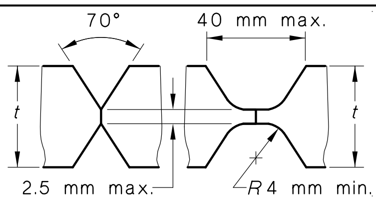
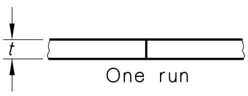
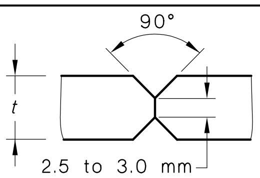
Figure	Joint type	Joint form (sectional view)	Recommended thickness *t*, mm	Application and Notes (see also joint limits in Table 3.5.1.7)
a	Single-welded square butt joint		3 max.	Inert gas backing or backing bar may be used
b	Single-welded square butt joint, with backing bar		3 max.	Backing bar required
c	Single-welded single V joint		3 and over	Either a backing bar or argon backing should be used. There should be no access for air to the back of the weld
d	Single-welded single V joint, with backing bar		5 max.	Frequently a filler rod is not used for the first run. Where the back of the joint cannot be dressed after welding, argon backing should be used, and there should be no access for air to the back of the weld
e	Single-welded single V joint, with backing bar (or with sealing run, i.e. double-welded)		7 max	Where no backing bar is used, cut back to sound metal and add sealing run
f	Double-welded double V joint		6 and over	Cut back after first run to sound metal before welding underside
g	Single-welded square butt joint		3 max	Butt welds in plate not exceeding 3 mm thick Double operator single run vertical GTAW process
h	Double-welded double V joint		3 to 6	Butt welds in plate between 3 mm and 6 mm thick Double operator single run vertical GTAW process

FIGURE 3.5.1.5(C) SOME TYPICAL WELD PREPARATIONS—AUSTENITIC CHROMIUM-NICKEL STEELS—GMAW AND GTAW PROCESSES

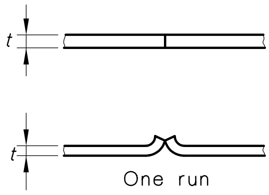
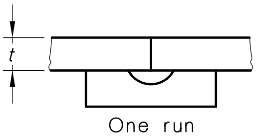
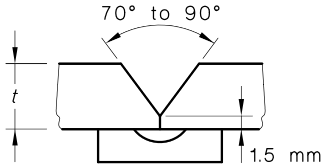
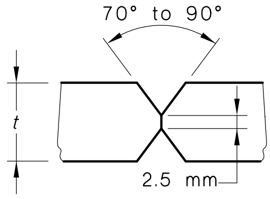
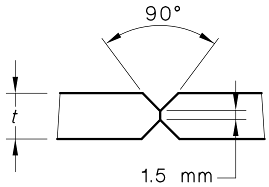
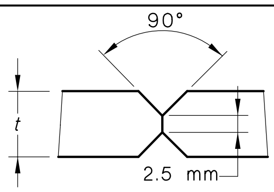
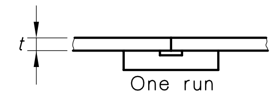
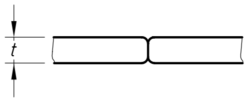
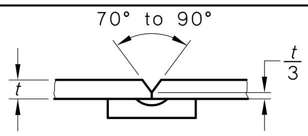
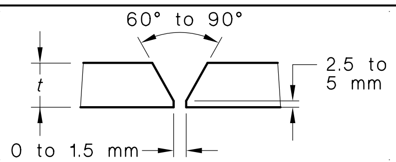
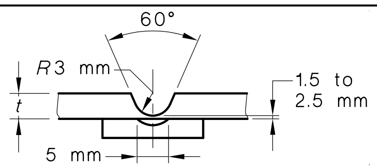
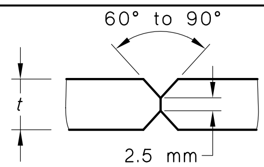
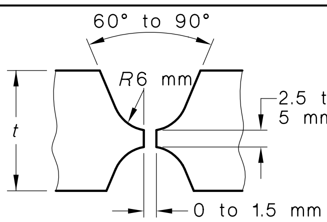
Figure	Joint type	Joint form (sectional view)	Recommended thickness *t*, mm	Application and Notes (see also joint limits in Table 3.5.1.7)
a	Single-welded square or flanged butt joint		2 max. 1.5 max.	Flanging would be used only where square-edge close butt welds are impracticable. if backing bar is used it should conform to Figure 3.5.1.5(E)(a)
b	Single-welded square butt joint with backing bar		2 to 5	Where a backing bar cannot be used, welding from both sides is recommended
c	Single-welded single V butt joint with backing bar (or with sealing run, i.e. double-welded)		6 to 10	Where no backing bar is used, it is good practice to chip back to sound metal and add sealing run
d	Double-welded double V butt joint		5 to 12	Chip back first run to sound metal before welding underside. Preheating may be necessary
e	Double-welded double V butt joint		5 to 6	Vertical butt welds by the double operator technique
f	Double-welded double V butt joint		6 to 12	

FIGURE 3.5.1.5(D) SOME TYPICAL WELD PREPARATIONS—ALUMINIUM AND ALUMINIUM ALLOYS—GTAW PROCESS

Figure	Joint type	Joint form (sectional view) (see Note)	Recommended thickness *t*, mm	Application and Notes (see also joint limits in Table 3.5.1.7)
a	Single-welded square butt with backing bar		1.5 to 5	—
b	Double-welded square butt		6 to 10	Weld from both sides, sighting Vs recommended. 6 mm is maximum material thickness for positional welding
c	Single-welded single V butt joint with backing bar		5 to 12	Weld in one run. Suitable also for positional welding, when welded from both sides
d	Single-welded single V butt joint		6 to 12	One or more runs from each side. Back chipping recommended after first run
e	Single-welded single U butt joint with backing bar		6 to 20	One or more runs from one side, depending on thickness. Suitable also for position welding
f	Double-welded double V butt joint		12 to 25	Up to 1.5 mm root gap. One or more runs from each side. Back chipping recommended after first run
g	Double-welded double U butt joint		12 to 25	—

NOTE: The use of minimum angle should be associated with maximum radius or gap; conversely the minimum radius or gap should be associated with the maximum angle.

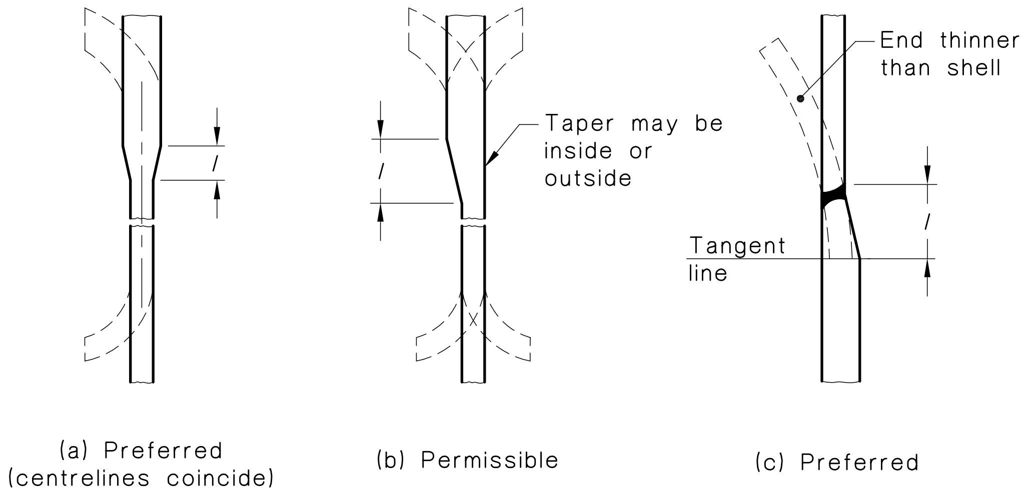
FIGURE 3.5.1.5(E) SOME TYPICAL WELD PREPARATIONS—ALUMINIUM AND ALUMINIUM ALLOYS—GMAW PROCESS

3.5.1.8 *Butt welding between plates of unequal thickness* Where two plates to be welded by a butt joint differ in thickness by more than 25 percent of the thinner plate, or by more than 3 mm, the thicker plate shall be reduced at the abutting edge on either the inside or the outside or both, as shown in Figure 3.5.1.8. In all such cases, the edge of the thicker plate shall be trimmed to a smooth taper extending for a distance of at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness. The length of the required taper may include the width of the weld.

For plates using a double welded double vee preparation the difference between the surfaces of both plates may be not more than 3 mm on each side before tapering of the thicker plate is required.

When the weld is required to be radiographically examined, the maximum thickness through the weld shall comply with AS 4037.

For attachment of ends to shells of differing thicknesses see Clause 3.12.6.



NOTES:

1 In all cases, *l* should be no less than three times the offset between the abutting plates.

2 Length of required taper *l* may include the width of the weld.

3 Misalignment of centrelines ≤$^1/_2$ (*t* thick − *t* thinner)

FIGURE 3.5.1.8 BUTT WELDING BETWEEN PLATES OF UNEQUAL THICKNESS

3.5.2 Not allocated

3.5.3 Brazed joints

3.5.3.1 *General* The following requirements apply specifically to pressure vessels and parts thereof that are fabricated from suitable materials listed in Table 3.3.1 by brazing in accordance with the general requirements of this Standard.

Brazed joints shall not be used for the following:

A3 (a) Vessels with lethal contents (see AS 4343 for 'lethal').

(b) Directly fired vessels.

(c) Joints at design temperatures above 95°C, except brazing filler metal B-CuP may be used up to 105°C maximum and B-Ag, B-CuZn, B-Cu and B-Al-Si may be used up to 205°C maximum provided joint tensile test shows a tensile strength and yield strength not less than the minimum tensile and yield strength of the weaker of the parent metals at the design temperature. If the design is based on creep properties, the joint creep strength shall be similarly proven.

3.5.3.2 *Strength of brazed joints* The designer is responsible to determine from suitable tests or from past experience that the specific brazing filler metal selected can produce a joint which will have adequate strength over the operating temperature range. AS 4458 specifies details for qualification requirements.

The strength of the brazed joint shall be no less than the strength of the parent material, or the weaker of two parent materials in case of dissimilar metal joints, for all temperatures within the operating range.

3.5.3.3 *Corrosion allowance* Provision shall be made for corrosion in accordance with the requirements of Clause 3.2.4.

Corrosion of the brazing filler metal and galvanic action between the brazing filler metal and the base material shall be considered in selecting the brazing filler metal.

The plate thickness in excess of that calculated for a seamless vessel taking into account the applicable loadings in Clause 3.2.3 may be taken as an allowance for corrosion in vessels that have longitudinal joints of double strap butt-joint type. Additional corrosion allowance shall be provided when needed, particularly on the inner buttstraps.

The requirements of this Standard are not intended to apply to brazing used for the attachment of linings of corrosion-resistant material that are not counted on to carry load but resultant galvanic action shall still be considered.

3.5.3.4 *Brazed joint efficiency* The brazed joint efficiency to be used in the design of pressure vessels and parts thereof shall be 1.0 for joints in which visual examination shows that the brazing filler metal has penetrated the entire joint (see Figure 3.5.3.4(a)).

The brazed joint efficiency to be used in the design of pressure vessels and parts thereof shall be 0.5 for joints in which visual examination will not provide proof that the brazing filler metal has penetrated the entire joint (see Figure 3.5.3.4(b)).

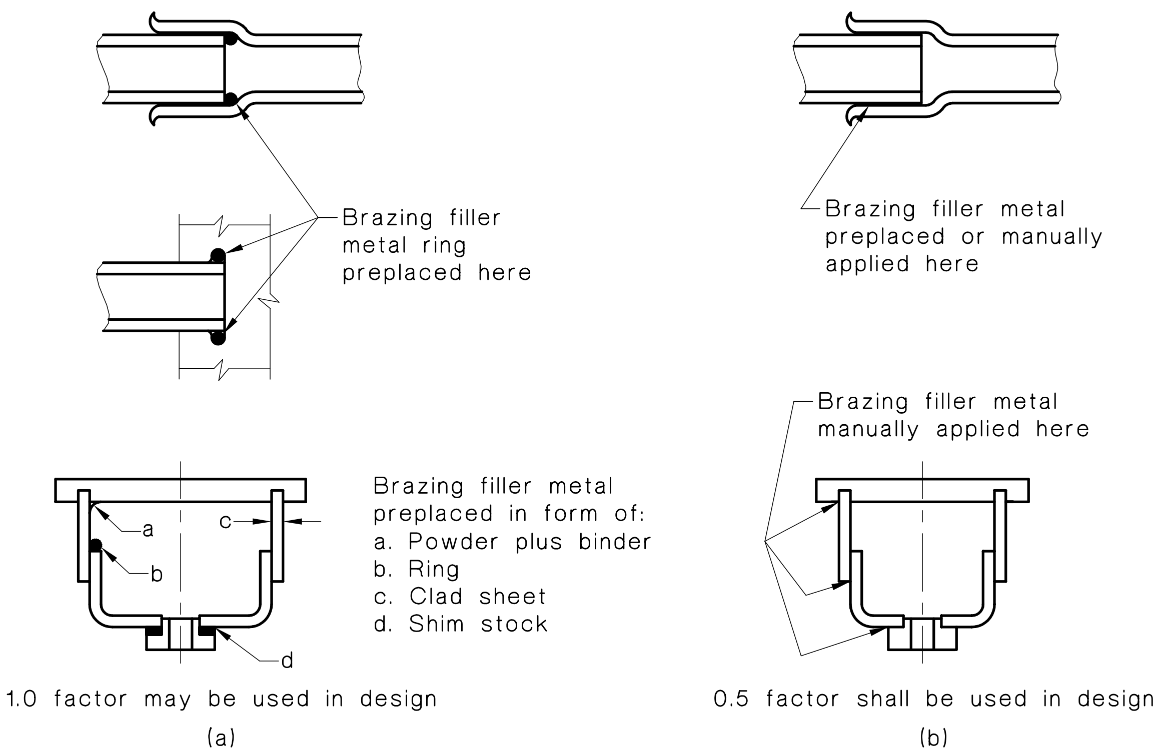
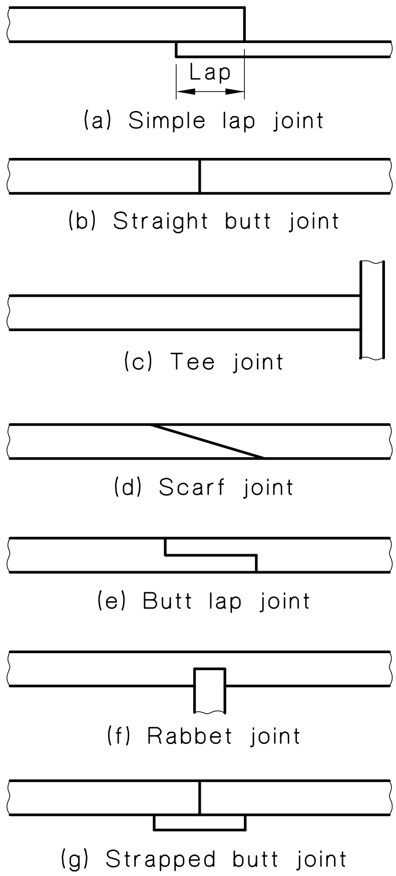


FIGURE 3.5.3.4 EXAMPLES OF FILLER METAL APPLICATION

3.5.3.5 *Application of brazing filler metal* The design shall provide for the application of the brazing filler metal as part of the design of the joint. Where practicable, the brazing filler metal shall be applied in such a manner that it will flow into the joint or be distributed across the joint and produce visible evidence that it has penetrated the joint.

3.5.3.6 *Permissible types of joints* Some permissible types of brazed joint are shown in Figure 3.5.3.6. For any type of joint, the strength of the brazed section shall exceed that of the base material portion of the test specimen in the qualification tension tests provided for
A3 in AS/NZS 3992. Lap joints shall have an overlap of five times the thickness of the thinner plate for longitudinal joints and not less than three times the thickness of the thinner plate for circumferential joints to provide a higher strength in the brazed joint than in the base material.



NOTE: Other equivalent geometries yielding substantially equal results also are acceptable.

FIGURE 3.5.3.6 SOME ACCEPTABLE TYPES OF BRAZED JOINTS

3.5.3.7 *Joint clearance* The joint clearance shall be kept sufficiently small so that the filler metal will be distributed by capillary action and shall be within the tolerances specified in the joint design and in the qualified brazing procedure (see Table 3.5.3.7).

TABLE 3.5.3.7

RECOMMENDED JOINT CLEARANCES AT BRAZING TEMPERATURE

Brazing filler metal classification (ANSI/AWS A5.8)	Clearance, mm
B-A1-Si group	0.15-0.25 for laps less than 6 mm 0.25-0.64 for laps greater than 6 mm
B-Cu-P group	0.03-0.13
B-Ag group	0.05-0.13
B-Cu-Zn group	0.05-0.13
B-Cu-group	0.0-0.05

3.5.4 Soldered joints Soldered joints are permitted for small vessels or parts provided the following are complied with:

(a) Vessel contents are not lethal.

(b) The vessel is not directly fired.

(c) The design temperature does not exceed 50°C.

(d) The joint comply with requirements equivalent to those in Clause 3.5.3.

(e) The joints are shown to be suitable for the particular application.

3.6 LIGAMENT EFFICIENCY Where a cylindrical shell is drilled with multiple holes, the ligament efficiency (η) to be used in determining the thickness of the shell, shall be determined in accordance with AS 1228 or other method agreed by the parties concerned.

For ligament efficiency in unstayed flat tubeplates, see Clause 3.17.1.

3.7 CYLINDRICAL AND SPHERICAL SHELLS SUBJECT TO INTERNAL PRESSURE AND COMBINED LOADINGS

3.7.1 General The minimum thickness of cylindrical or spherical shells or cylindrical or spherical parts of vessels subject to internal pressure and, when applicable, combined loading, shall be no less than that determined in accordance with this Clause (3.7) and Clause 3.4.3. See also Clause 3.8.

3.7.2 Notation For the purpose of this Clause the following notation applies:

D = inside diameter of shell, in millimetres

$D_m = \frac{D + D_o}{2}$ = mean diameter of shell, in millimetres

D_o = outside diameter of shell, in millimetres

E = Young modulus at design temperature, in megapascals

f = design tensile strength at the design temperature (see Clause 3.3), in megapascals

f_a = f at test temperature, in megapascals

M = longitudinal bending moment, in newton millimetres

P, P_h = calculation pressure P (see Clause 3.2.1), or the pressure under hydrostatic test P_h, as appropriate, in megapascals

Q = torque about vessel axis, in newton millimetres

A3 S_b = bending stress in vessel, in megapascals

S_c = circumferential pressure stress in vessel, in megapascals

S_E = equivalent stress at any given point in vessel (maximum shear stress basis), in megapascals

S_l = longitudinal stress in vessel, in megapascals

S_s = shear stress in vessel, in megapascals

A3 S_w = weight stress in vessel, in megapascals

t = minimum calculated thickness of the pressure part (exclusive of added allowances, see Clause 3.4.2), in millimetres

A3 T = actual thickness (taken as nominal thickness less allowances), in millimetres

W = (vertical vessel only)—

(a) for points above plane of support: force due to the mass of the vessel, fittings, attachments and fluid supported above point considered, the sum to be given a negative sign in Equation 3.7.5(1), in newtons; and

(b) for points below plane of support: force due to the mass of the vessel, fittings and attachments below point considered, plus fluid content, the sum to be given a positive sign in Equation 3.7.5(1), in newtons

A3 α = half apex angle of a conical vessel shell or skirt, in degrees

η = efficiency of the welded joint or any line of holes or ligaments in the shell, whichever is the least (see Clauses 3.5 and 3.6)

3.7.3 Cylindrical shells The minimum calculated thickness of a cylindrical shell shall be the greater thickness determined from the following equations:

(a) Based on circumferential stress (longitudinal joints)—

A3
$$t = \frac{PD}{2f\eta - P} = \frac{PD_m}{2f\eta} = \frac{PD_o}{2f\eta + P} \qquad \ldots 3.7.3(1)$$

(b) Based on longitudinal stress (circumferential joints)—

A3
$$t = \frac{PD}{4f\eta - P} = \frac{PD_m}{4f\eta} = \frac{PD_o}{4f\eta + P} \qquad \ldots 3.7.3(2)$$

3.7.4 Spherical shells The minimum calculated thickness of a spherical shell shall be determined from the following equation:

A3
$$t = \frac{PD}{4f\eta - P} = \frac{PD_m}{4f\eta} = \frac{PD_o}{4f\eta + P} \qquad \ldots 3.7.4$$

NOTES:

1 The equation $\left(t = \frac{PD}{4f\eta - 0.4P}\right)$ used prior to Amendment 3, was based on the asymptotic approximation of the Lame equations. The new equation is based on burst considerations.

2 Equation 3.7.4, as amended by Amendment 3, will result in a small increase in thickness. This change is not intended to apply retrospectively. See AS/NZS 1200, Clause 1.12.

A3 **3.7.5 Vertical vessels under combined loading (for internal or external, or both pressures)** Calculation in accordance with this Clause (3.7.5) is not necessary for many vessels and is only required for tall vessels where additional stresses due to combined loading become significant.

The minimum calculated thickness of vertical cylindrical or conical vessels subject to combined loading shall be calculated using the equations below, but in addition the calculated thickness shall be no less than that required by Clause 3.7.3. These equations adopt the basis that the stress equivalent to the membrane stress shall nowhere exceed the design strength.

The loadings include those referred to in Clause 3.2.3 which cause bending, or axial stresses, or both, in addition to those due to internal and external pressure.

The normal operating condition may not be the most critical one. The out-of-service condition, with pressure terms equal to zero, or the hydrostatic test condition including force due to standard gravity acting on the mass of water may be the governing one. The need to allow for simultaneous application of full wind loading during hydrostatic test shall be examined to suit local conditions (see Clause 3.2.3(e)).

The following stresses shall be calculated with regard to signs, tensile (positive), compressive (negative), internal pressure (positive), external pressure (negative):

$$S_b = 4M/(\pi D_m^2 t \cos \alpha) \text{ (bending stress)} \qquad \ldots 3.7.5(1)$$

$$S_c = PD_m/(2t \cos \alpha) \text{ (circumferential pressure stress)} \qquad \ldots 3.7.5(2)$$

$$S_w = W/(\pi D_m t \cos \alpha) \text{ (weight stress)} \qquad \ldots 3.7.5(3)$$

S_E shall be taken as the greatest of—

$$(|S_c|, |S_c/2 + S_w + S_b|, |S_c/2 + S_w - S_b|, |S_w + S_b - S_c/2|, |S_w - S_b - S_c/2| \qquad \ldots 3.7.5(4)$$

(equivalent stress or Tresca stress).

The above stresses shall be calculated for the worst case condition (of those listed below) and the location (height) on the vertical vessel where the stress is maximum. Note that the place of maximum stress could be different in each case.

(a) Design conditions.

(b) Hydrostatic test conditions.

(c) Hydrostatic test conditions without pressure.

(d) Full weight, no pressure.

(e) Design pressure, vessel empty (where relevant).

(f) Zero pressure, vessel empty.

(g) Any other foreseeable operating condition.

The above stresses shall be limited as follows:

Where S_c, or $(S_c/2 + S_w + S_b)$ are tensile (positive) then:

$$S_E, S_c, (S_c/2 + S_w + S_b) \le \eta f \text{ or } 1.5\,\eta f \text{ under hydrostatic test conditions} \qquad \ldots 3.7.5(5)$$

A3 When $(S_w - S_b)$ is negative, its magnitude shall be limited to the lesser of f and S_{lL}

$$\text{where } S_{lL} = 0.605E \frac{t \cos \alpha}{D_m} \times \frac{(2880 + D_m/t \cos \alpha)}{(3200 + 10D_m/t \cos \alpha)} \quad \text{. . . 3.7.5(6)}$$

NOTE: This equation is a curve fit with a factor of safety of 2.0, taken from Baker E. H., Kovalevsky, L. & Rish F. L., '*Structural Analysis of Shells*' Robert E. Krieger Publishing Co. Malibar, 1972 Figures 10-9 and 10-13.

When S_c is compressive (negative) then:

$$|S_c| \leq |S_{cL}|$$

where $S_{cL} = P_e D_m/2t \cos \alpha$ . . . 3.7.5(7)

and P_e is calculated according to Clause 3.9.3.

When both S_c and $(S_w - S_b)$ are negative then:

$$\frac{|S_c|}{|S_{cL}|} + \frac{|S_w - S_b|}{S_{lL}} \leq 1.0 \quad \text{. . . 3.7.5(8)}$$

NOTES:

1 In the above equations, it is permissible to replace t by T minus corrosion allowance.

2 The above tensile and equivalent stress limits may be increased by a factor of 1.2 for conditions when wind and earthquake loadings are taken into consideration. Earthquake and wind loadings need not be considered to act simultaneously.

3 The above equations cannot be reduced to a convenient explicit expression for the calculation of t, and the solution must be by trial and error.

3.7.6 Horizontal cylindrical vessels under combined loading The minimum calculated thickness of horizontal cylindrical vessels subjected to combined loading shall be A3 determined in the same manner as for vertical cylindrical vessels, except that the force due to the mass shall be incorporated in the bending moment M and the symbol W shall be omitted.

A3 For local stresses at supports, see Clause 3.24.4.

3.7.7 Conical shells subject to internal pressure The minimum calculated thickness of a conical shell subject to internal pressure shall be determined from Clause 3.10.

3.8 THICK-WALLED CYLINDRICAL AND SPHERICAL SHELLS SUBJECT TO INTERNAL PRESSURE

Thick-walled cylinders and spherical shells subject to internal pressure shall be in accordance with Clause 3.7. As an alternative they maybe designed to AS 1210 Supplement 1, using the stress levels of this Standard.

3.9 CYLINDRICAL AND SPHERICAL SHELLS SUBJECT TO EXTERNAL PRESSURE

3.9.1 General The minimum thickness of cylindrical or spherical shells or cylindrical or spherical parts of vessels subject to external pressure shall be no less than that determined in accordance with this Clause (3.9), or the method given in ANSI/ASME BPV-VIII-1. The thickness so determined shall be not less than that required by Clause 3.4.3.

This Clause applies to vessels either with or without longitudinal or circumferential joints, and either with or without stiffening rings. The possible influence of other loadings (Clause 3.2.3) shall be considered and, where necessary, the stiffness of the shell shall be suitably increased. See also Clauses 3.24 and 3.25 for supports and attachments to avoid local distortion.

The minimum calculated thickness shall be increased where necessary to meet the requirements of Clause 3.4.2.

3.9.2 Notation For the purpose of this Clause 3.9, the following notation applies:

where

A_a = circumferential strain of shell or cone

A_a' = circumferential strain of stiffening ring

A_s = cross-sectional area of stiffening ring, in square millimetres

B_a' = theoretical buckling stress of stiffening ring, in megapascals

d = radial depth of stiffeners used (between flanges, if any), in millimetres

D = inside diameter of shell, in millimetres

D_m = mean diameter of shell, in millimetres

= $D_o - t$ (see Figure 3.9.2)

D_o = outside diameter of shell in the fully corroded condition, in millimetres

E = Young modulus of shell, cone or stiffener at design temperature, in megapascals

f = design strength of shell or cone at design temperature, in megapascals

I_c = required second moment of area of the combined ring/shell on a section normal to the shell and about its neutral axis parallel to the axis of the cylindrical shell, in millimetres to the fourth power

I_r = required second moment of area of stiffening ring on a section normal to the shell and about its neutral axis parallel to the axis of the cylindrical shell, in millimetres to the fourth power.

L = effective length of cylindrical shell, in millimetres (see Figure 3.9.2)

L' = length of shell which may be included for the calculation of the second moment of area provided by the stiffening rings, in millimetres (see Figure 3.9.6.2)

A3 = $(D_m T)^{1/2}$, or L_s, whichever is less

L_s = sum of half distances from stiffening ring to rings on either side (for equispaced rings $L_s = L$), in millimetres

n = number of circumferential buckling lobes

P = calculation pressure (i.e. net external pressure), in megapascals (see Clause 3.2.1.3)

P_e = theoretical pressure required to cause elastic buckling of shell, in megapascals

P_y = theoretical pressure required to cause plastic yielding of shell, in megapascals

A2 V = radial shear load, in newtons

Q = first moment of area about the newtral axis of that part of shell which is being credited as part of the stiffener ring, in millimetres cubed

A3 T = actual thickness (taken as nominal thickness less allowances), in millimetres

t = minimum calculated thickness of the pressure part (exclusive of added allowances, see Clause 3.4.2), in millimetres

t_f = thickness of stiffener flange, in millimetres

t_w = thickness of stiffener web, in millimetres

Y = specified minimum yield strength (0.2 percent proof stress) at design temperature, in megapascals; if values are not available, Y may be taken as—

1.5f for carbon, low alloy and ferritic steels

1.1f for austenitic steels and non-ferrous metals

Z = $\frac{\pi D}{2L}$

α = half apex angle of conical end or reducer, in degrees

λ = buckling wave length, in millimetres

w = outstanding width of stiffener flange from centre of web, in millimetres

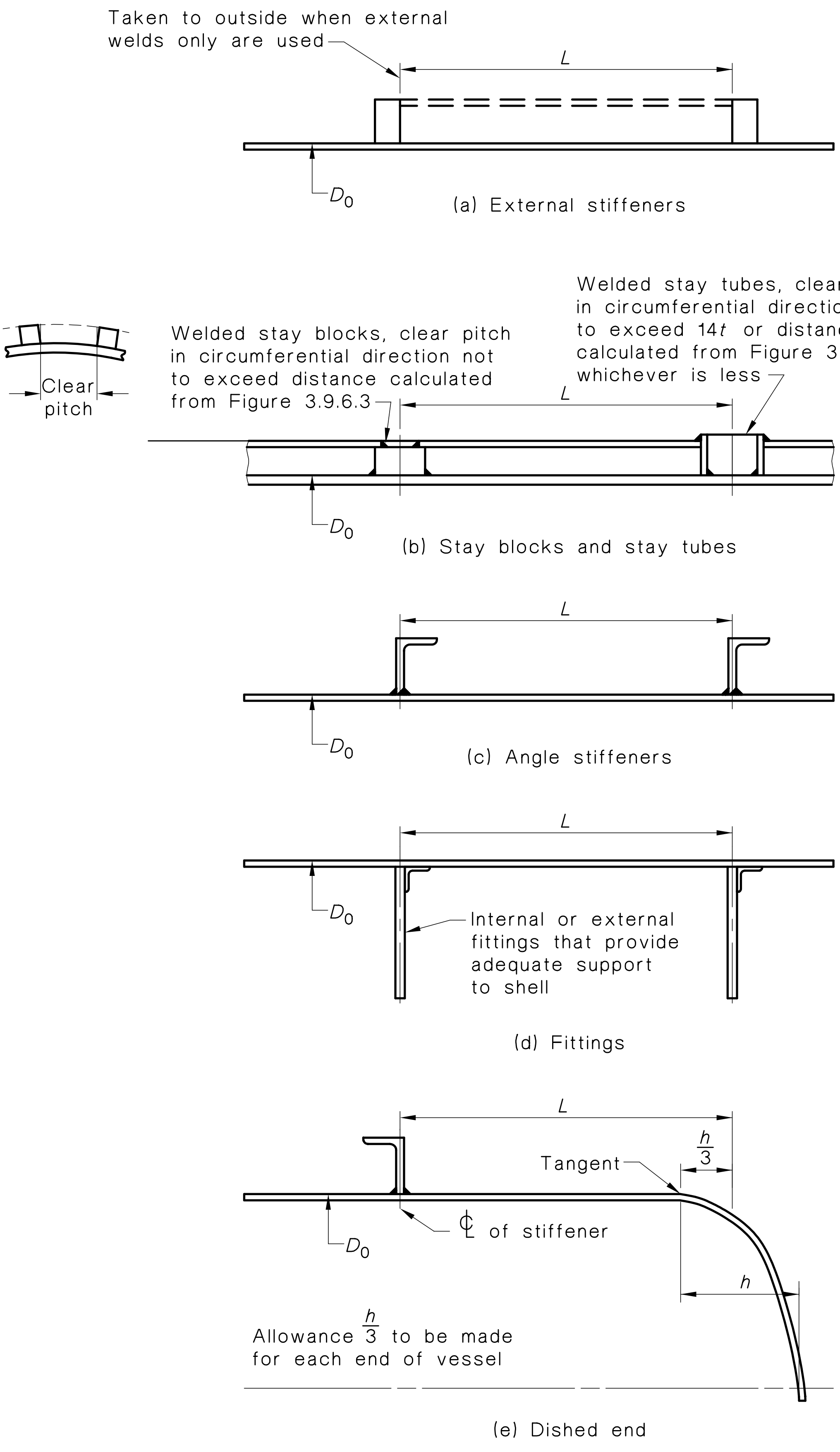
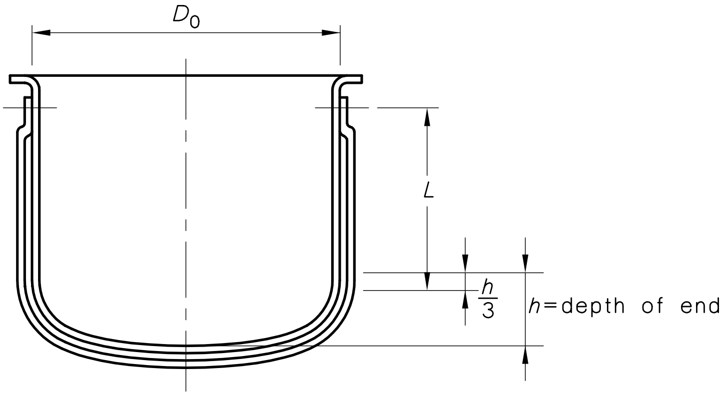
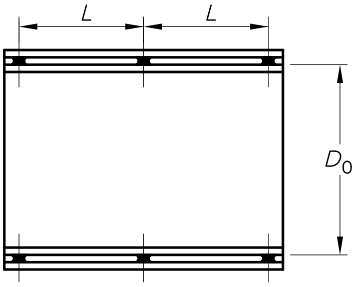


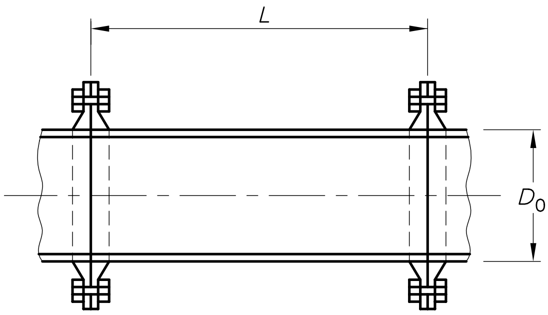
FIGURE 3.9.2 (in part) EFFECTIVE LENGTH (*L*) OF VESSELS SUBJECT TO EXTERNAL PRESSURE



(f) Jacketed vessel

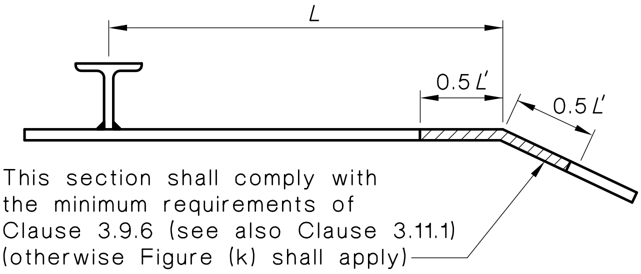


(g) Jacketed cylinder with supports

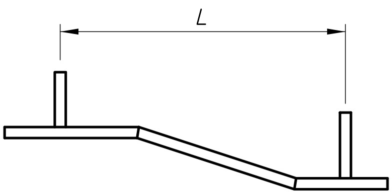


(h) Flanges

A2 |



(j) Integral cone to cylinder stiffening



NOTES:

1 When the cone-to-cylinder or the knuckle-to-cylinder junction is not a line of support, the nominal thickness of the cone, knuckle, or toriconical section shall not be less than the minimum required thickness of the adjacent cylindrical shell.

2 Calculations shall be made using the diameter and corresponding thickness of each section with dimension L as shown.

(k) Conical section or end

FIGURE 3.9.2 (in part) EFFECTIVE LENGTH (L) OF VESSELS SUBJECT TO EXTERNAL PRESSURE

3.9.3 Cylindrical shells The minimum calculated thickness of a cylindrical shell, either seamless or with butt joints, under external pressure shall not be less than that determined from the following procedure:

(a) Assume a value for t and determine a value of A_a as follows:

(i) A conservative value of A_a may be taken as the greater of the values given by the following equations:

$$A_a = \frac{1.3t^{1.5}}{D_m^{0.5}L} \quad \text{. . . 3.9.3(1)}$$

$$A_a = 1.1\left(\frac{t}{D_m}\right)^2 \quad \text{. . . 3.9.3(2)}$$

(ii) Where greater accuracy is required, A_a may be calculated from Equation 3.9.3(3).

$$A_a = \frac{1}{n^2 - 1 + \frac{Z^2}{2}}\left[\left(\frac{Z^2}{n^2 + Z^2}\right)^2 + \frac{t^2(n^2 - 1 + Z^2)^2}{2.73D_m^2}\right] \quad \text{. . . 3.9.3(3)}$$

where

n = number of circumferential buckling lobes and is an integer ≥2 which minimizes the value of A_a, determined by iterative application of Equation 3.9.3(3).

A first approximation of the value of n may be determined from Equation 3.9.3(4) but shall not be less than 2.

$$n = Z\left[\frac{L}{(D_m t)^{0.5} - 1}\right]^{0.5} \quad \text{. . . 3.9.3(4)}$$

NOTE: This value of n is used in determining the stiffening parameters.

(b) Determine values of P_e and P_y from Equations 3.9.3(5) and 3.9.3(6), respectively.

$$P_e = \frac{2EA_a t}{D_m} \quad \text{. . . 3.9.3(5)}$$

$$P_y = \frac{2Yt}{D_m} \quad \text{. . . 3.9.3(6)}$$

(c) Calculate the value of the maximum permissible calculation pressure, P, for the value of t assumed in Item (a) from Equation 3.9.3(7) or Equation 3.9.3(8), as applicable.

where $P_e \leq P_y$

$$P = \frac{P_e}{3} \quad \text{. . . 3.9.3(7)}$$

where $P_e > P_y$

$$P = \frac{P_y\,(2 - P_y/P_e)}{3} \quad \text{. . . 3.9.3(8)}$$

(d) If the value of P so obtained is less than the required calculation pressure, the assumed value of t shall be increased and the procedure repeated until the value of P obtained is equal to or greater than the required calculation pressure.

3.9.4 Spherical shells The minimum calculated thickness of spherical shells under external pressure, either seamless or with butt joints, shall not be less than that determined from the following procedure:

(a) Assume a value for t and calculate values for P_e and P_y from Equations 3.9.4(1) and 3.9.4(2), respectively.

$$P_e = 4.84E \left(\frac{t}{D_m}\right)^2 \quad \ldots 3.9.4(1)$$

$$P_y = 4\frac{Yt}{D_m} \quad \ldots 3.9.4(2)$$

(b) Calculate the value of the maximum permissible external pressure for the value of t assumed in Item (a) from Equation 3.9.4(3) or Equation 3.9.4(4), as applicable.

Where

$P_e \leq P_y$

$$P = 0.07P_e \quad \ldots 3.9.4(3)$$

Where

A1 | $P_e > P_y$

$$P = 0.07P_y\left(5 - \frac{16}{3 + P_e/P_y}\right) \quad \ldots 3.9.4(4)$$

(c) If the value of P so obtained is less than the required calculation pressure, the assumed value of t shall be increased and the procedure repeated until the value of P obtained is equal to or greater than the required calculation pressure.

3.9.5 Shells subject to external pressure and combined loadings Cylindrical shells subject to external pressure and combined loadings, in addition to satisfying the requirements of this Clause (3.9), shall also satisfy Clause 3.7.5 (vertical vessels) or Clause 3.7.6 (horizontal vessels). In both the latter Clauses the sign of P shall be negative.

Where necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or excessive distortion due to external loadings listed in Clause 3.2.3.

3.9.6 Stiffening rings for cylindrical shells subject to external pressure

3.9.6.1 *Second moment of area* Stiffening rings consisting of internal or external diaphragms or structural sections may be used to limit the effective length of a cylindrical shell subject to external pressure. The required second moment of area and the available second moment of area of the stiffener shall be determined in accordance with Items (a) and (b), respectively, and shall comply with Item (c) as follows.

(a) The required second moment of area of a circumferential stiffening ring shall be not less than that determined from Equation 3.9.6(4) or Equation 3.9.6(5) as applicable, (see Note), in accordance with the following procedure:

$$B_a' = \frac{1.5PD_m}{t + A_s/L_s} \quad \ldots 3.9.6(1)$$

$$\text{For } B_a' < Y, \quad A_a' = \frac{B_a'}{E} \quad \ldots 3.9.6(2)$$

$$\text{For } B_a' \geq Y, \quad A_a' = \frac{Y}{E(2 - B_a'/Y)} \quad \ldots 3.9.6(3)$$

$$I_r \geq \frac{D_m^{2} L_s A_a' (t + A_s/L_s)}{14} \quad \ldots 3.9.6(4)$$

$$I_c \geq \frac{D_m^{2} L_s A_a' (t + A_s/L_s)}{10.9} \quad \ldots 3.9.6(5)$$

NOTE: Where the stiffening ring is not attached to the shell, or where the stiffening ring is attached but only the ring is considered, I_r determined from Equation 3.9.6(4) is applicable.

Where the stiffening ring is attached to the shell and part of the shell is credited in the actual second moment of area of the combined shell/ring, I_c determined from Equation 3.9.6(5) is applicable.

(b) The available second moment of area of a circumferential stiffening ring shall be calculated using the same cross-sectional area as that used to determine I_r or I_c as applicable.

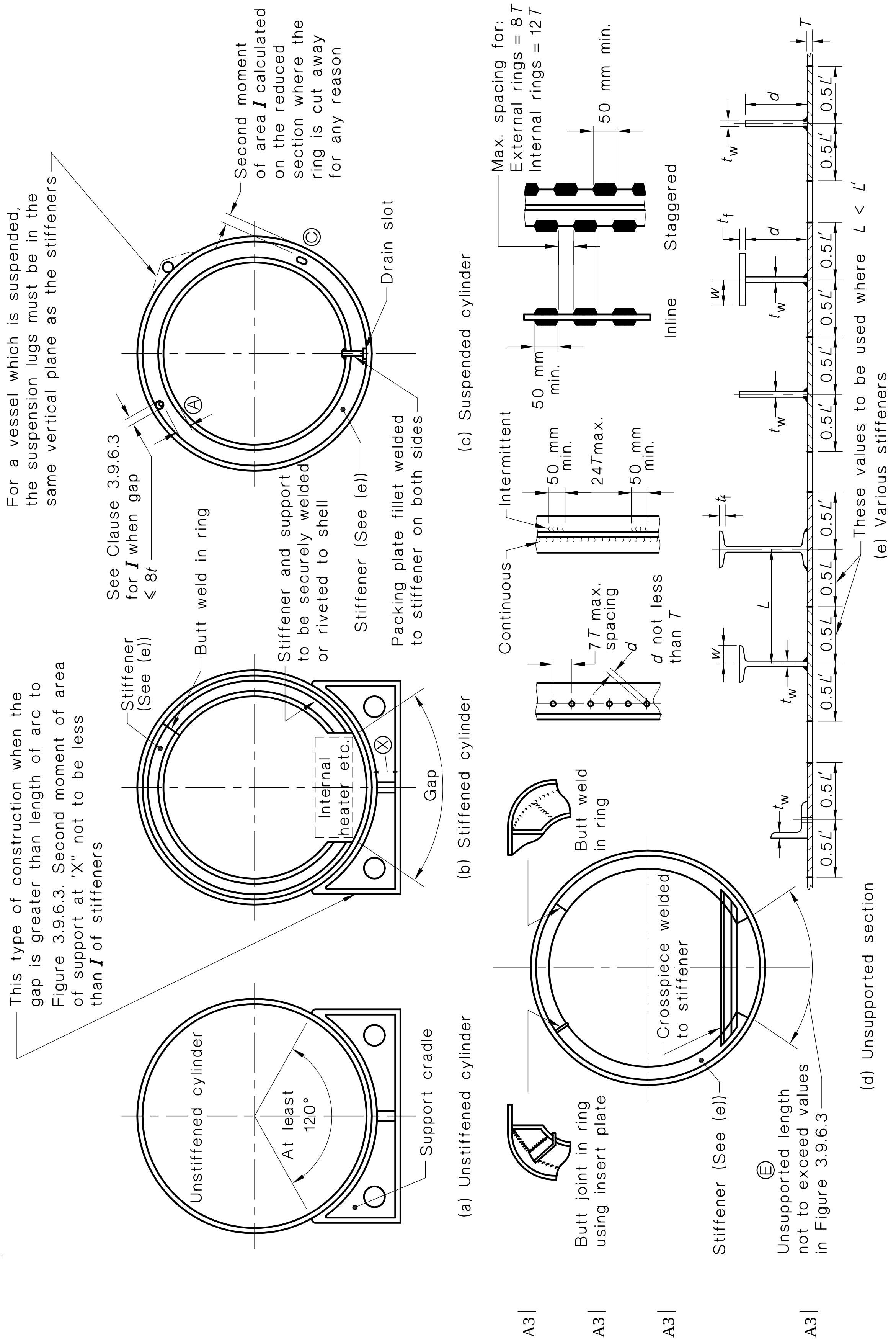
Where I_c is the applicable required second moment of area, the length L' of the shell plate (taken as one half on each side of the ring centroid) may be included as part of the cross-section of the stiffener provided that such length contributes area to only one ring and the stiffening ring is effectively welded to the shell.

(c) If the required second moment of area determined from Item (a) is greater than the available second moment of area calculated from Item (b), a new size of stiffener with a larger second moment of area shall be selected and the procedures of Items (a) and (b) repeated.

3.9.6.2 *Form of stiffening rings* Stiffening rings shall extend completely around the circumference of the shell except as provided in Clause 3.9.6.3.

Each joint between the ends or sections of rings shall be made so that the required second moment of area of the ring is maintained. (See Figure 3.9.6.2.)

Internal plane structures perpendicular to the longitudinal axis of the cylinder, such as bubble trays, baffle plates or diaphragms, may be considered to act as stiffening rings provided that they are suitably designed for both purposes. Internal diaphragms used as stiffening rings and subject to transverse pressure shall be designed to support the loads due to the pressure on the diaphragm and on the effective length of the shell, consideration being given to the buckling of the diaphragm under the edge load using a factor of safety of three against buckling and making allowance for the attached or free edge condition.



A1 | FIGURE 3.9.6.2 STIFFENING RINGS FOR CYLINDRICAL VESSELS SUBJECT TO EXTERNAL PRESSURE

To ensure lateral stability, stiffening rings (whether on the inside or outside of the vessel) shall comply with the following limiting proportions (see Note):

(a) For stiffeners flanged at the edge remote from the shell surface—

$$\frac{d}{t_w} \leq 1.1 \sqrt{\frac{E}{R_{e(T)}}}; \text{ and} \quad \ldots 3.9.6(6)$$

$$\frac{w}{t_f} \leq 0.5 \sqrt{\frac{E}{R_{e(T)}}} \quad \ldots 3.9.6(7)$$

(b) For flat bar stiffener—

$$\frac{d}{t_w} \leq 0.5 \sqrt{\frac{E}{R_{e(T)}}} \quad \ldots 3.9.6(8)$$

NOTE: The values of d and w, so determined, are the maxima that can be used for determining the required I_r and I_c. The actual dimensions used in manufacture should not greatly exceed these values.

Where the effective length of a shell is determined by a row of screwed or welded stays or stay blocks, the stay diameter shall not be less than twice the thickness of the shell plate, and the maximum unsupported arc of shell, measured between stay centres, shall comply with Clause 3.9.6.3.

Corrosion-resistant linings shall not be included in the calculation for the wall thickness except where permitted by Clause 3.3.1.2.

3.9.6.3 *Local spaces in stiffening rings* Stiffening rings having local spaces between the ring and the shell (as shown at A and E in Figure 3.9.6.2) shall not have any unsupported arc of the shell exceeding the length of arc specified below unless additional reinforcement is provided as shown at X in Figure 3.9.6.2 or unless—

(a) the unsupported shell arc does not exceed 90°; and

(b) the unsupported shell arcs in adjacent stiffening rings are staggered 180°; and

(c) the dimension L defined in Figure 3.9.2 is taken as larger of—

 (i) the greatest distance between alternate stiffening rings; and

 (ii) the distance from the end tangent line to the second stiffening ring plus 0.33 times the end depth.

The maximum unsupported arc length shall not exceed $\frac{\lambda}{4}$

where

$$\lambda = \frac{\pi D_m}{n} \quad \ldots 3.9.6(9)$$

n = number of circumferential buckling lobes and is an integer ≥2 which minimizes the value of A_a (see Clause 3.9.3(a)(ii)).

Stiffening rings with holes or spaces in the ring as shown at A and C in Figure 3.9.6.2, shall be suitably reinforced so that the second moment of area required for the ring in A or the combined ring/shell section in C is maintained within the sections indicated. The second moment of area of each section shall be taken about its own neutral axis. Where the gap at A does not exceed eight times the thickness of the shell, the combined second moment of area of the ring and shell section may be used.

3.9.6.4 *Attachment of stiffening rings stiffening* Stiffening shall be attached as follows:

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel. Internal rings need not be attached to the shell provided that they have adequate lateral support. The attachment of rings to the shell shall be by welding, brazing, riveting or bolting. Brazing may be used if the vessel is not to be subsequently stress-relieved. The ring shall be in contact with the shell around the circumference.

(b) Stiffening rings may be attached to the shell by either continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be—

(i) no less than one-half of the outside circumference of the vessel for rings on the outside; and

(ii) no less than one-third of the circumference of the vessel for rings on the inside. Acceptable arrangements and spacings of intermittent welds are shown in Figure 3.9.6.2.

(c) Where the rings are on the outside and riveted to the shell—

(i) the nominal diameter of the rivets shall be no less than the thickness of the shell plate; and

(ii) the centre-to-centre distance of the rivet holes shall not exceed that required by Figure 3.9.6.2.

(d) Where the stiffening ring and shell are subject to corrosion, the stiffening ring shall be attached to the shell by continuous welds on both sides.

3.9.6.5 *Strength of attachment welds* Welds attaching a stiffener ring shall be sized to resist the combination of:

(a) Full radial pressure load from the shell between stiffeners. This equals PL_s, in newtons/millimetre.

(b) Shear loads acting radially across the stiffener from any external design load, in newtons/millimetre.

(c) Radial shear load, V, equal to 2% of the ring's compressive load, i.e. $0.01\, PL_s\, D_o$, in newtons. This value results in a weld load equal to $\frac{VQ}{I_c}$, in newtons/millimetre.

A2 The combined weld load = $\left[(PL_S)^2 + \left(\frac{VQ}{I_c}\right)^2\right]^{0.5}$ in newtons/millimetre.

The fillet welds shall be sized so that—

(i) the total throat area is sufficient to withstand the combined weld load without exceeding the allowable shear stress; and

(ii) the minimum leg length is not less than the smallest of 6 mm, the vessel thickness at the stiffener, or the stiffener thickness.

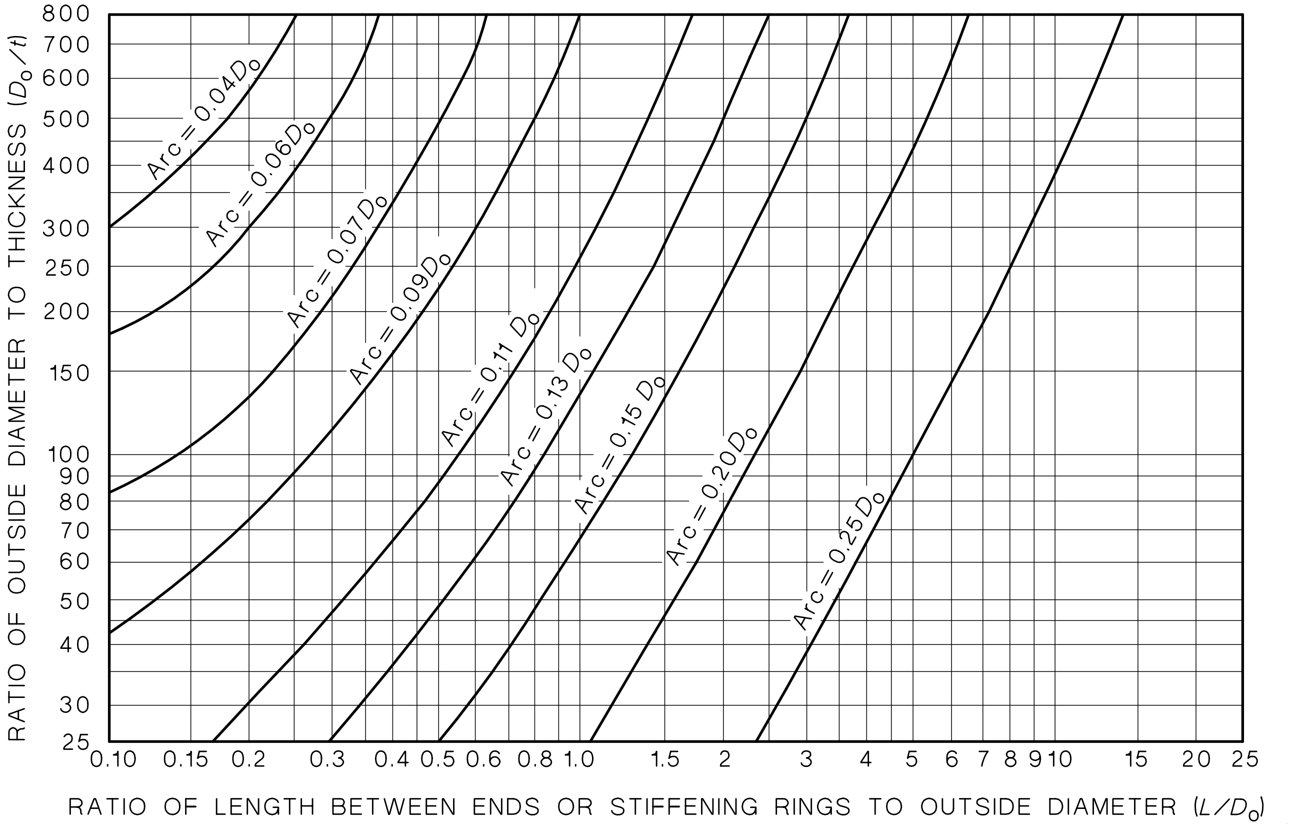


FIGURE 3.9.6.3 MAXIMUM ARC OF SHELL UNSUPPORTED BY STIFFENING RINGS

3.10 CONICAL ENDS AND REDUCERS SUBJECT TO INTERNAL PRESSURE

3.10.1 General Conical ends and reducers subject to internal pressure shall be designed in accordance with this Clause (3.10). The minimum calculated thickness shall be increased where necessary to meet the requirements of Clauses 3.4.2 and 3.4.3 and to meet other appropriate loadings given in Clause 3.2.3.

Conical ends and reducers may be constructed in several ring sections of decreasing thickness as determined by the corresponding decreasing diameter.

This Clause applies to conical ends or reducers which are concentric with the cylindrical shell and where all the longitudinal loads are transmitted wholly through the conical section.

NOTE: It may be assumed that this Clause applies also to an offset cone such as a reboiler provided that all parts of the cone fall within the projected perimeter of the large end.

3.10.2 Notation For purposes of this Clause (3.10), the following notation applies:

D_1 = inside diameter of conical section or end at the position under consideration, i.e. D_1 may vary between D_s and D_L (see Figure 3.10.2), in millimetres

D_{mL} = mean diameter of conical end or reducer at the large end, in millimetres

= $D_L + t$ (see Figure 3.10.2)

A3 D_{mS} = mean diameter of conical end or reducer at the small end, in millimetres

f = design tensile strength at the calculation temperature (see Table 3.3.1), in megapascals

P = calculation pressure (see Clause 3.2.1), in megapascals

r_L = inside radius of knuckle at larger cylinder, in millimetres

r_s = inside radius of knuckle at smaller cylinder, in millimetres

t = minimum calculated thickness of conical ends or reducers (exclusive of added allowances–see Clause 3.4.2), in millimetres

α = angle of slope of conical end or reducer (at the point under consideration) to the vessel axis (see Figure 3.10.2), in degrees

NOTE: For offset cones, use the larger α.

η = lowest efficiency of any joint in the conical ends or reducers (see Clause 3.10.4 for attachment joints)

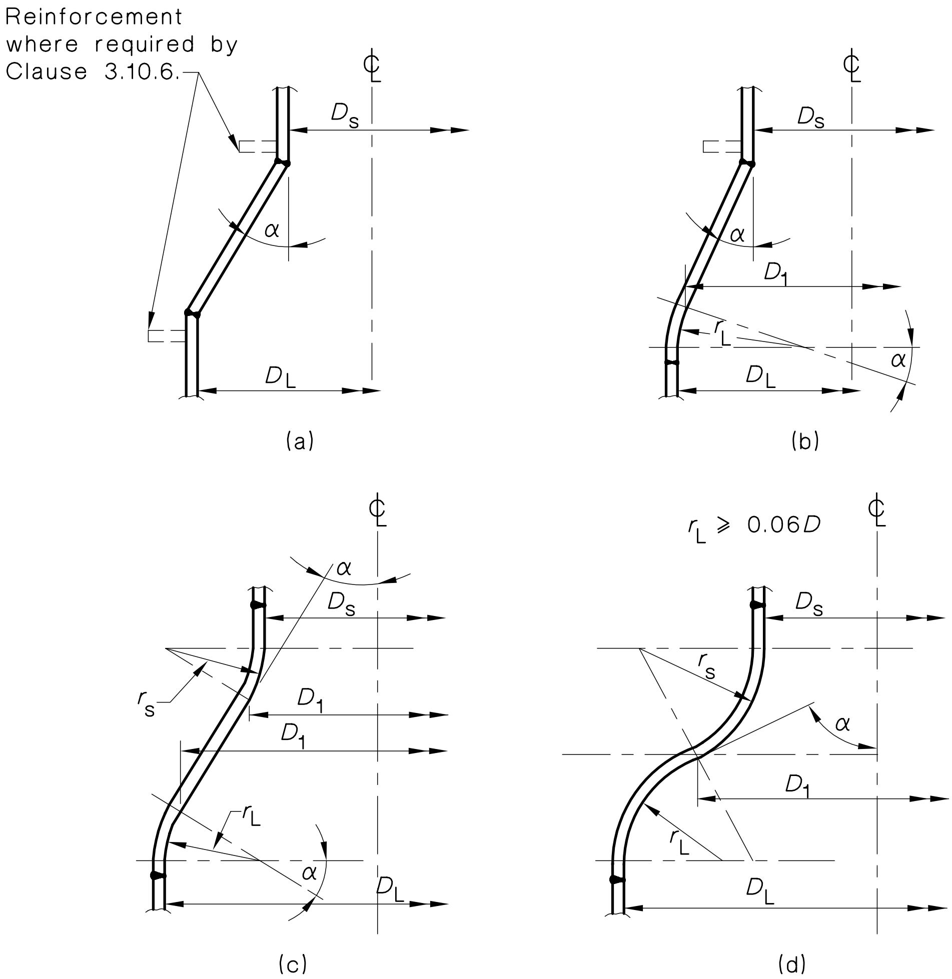


FIGURE 3.10.2 CONICAL ENDS AND REDUCERS

3.10.3 Conical sections The minimum calculated thickness of a conical section shall be determined by—

$$t = \frac{PD_1}{2f\eta - P} \times \frac{1}{\cos\alpha} \qquad \ldots 3.10.3(1)$$

or

$$P = \frac{2\ f\eta t\ \cos\alpha}{D_1 + (t\ \cos\ \alpha)} \qquad \ldots 3.10.3(2)$$

When the angle α exceeds 70 degrees the thickness of the conical section shall be determined as for a flat end as specified in Clause 3.15.

3.10.4 Attachment of cone to cylinder

(a) A transition knuckle is recommended between the cone and the cylinder and shall be used when the angle α is greater than 30 degrees. See Clause 3.10.5 for minimum calculated thickness.

(b) Where the angle α does not exceed 30 degrees the cone may be attached to the cylinder without a transition knuckle provided that the attachment is a double butt-welded joint and complies with the requirements of Clause 3.10.6.

3.10.5 Transition knuckles The minimum calculated thickness of a transition knuckle between the large end of the cone and the cylinder shall be at least equal to the thickness required for a torispherical end as determined in Clause 3.12.5.2, substituting—

$$\frac{D_1}{2\cos\alpha} \text{ for } R \qquad \ldots 3.10.5$$

The transition knuckle shall have a length of straight flange sufficient to meet the requirements shown in Figure 3.12.6.

Any taper between the knuckle and cone shall be in accordance with Figure 3.5.1.8.

Transition knuckles at the small end of the cone shall have a minimum actual thickness at least equal to the minimum required thickness of the cylinder to which they attach.

'Reverse curve' transition knuckles shown in Figure 3.10.2(d) may be used provided that their design conforms to the requirements of Clause 1.5.

Conical sections in Group F or Group G steels shall have transition knuckles at both ends, terminating in skirts (or extensions). The knuckle radius shall be no less than 10 percent of the outside diameter of the skirt, or no less than three times the cone thickness, whichever is larger. The skirt length shall be not less than $0.50\sqrt{rt}$ (where r is the inside radius of the adjacent cylinder and t is the thickness of the cone) or not less than 38 mm, whichever is larger.

3.10.6 Reinforcement

3.10.6.1 *General* Reinforcement may be required where the cone attaches to the cylinder without a transition knuckle, as provided in Clause 3.10.4(b). Where reinforcement is required, it shall be in accordance with this Clause (3.10.6).

3.10.6.2 *Notation*

t = minimum calculated thickness of cylinder at cone-to-cylinder junction, (exclusive of added allowance, see Clause 3.4.2), in millimetres.

T_s = nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in millimetres

T_c = nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance, in millimetres

T_e = the smaller of $(T_s - t)$ and $[T_c - (t/\cos\alpha)]$, in millimetres

D_S = inside diameter of small cylinder, in millimetres

D_L = inside diameter of large cylinder, in millimetres

A = required area of reinforcement, in square millimetres

A_e = effective area of reinforcement due to excess metal thickness, in square millimetres

Δ = value to indicate need for reinforcement at cone-to-cylinder intersection having an angle $\alpha \leq 30$ degrees; when $\Delta \geq \alpha$, no reinforcement at the junction is required (see Tables 3.10.6.3 and 3.10.6.4)

$$m = \text{the smaller of } \left(\frac{T_s}{t}\cos(\alpha - \Delta)\right) \text{ and } \left(\frac{T_c \cos\alpha \cos(\alpha - \Delta)}{t}\right) \quad \ldots 3.10.6.2$$

η = lowest efficiency of the longitudinal joint in the shell or end or of the joint in the reinforcement ring; for the large end of the reducer in compression $\eta = 1$ for butt welds.

P,f and α are as defined in Clause 3.10.2.

3.10.6.3 *Reinforcement at large end of cone to cylinder* Reinforcement shall be provided at the junction of the cone with the large cylinder of conical ends and reducers without knuckles when the value of Δ obtained from Table 3.10.6.3 using the appropriate ratio $P/f\eta$ is less than α. Intermediate values may be interpolated.

TABLE 3.10.6.3

VALUES OF Δ FOR JUNCTION AT THE LARGE CYLINDER FOR α ≤ 30 DEGREES

$P/f\eta$ Δ, degrees	0.001 11	0.002 15	0.003 18	0.004 21	0.005 23
$P/f\eta$ Δ, degrees	0.006 25	0.007 27	0.008 28.5	0.009* 30	

* Δ = 30 degrees for greater values of $P/f\eta$.

The cross-sectional area of the reinforcement ring shall be at least equal to that determined by Equation 3.10.6.3(1), as follows:

$$A = \frac{PD_L^2}{8f\eta}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \quad \ldots 3.10.6.3(1)$$

When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equation, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = 2.8\ T_e\sqrt{(D_L\ T_s)} \quad \ldots 3.10.6.3(2)$$

The additional area of reinforcement as required shall be situated within a distance of $0.7\sqrt{(D_L T_s)}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.35\sqrt{D_L T_S}$ from the junction.

3.10.6.4 *Reinforcement at small end of cone to cylinder* Reinforcement shall be provided at the junction of the cone with the small cylinder of conical ends and reducers without knuckles when the value of the Δ obtained from Table 3.10.6.4 using the appropriate ratio $P/f\eta$, is less than α. Intermediate values may be interpolated.

TABLE 3.10.6.4

VALUES OF Δ FOR JUNCTIONS AT THE SMALL CYLINDER FOR α ≤ 30 DEGREES

$P/f\eta$ Δ, degrees	0.002 4	0.005 6	0.010 9	0.02 12.5
$P/f\eta$ Δ, degrees	0.04 17.5	0.08 24	0.10 27	0.125* 30

* Δ = 30 degrees for greater values of $P/f\eta$.

The cross-sectional area of the reinforcement ring shall be at least equal to that determined by the following equation:

$$A = \frac{PD_s^2}{8f\eta}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \qquad \ldots 3.10.6.4(1)$$

When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = 0.7m(D_s t)^{1/2}\left[\left(T_c - \frac{t}{\cos\alpha}\right) + (T_s - t)\right] \qquad \ldots 3.10.6.4(2)$$

The additional area of reinforcement as required shall be situated within a distance of $0.7(D_s T_s)^{1/2}$ from the junction and the centroid of the added area shall be within a distance of $0.35(D_s T_s)^{1/2}$ from the junction.

3.11 CONICAL ENDS AND REDUCERS SUBJECT TO EXTERNAL PRESSURE

3.11.1 General The minimum calculated thickness of conical ends and reducers subject to external pressure, i.e. on the convex side, shall be no less than that required in Clause 3.11.2, and no less than that required by Clause 3.10 for an internal pressure equal to the external pressure, assuming η = 1.0. The minimum calculated thickness shall be increased where necessary to meet the requirements of Clauses 3.4.2 and 3.4.3 and to meet other appropriate loadings given in Clause 3.2.3.

A3 **3.11.2 Minimum calculated thickness** The minimum calculated thickness of a conical end or reducer under external pressure, either seamless or with butt joints, may be determined from Clause 3.9.3 by calculating P_e and P_y for a cylinders of the following equivalent dimensions:

(a) Determine the value of P_e using—

(i) Equivalent mean diameter D_m, of cylinder = $(D_{mL} + D_{mS})/2$ . . . 3.11.2(1)

(ii) Equivalent thickness, $t_e = T\cos\alpha$ . . . 3.11.2(2)

(iii) Equivalent length, L_e = the axial length between centres of stiffeners or equivalent. (See Figures 3.9.2(j) and (k), dimension L).

(b) Determine the value of P_y using—

(i) Equivalent mean diameter, $D_m = D_{mL}$ . . . 3.11.2(3)

(ii) Equivalent thickness, $t_e = T\cos\alpha$ . . . 3.11.2(4)

The junction of the cone shall also comply with the requirements of Clause 3.10 for the design external pressure.

The nomenclature is the same as that given in Clauses 3.9.2 and 3.10.2.

3.12 DISHED ENDS SUBJECT TO INTERNAL PRESSURE

3.12.1 General Unstayed dished ends of spherical, ellipsoidal, or torispherical shape, subject to internal pressure (i.e. pressure on the concave side), shall be designed in accordance with this Clause (3.12). Ends constructed of Group F or Group G steels shall be spherical or ellipsoidal in shape.

3.12.2 Notation For the purpose of this Clause (3.12), the following notation applies:

t = minimum calculated thickness of end at thinnest point after forming (exclusive of added allowances, see Clause 3.4.1), in millimetres

P = calculation pressures (see Clause 3.2.1), in megapascals

D = inside diameter of end in millimetres

D_o = outside diameter of end in millimetres

R = inside spherical or crown radius of end, in millimetres

R_o = outside spherical or crown radius of end, in millimetres

r = inside knuckle radius, in millimetres

η = lowest efficiency of any joint in an end including the end to shell joint in the case of an end not having a straight flange

= 1.0 for end made from one plate having a straight flange

f = design tensile strength at the design temperature (see Table 3.3.1), in megapascals

h = one-half of the length of the inside minor axis of an ellipsoidal end, or the inside depth of a torispherical end measured from the tangent line in the fully corroded condition, in millimetres

h_o = one-half of the length of the outside minor axis of an ellipsoidal end measured from the tangent line, in millimetres

K = a factor in the equation for ellipsoidal ends, depending on the end proportion $D/2h$

$$= \frac{1}{6}\left[2 + \left(\frac{D}{2h}\right)^2\right] \text{(see Table 3.12.5.1.)}$$

M = a factor in the equation for torispherical ends depending on the end proportion R/r

$$= \frac{1}{4}\left[3 + \left(\frac{R}{r}\right)^{1/2}\right] \text{(see Table 3.12.5.2.)}$$

3.12.3 Shape limitations The shape of typical ends is shown in Figure 3.12.3.

Dished ends with reverse knuckles may be used provided that the calculation pressure for the end is determined in accordance with Clause 5.12.

The inside crown radius to which an unstayed end is dished shall be no greater than the outside diameter of the end at the tangent line.

The possibility of buckling due to the setting up of high localized stresses during hydrostatic testing shall be considered. Particular care shall be exercised when the following limits are approached or exceeded:

(a) *For ellipsoidal ends*: $\dfrac{D}{t} \geq 600$

(b) *For torispherical ends* with knuckle radius approaching the minimum permitted (six percent of crown radius):

$$\frac{D}{t} > 100 \text{ or } P \geq 690 \text{ kPa}$$

Where an end is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for unstayed flat ends in Clause 3.15, using $K = 5$.

NOTE: For torispherical ends with $\frac{D}{t_k} > 300$, it is recommended that—

$$\frac{P}{f} \leq \frac{150\left(\frac{r}{D}\right)^{0.84}}{\left(\frac{D}{t_k}\right)^{1.53}\left(\frac{R}{D}\right)^{1.1}}$$

where

A3 t_k = minimum calculated thickness of knuckle (exclusive of added allowances, see Clause 3.4.2), in millimetres.

For other notation, see Clause 3.12.2.

This equation applies below the creep range.

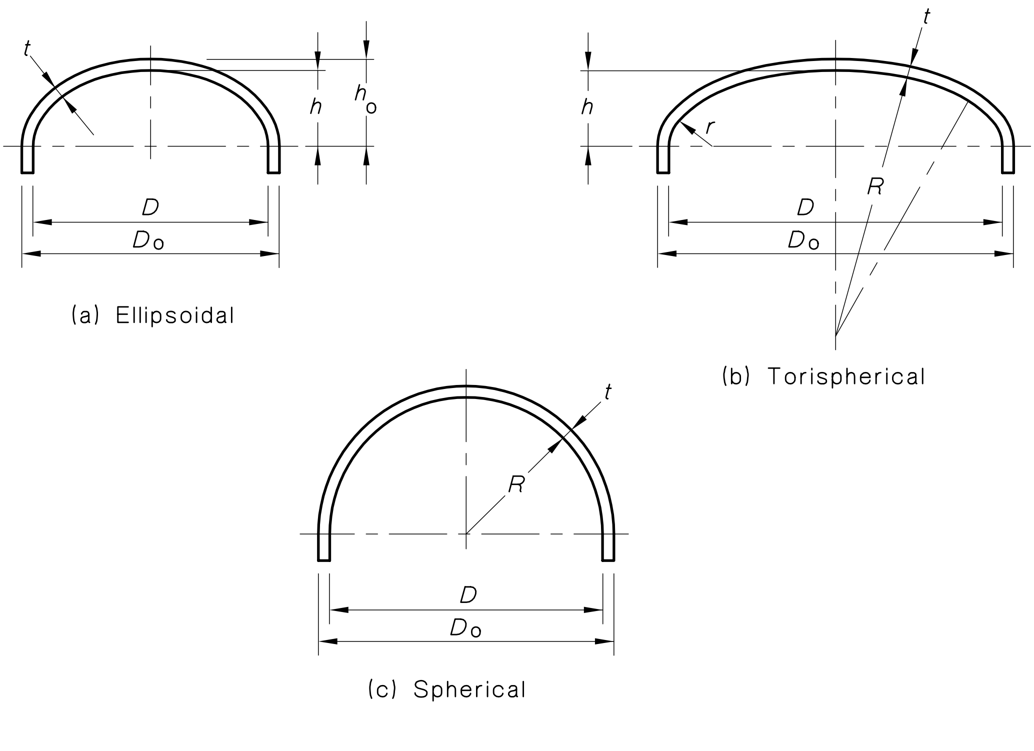


FIGURE 3.12.3 DIMENSIONS OF DISHED ENDS

3.12.4 Openings in ends Openings in ends shall comply with the requirements of Clause 3.18.

3.12.5 Thickness of ends

3.12.5.1 *Ellipsoidal ends* The minimum calculated thickness of ellipsoidal ends, with or without openings, shall be determined by the following equation:

A3 $$t = \frac{PDK}{2f\eta - P} \quad \ldots 3.12.5.1$$

3.12.5.2 *Torispherical ends* The minimum calculated thickness of torispherical ends, with or without openings, shall be determined by the following equation:

A3

$$t = \frac{PRM}{2f\eta - 0.5P} \quad \ldots 3.12.5.2$$

TABLE 3.12.5.1

VALUES OF FACTOR *K*
(Use nearest value of *D*/2*h*; interpolation unnecessary)

$\frac{D}{2h}$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0*
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$\frac{D}{2h}$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.50	0.50	

* Usually referred to as a 2:1 ellipsoidal end.

TABLE 3.12.5.2

VALUES OF FACTOR *M*
(Use nearest value of *R*/*r*; interpolation unnecessary)

$\frac{R}{r}$	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18
$\frac{R}{r}$	3.25	3.50	4.0	4.5	5.0	5.5	6.0	6.5	—
M	1.20	1.22	1.25	1.28	1.31	1.34	1.36	1.39	—
$\frac{R}{r}$	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	—
M	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	—
$\frac{R}{r}$	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.66*	—
M	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77	—

* Maximum ratio allowed when R equals the outside diameter (D_o) of the end.

3.12.5.3 *Spherical ends* The minimum thickness of spherical ends, with or without openings, shall be determined by the following equation:

A3

$$t = \frac{PR}{2f\eta - 0.5P} \quad \ldots 3.12.5.3$$

3.12.5.4 *Straight flange on ends* The minimum calculated thickness of any cylindrical portion of an end shall comply with the appropriate requirements for cylindrical shells, including any applicable joint efficiency.

3.12.6 Attachment of ends Ends intended for attachment by welding shall comply with Figure 3.12.6 and for Group F or Group G steels shall be attached by full penetration welds in accordance with Figure 3.12.6(a), (b), (c), (d) or (e).

Ends intended for attachment by brazing shall have a straight flange sufficient to meet the requirements for circumferential joints in Clause 3.5.

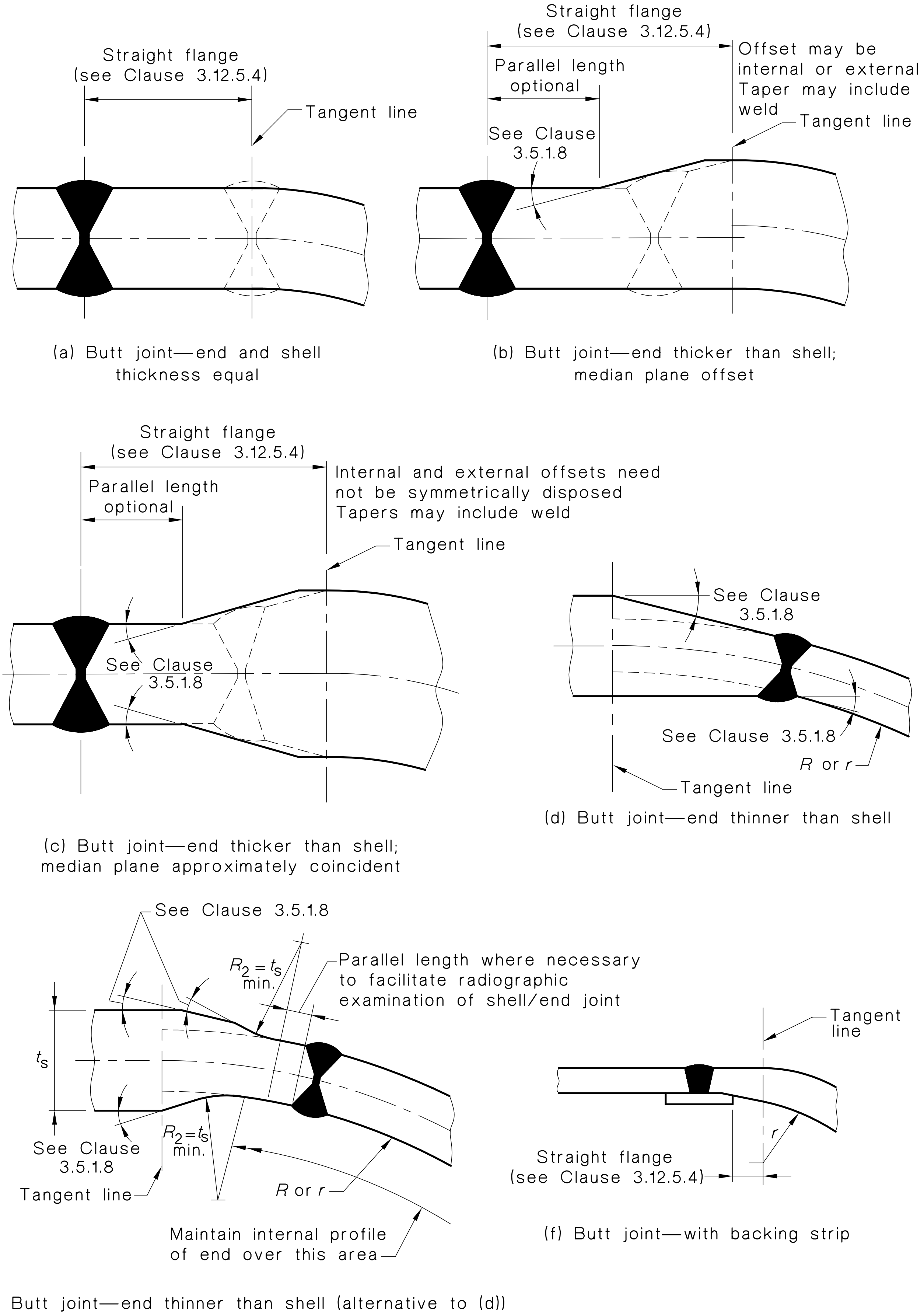
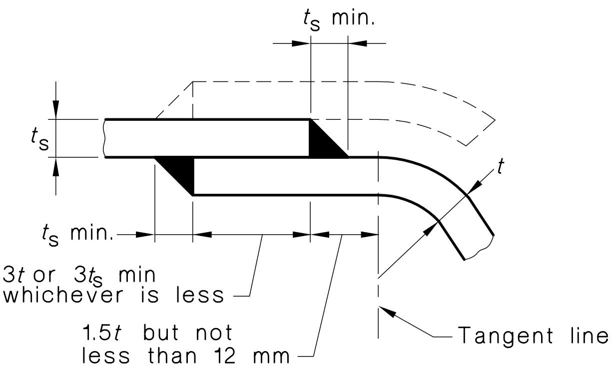
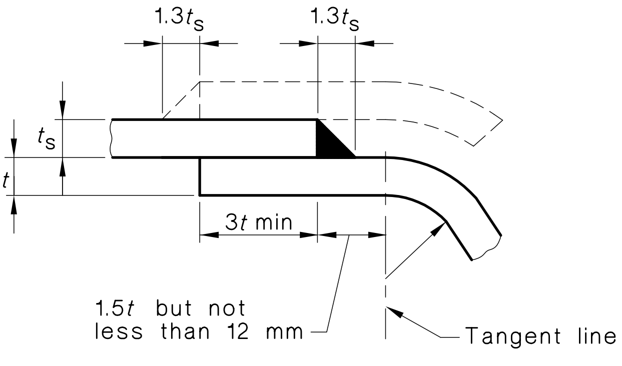


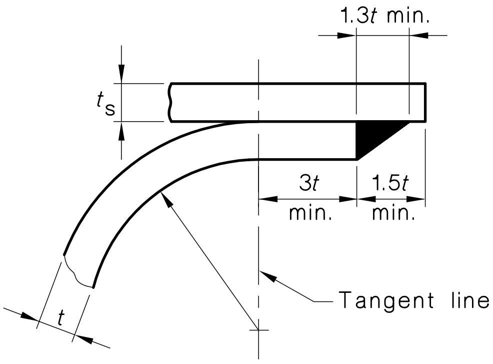
FIGURE 3.12.6 ATTACHMENT OF DISHED ENDS



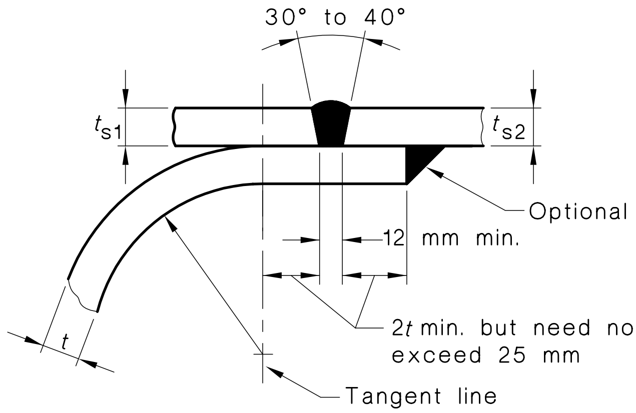
(g) Double fillet lap weld
(Class 3 vessels only)



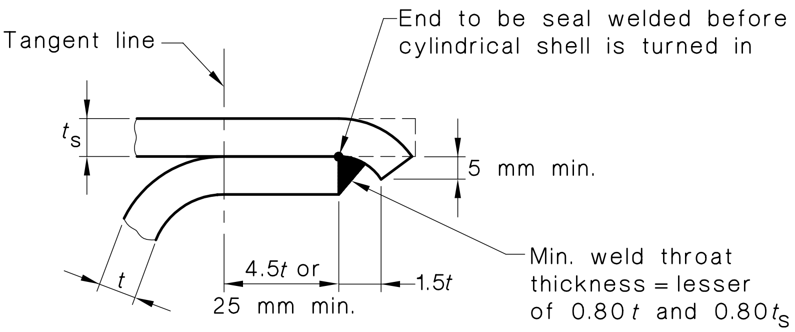
(h) Single fillet lap weld
For limitations see Table 3.5.1.7



(j) Single fillet lap weld
For limitations see Table 3.5.1.7



(k) Intermediate end
(t_{s1} and t_{s2} may be different)



(l) Single fillet lap weld ends convex to pressure
(Class 3 vessels only)

FIGURE 3.12.6 (in part) ATTACHMENT OF DISHED ENDS

3.13 DISHED ENDS SUBJECT TO EXTERNAL PRESSURE

3.13.1 General Unstayed dished ends of spherical, ellipsoidal or torispherical shape subject to external pressure (i.e. pressure on the convex side) shall be designed in accordance with this Clause (3.13). The thickness so determined shall be not less than that required by Clause 3.4.3. Ends constructed of Group F or Group G steels shall be spherical or ellipsoidal in shape.

3.13.2 Notation See Clause 3.12.2.

3.13.3 Ellipsoidal ends The minimum calculated thickness of ellipsoidal ends of seamless or butt joint fabrication at any point after forming shall be the greater thickness determined by the following:

(a) The thickness of an equivalent sphere determined in accordance with Clause 3.9. The value of R_o shall be taken as equal to the outside diameter of the end multiplied by a factor determined from Equation 3.13.3 or taken from the following:

h_o/D_o Factor	0.167 1.36	0.178 1.27	0.192 1.18	0.208 1.08	0.227 0.99	0.25 0.90
h_o/D_o Factor	0.278 0.81	0.313 0.73	0.357 0.65	0.417 0.57	0.50 0.50	

NOTE: Intermediate values may be obtained by interpolation.

The factor may be derived from the following equation:

$$\text{Factor} = \frac{0.25}{h_o/D_o} + 0.4\frac{h_o}{D_o} - 0.2 \qquad \text{. . . .3.13.3}$$

(b) The thickness t as determined for a dished end under an equivalent internal pressure equal to 1.67 times the external pressure, assuming a joint efficiency $\eta = 1.0$.

3.13.4 Spherical and torispherical ends The minimum calculated thickness at any point after forming of spherical or torispherical ends shall be the greater thickness determined by the following:

(a) The thickness of an equivalent sphere, having an outside radius R_o equal to the outside crown radius of the end, determined in accordance with Clause 3.9.

(b) The thickness t, as determined for a dished end under an equivalent internal pressure equal to 1.67 times the external pressure, assuming a joint efficiency $\eta = 1.0$.

3.13.5 Attachment of ends The required length of straight flange on ends convex to pressure shall comply with the requirements of Clause 3.12.6.

3.14 DISHED ENDS—BOLTED SPHERICAL TYPE

3.14.1 General Circular spherically dished ends with bolting flanges concave or convex to pressure and conforming with Figure 3.14.1 shall be designed in accordance with this Clause (3.14). The thickness so determined shall also comply with Clause 3.4.3.

NOTES:

1 Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

2 Equations 3.14.3(1) to (8), inclusive, are approximate in that they do not take into account continuity between the flange ring and the dished end. A more exact method of analysis which takes this into account may be used if it meets the requirements of Clause 1.5. Such a method should parallel the method of analysis and allowable stresses for flange design in Clause 3.21.

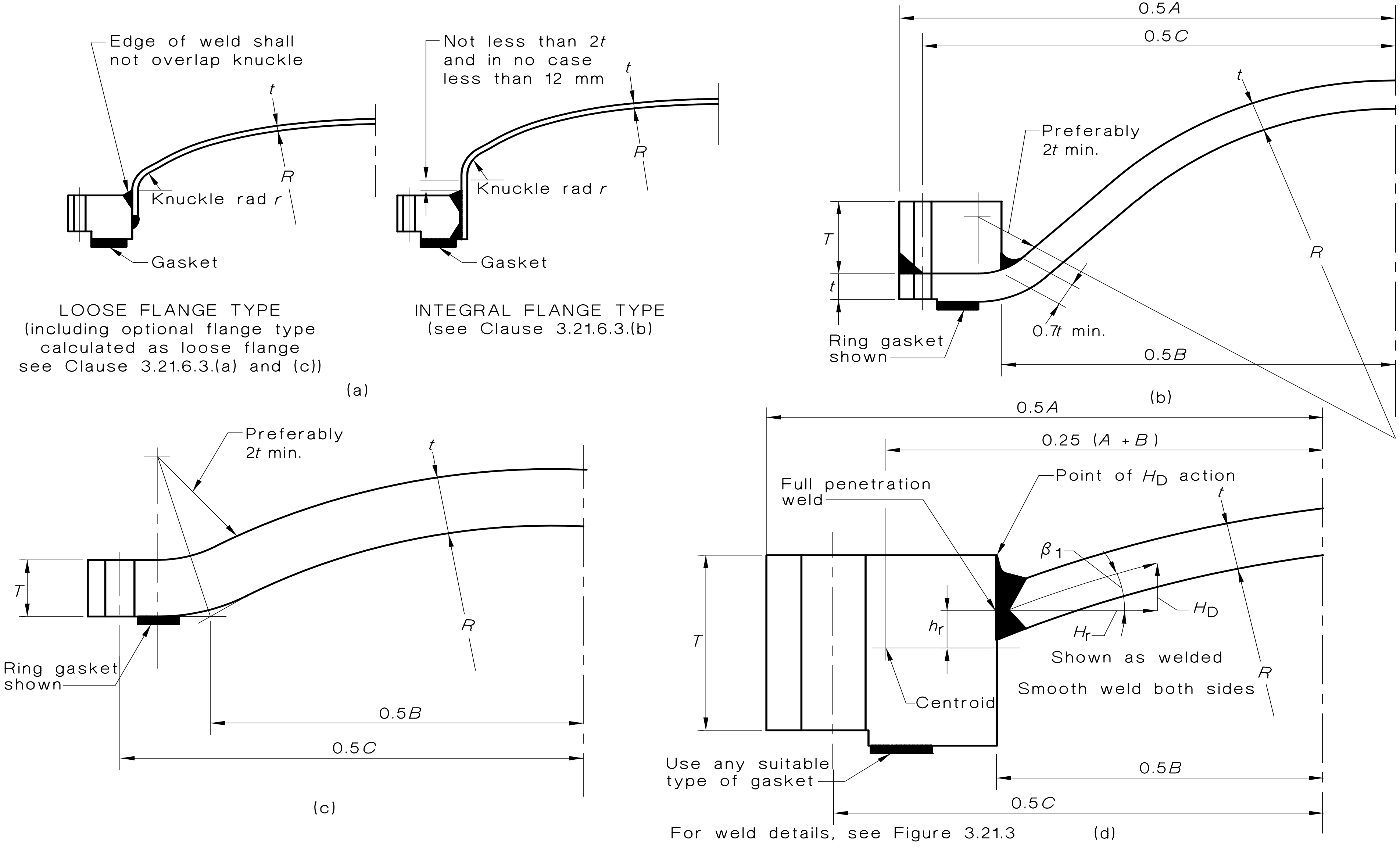


FIGURE 3.14.1 SPHERICALLY DISHED ENDS WITH BOLTING FLANGES

3.14.2 Notation For the purpose of this Clause (3.14), the following notation applies:

A = outside diameter of flange, in millimetres

B = inside diameter of flange, in millimetres

C = bolt circle diameter, in millimetres

t = minimum calculated thickness of end after forming at the thinnest point (exclusive of added allowances–see Clause 3.4.2), in millimetres

R = inside radius of crown, in millimetres

r = inside knuckle radius, in millimetres

P = calculation pressure (see Clause 3.2.1), in megapascals

= 0 for the gasket seating condition in those equations of Clause 3.14.3 which include the term M_o

f = design tensile strength at the design temperature (see Table 3.3.1), in megapascals

T = minimum calculated flange ring thickness, in millimetres

= the greater of the thickness calculated for the operating conditions (P equals calculation pressure) and the gasket seating conditions (P equals 0)

M_o = the total moment determined from Clause 3.21 for both operating and gasket seating conditions, except that for ends in Figure 3.14.1(d), additional moment $H_r h_r$ shall be included (see Note 1 of Clause 3.14.1), in newton millimetres

H_r = radial component of the membrane force in the spherical crown section (equals $H_D \cot \beta_1$), acting at the intersection of the inside of the flange ring with the centreline of the dished end thickness, in newtons

H_D = axial component of the membrane force in the spherical crown section (equals $0.785B^2P$) acting at the inside of the flange ring, in newtons

h_D = radial distance from the bolt circle to the inside of the flange ring, in millimetres

h_r = lever arm of force H_r about centroid of flange ring, in millimetres

β_1 = angle between tangent to the centreline of the dished end at its intersection with the flange ring, and a line perpendicular to the axis of the dished end, in degrees

$$= \arcsin\left(\frac{B}{2R + t}\right)$$

NOTE: $\cot \beta_1 = \left[\left(\frac{2R + t}{B}\right)^2 - 1\right]^{½}$

3.14.3 Ends subject to internal pressure (concave to pressure) The minimum calculated thickness of the end and flange shall be no less than that determined by the following equations:

(a) *Ends of type shown in Figure 3.14.1(a)*

t ≥ thickness determined from appropriate equation in Clause 3.12, and R and r shall not exceed the limits in Clause 3.12.

T ≥ thickness determined from Clause 3.21.

(b) *Ends of type shown in Figure 3.14.1(b)* (efficiency of any butt joint in end may be disregarded).

$$t = \frac{5PR}{6f} \qquad \text{. . . 3.14.3(1)}$$

$$T \text{ (for ring gasket)} = \left[\frac{M_o}{fB}\left(\frac{A+B}{A-B}\right)\right]^{½} \qquad \text{. . . 3.14.3(2)}$$

$$T \text{ (for full face gasket)} = 0.6\left(\frac{P}{f}\left[\frac{B(A+B)(C-B)}{A-B}\right]\right)^{½} \qquad \text{. . . 3.14.3(3)}$$

NOTE: The radial components of the membrane load in the spherical section are assumed to be resisted by its flange.

(c) *Ends of type shown in Figure 3.14.1(c)* (efficiency of any butt joint in end may be disregarded).

$$t = \frac{5PR}{6f} \qquad \text{. . . 3.14.3(4)}$$

$$T \text{ (for ring gasket)} = Q\left[1 + \left(1 + \frac{7.5M_o}{PQBR}\right)^{½}\right] \qquad \text{. . . 3.14.3.(5)}$$

$$T \text{ (for full face gasket)} = Q\left[1 + \left[1 + \frac{3B(C-B)}{QR}\right]^{½}\right] \qquad \text{. . . 3.14.3(6)}$$

where

$$Q = \frac{PR}{4f}\left[\frac{1}{1 + 6\left(\frac{C-B}{C+B}\right)}\right] \text{ for round bolting holes}$$

$$Q = \frac{PR}{4f}\left[\frac{1}{1 + 2\left(\frac{C-B}{C+B}\right)}\right] \text{ for bolting holes slotted through edge.}$$

(d) *Ends of type shown in Figure 3.14.1(d)*(efficiency of any butt joint in end may be disregarded).

$$t = \frac{5PR}{6f} \qquad \text{. . . 3.14.3(7)}$$

$$T = F + (F^2 + Z)^{½} \qquad \text{. . . 3.14.3(8)}$$

where

$$F = \frac{PB(4R^2 - B^2)^{½}}{8f(A-B)}$$

$$Z = \frac{M_o(A+B)}{fB(A-B)}$$

3.14.4 Ends subject to external pressure (convex to pressure) Circular spherically dished ends convex to pressure shall be designed to the equations in Clause 3.14.3. The spherical sections shall then be thickened, where necessary, to meet the requirements of Clause 3.13.

3.15 UNSTAYED FLAT ENDS AND COVERS

3.15.1 General Unstayed flat ends, covers, plates and blind flanges shall be designed in accordance with this Clause (3.15). The thickness so determined shall be not less than that required by Clause 3.4.3. These requirements apply to both circular or non-circular ends and covers. Clause 3.15.5 gives requirements for internally fitted doors.

Some acceptable types of flat ends and covers are shown in Figure 3.15.1.

3.15.2 Notation For the purpose of this Clause (3.15), the following notation applies.

K = a factor depending upon the method of attachment of end, shell dimensions, and other items as listed below (see Figure 3.15.1)

D_1 = long span of non-circular ends or covers measured perpendicular to short span, in millimetres

D = diameter, measured as indicated in Figure 3.15.1, in millimetres; or short span of non-circular ends or covers measured perpendicular to long span, in millimetres

G = used in the narrow-face calculations to which the flat cover is attached (see Clause 3.21.6).

h_G = gasket moment arm taken from values in the design of the flange to which the plate is attached (refer Clause 3.21.6) or if the flange is not designed, equal to the radial distance from the centreline of the bolts to the line of the gasket reaction, as shown in Figure 3.15.1 (k) and (l), in millimetres

L = perimeter of non-circular bolted end measured along the centre of the bolt holes, in millimetres

l = length of flange of flanged ends, measured from the tangent line of knuckle, as indicated in Figure 3.15.1(a) and (c), in millimetres

m = the ratio $\dfrac{t_r}{t_s}$

P = calculation pressure, in megapascals

r = inside corner radius on an end formed by flanging or forging, in millimetres

f = design tensile strength at design temperature (see Table 3.3.1), in megapascals

t = minimum calculated thickness of flat end or cover (exclusive of added allowances—see Clause 3.4.2), in millimetres

t_e = minimum distance from bevelled end of vessel, before welding, to outer face of end, as indicated in Figure 3.15.1(h) and (j), in millimetres

t_f = actual thickness of the flange on a forged end, at the large end (exclusive of added allowances—see Clause 3.4.2) as indicated in Figure 3.15.1, in millimetres

t_h = actual thickness of flat end or cover (exclusive of added allowances–see Clause 3.4.2), in millimetres

t_r = required thickness of seamless shell, for pressure, in millimetres

t_s = actual thickness of shell (minus any allowances, see Clause 3.4.2), in millimetres

t_w = thickness through the weld joining the edge of an end to the inside of a vessel, as indicated in Figure 3.15.1(g), in millimetres

t_1 = throat dimension of the closure weld, as indicated in Figure 3.15.1(r), in millimetres.

A3 W = total bolt force, given for circular ends in Equations 3.21.6.4.4(1) and 3.21.6.4.4(2), in newtons

Z = a factor for non-circular ends and covers that depends on the ratio of short span to long span, as given in Clause 3.15.4 (dimensionless)

η = lowest efficiency of any type A (longitudinal) welded joint in an end

3.15.3 Minimum calculated thickness for circular ends The minimum calculated thickness shall be determined by the following equations:

$$t = D\left(\frac{P}{Kf\eta}\right)^{0.5} \qquad \text{. . . 3.15.3(1)}$$

except for bolted ends, covers and blind flanges with edge moment (see Figure 3.15.1(k) and (l))—

$$t = D\left(\frac{P}{Kf\eta} + \frac{1.78Wh_G}{f\eta D^3}\right)^{0.5} \qquad \text{. . . 3.15.3(2)}$$

In the latter equation, t shall be the greater thickness calculated for both the operation and gasket seating conditions. For operating condition, P = calculation pressure, f = design strength at calculation temperature, and W is obtained for the operating condition in Clause 3.21. For gasket seating, P = 0, f = design strength at atmospheric temperature, and W is obtained for the gasket seating condition in Clause 3.21.

3.15.4 Minimum calculated thickness for non-circular ends The minimum calculated thickness of rectangular, elliptical and obround (see Clause 3.18.3) ends and covers shall be determined by the following equations:

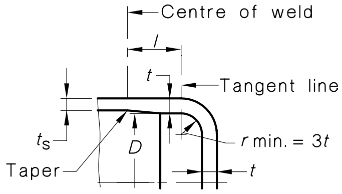
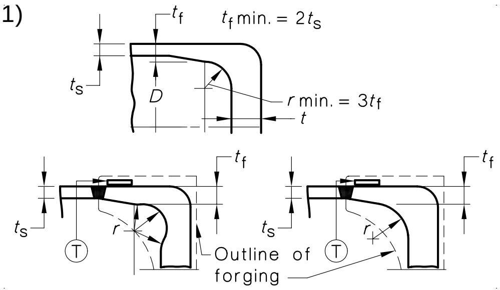
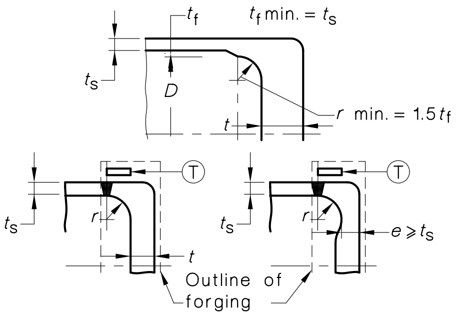
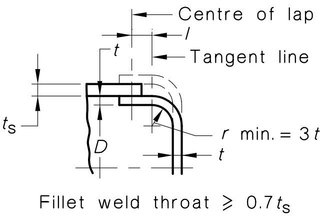
$$t = D\left(\frac{ZP}{Kf\eta}\right)^{0.5} \qquad \text{. . . 3.15.4(1)}$$

where

$$Z = 3.4 - \frac{2.4D}{D_1} \quad \text{but not greater than 2.5.}$$

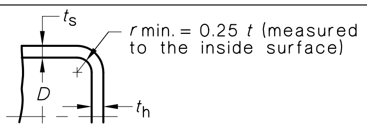
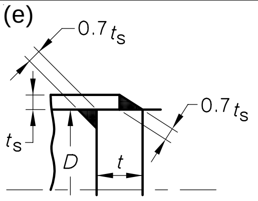
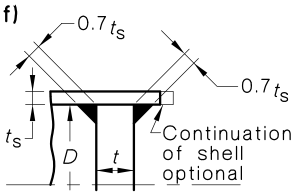
For bolted flanges with edge moment (see Figure 3.15.1(k) and (l)) the thickness shall be determined in the same way as for bolted flanges in Clause 3.15.3, using the following equation:

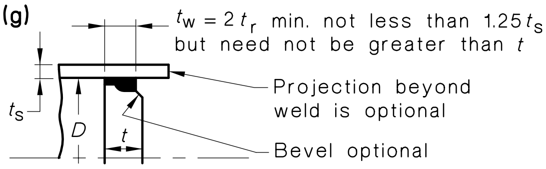
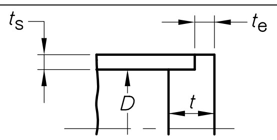
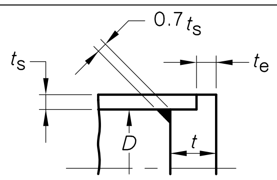
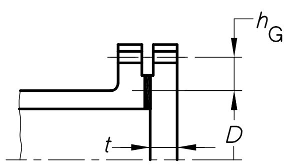
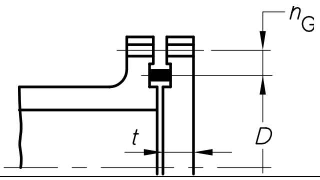
$$t = D\left(\frac{ZP}{Kf\eta} + \frac{6Wh_G}{f\eta LD^2}\right)^{0.5} \qquad \text{. . . 3.15.4(2)}$$

Figure	Value of K	Circular or non-circular ends	Conditions (in addition to those shown in Figure)
(a) 	5.9	C or N-C	No special requirement for l
	10.0	C only	$l \geq \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{(Dt_h)}$ For taper see Clause 3.5.1.8
	10.0	C	l less than above; but $t_s = 1.12t_h\sqrt{\left(1.1 - \frac{1}{Dt_h}\right)}$ For length $\geq 2\sqrt{Dt_s}$; For taper see Clause 3.5.1.8
(b-1) 	5.9	C or N-C	Seamless or welded Two welded alternatives machined from forgings (not plate) are shown
(b-2) 	3/m, but not more than 5.0	C or N-C	Seamless or welded Two welded alternatives machined from forgings (not plate) are shown
(c) 	7.7	C	Lap welded or brazed $l \geq$ that give in (a) above
	5.0	C or N-C	Lap welded or brazed. No limit on l
	3.3	C	Screwed cap over end; threads designed against failure by shear, tension or compression resulting from end pressure force using a factor of safety of 4. Threaded parts also at least as strong as the threads for standard piping of the same diameter. Seal welding may be used if desired.

(*continued*)

FIGURE 3.15.1(in part) SOME ACCEPTABLE TYPES OF UNSTAYED FLAT ENDS AND COVERS

<table>
<tr><th>Figure</th><th>Value of K</th><th>Circular or non-circular ends</th><th>Conditions (in addition to those shown in Figure)</th></tr>
<tr><td>A3 (d)
</td><td>7.7</td><td>C</td><td>Integral end by upsetting or spinning of shell as in closing header ends
$D \le 600$ mm $t_h \ge t_s$; $0.05 \le \frac{t_h}{D} < 0.25$</td></tr>
<tr><td>(e)

(f)
</td><td rowspan="2" colspan="2">3/m but not more than 5.0 for circular ends C

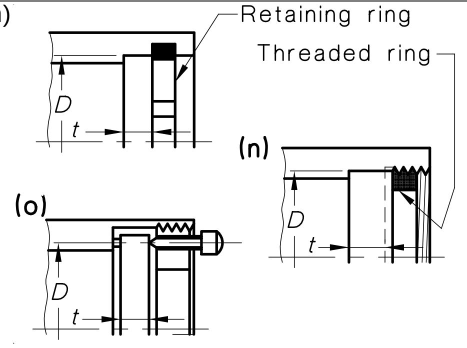
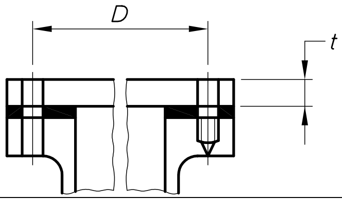
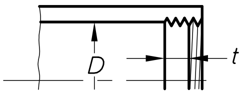
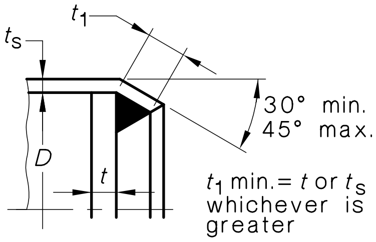
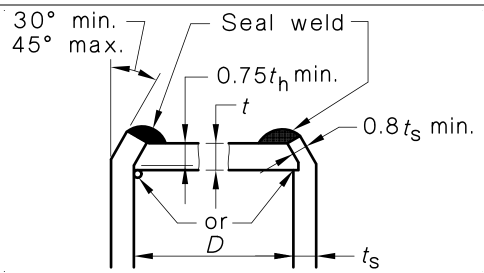
3.0 for non-circular ends N-C</td><td>If m <1 then t_s shall be maintained inwardly for a distance $2\sqrt{Dt_s}$ from the inside face of the end</td></tr>
<tr><td>(g)
</td><td>Standard single bevel or J weld preparation shall be used</td></tr>
<tr><td>(h)
</td><td>3.0</td><td>C</td><td>See Figure 3.17.12(a)-(m) inclusive for details of welded joint</td></tr>
<tr><td>(j)
</td><td>3/m but ≤ 5.0</td><td>C</td><td>The fillet weld may contribute an amount equal to t_s to the sum of weld dimensions (see Figure 3.17.12(a) to (m) inclusive for outside weld)</td></tr>
<tr><td>A3 (k)

(l)
</td><td>3.3</td><td>C and N-C</td><td>Use Equations 3.15.3(2) and 3.15.4(2).

The net end plate thickness under the groove or between the groove and the outer edge of the end, shall be not less than:
$D\sqrt{\left(\frac{1.78\,Wh_g}{fD^3}\right)}$
(for circular ends and covers)

$D\sqrt{\left(\frac{6\,Wh_G}{fLD^2}\right)}$
(for non-circular ends and covers)</td></tr>
</table>

(*continued*)

FIGURE 3.15.1(in part) SOME ACCEPTABLE TYPES OF UNSTAYED FLAT ENDS AND COVERS

Figure	Value of *K*	Circular or non-circular ends	Conditions (in addition to those shown in Figure)
(m) 	3.3	C	Positive mechanical locking required. All possible means of failure, (shear, tension, compression or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are to be designed with a factor of safety of at least 4. Seal welding may be used, if desired.
A3 (p) 	4.0	C and N-C	Full face joint
(q) 	1.3	C	$D \le 315$ mm. Also applies to ends with integral flange screwed over the vessel end, when thread is designed as for (n). Seal welding may be used, if desired
(r) 	3.0	C	$D \le 450$ mm. Crimping may be done cold when this operation will not injure the metal
(s) 	3.0	C	$D \le 450$ mm. Undercutting for seating shall leave at least $0.80t_s$. Bevelling shall be not less than $0.75t_h$. Crimping shall be done when the entire circumference of the cylinder is uniformly heated to forging temperature. Also $0.05 \le \frac{t_s}{D} > \frac{P}{f}$ $\quad P \le \frac{f}{5D}$

NOTES:

1 All welding to comply with appropriate requirements of Section 4.

2 In (b-1) and (b-2), *T* indicates position of tension test specimen taken from forging.

3 Ends and covers in Group F or Group G steels which are attached by welding shall be attached with full penetration butt welds.

FIGURE 3.15.1(in part) SOME ACCEPTABLE TYPES OF UNSTAYED FLAT ENDS AND COVERS

3.15.5 Internally fitted doors

3.15.5.1 *General* Internally fitted flat elliptical or circular doors or elliptical doors formed to the curvature of the surface to which they are fitted, shall be secured by studs or bolts and bridge pieces. The doors shall be of plate, built-up or pressed to shape (e.g. stiffened by forming) and subsequently heat treated, or made of one thickness of plate with a machined spigot or recess or other means of securing the jointing material. Doors shall fit closely and properly to the internal surfaces and when the spigot or recess is in a central position it shall not have a clearance greater than 1.5 mm at any point. Doors shall be machined on the bearing surfaces for nuts or collars. The plate shall be inspected before welding and shall be free from material defects.

The width of the gasket bearing surface for an internal manhole door where internal pressure forces the door against a flat gasket shall be not less than 17 mm. Where the plate thickness at the joint is less than 17 mm, the bearing width may be increased by either of the methods shown in Figure 3.15.5.

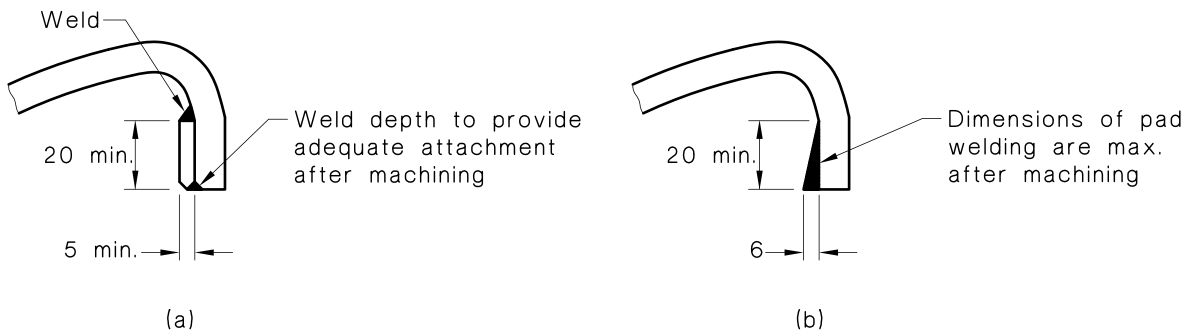


FIGURE 3.15.5 INCREASED WIDTH OF JOINTING SURFACE

3.15.5.2 *Thickness of one-plate doors* The minimum calculated thickness of an unstiffened one-plate door, either flat or formed to a cylindrical curvature, shall be no less than that determined by the following Equation:

$$t = \left(\frac{K_1 P d^2 + K_2 W_1}{f}\right)^{0.5} \quad \text{. . . 3.15.5.2}$$

where

t = minimum calculated thickness of one-plate door (exclusive of added allowances, see Clause 3.4.2), in millimetres

P = calculation pressure of vessel to which door is fitted, in megapascals

d = for elliptical doors—minor axis of the opening to which the door is fitted, in millimetres

= for circular doors—diameter of opening to which the door is fitted, in millimetres

W_1 = full load capacity of one stud (core area × design strength for stud material), in newtons

f = design strength at the design temperature (see Table 3.3.1), in megapascals

K_1 = stress factor

= 0.40 for all flat doors and for curved doors smaller than 180 mm × 125 mm (see Table 3.15.5.2 for curved doors 180 mm × 125 mm and larger)

K_2 = stress factor

= 0.80 for flat doors and 0.60 for curved doors

D = (diametrical) cylindrical curvature of door, in millimetres.

TABLE 3.15.5.2

STRESS FACTOR K_1 FOR CYLINDRICALLY CURVED ELLIPTICAL DOORS FITTED INTERNALLY

Size of opening mm	For values of $t \times D \times 10^{-4}$, mm²													
	0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**
(A) MINOR AXIS OF DOOR PARALLEL TO VESSEL AXIS														
400 × 300	0.07	0.07	0.13	0.18	0.21	0.24	0.26	0.28	0.29	0.31	0.33	0.34	0.35	0.36
380 × 280	0.08	0.08	0.14	0.19	0.24	0.25	0.27	0.29	0.31	0.32	0.34	0.35	0.36	0.37
280 × 180	0.10	0.19	0.24	0.29	0.32	0.34	0.35	0.36	0.36	0.37	0.38	0.38	0.39	0.39
225 × 180	0.16	0.25	0.30	0.33	0.35	0.36	0.37	0.38	0.38	0.38	0.38	0.38	0.39	0.39
180 × 125	0.21	0.31	0.34	0.37	0.37	0.37	0.8	0.38	0.38	0.38	0.38	0.39	0.39	0.40
(B) MAJOR AXIS OF DOOR PARALLEL TO VESSEL AXIS (See Clause 3.18.5.3)														
400 × 300	0.09	0.13	0.22	0.28	0.32	0.34	0.36	0.37	0.38	0.38	0.39	0.40	0.40	0.40
380 × 280	0.10	0.16	0.24	0.30	0.33	0.35	0.37	0.38	0.38	0.39	0.40	0.40	0.40	0.40
280 × 180	0.16	0.34	0.35	0.37	0.38	0.39	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.40
225 × 180	0.20	0.38	0.38	0.39	0.39	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
180 × 125	0.32	0.38	0.39	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

3.15.5.3 *Thickness of two-plate doors* Where a door is made of two plates attached together in such a manner as to adequately resist the shearing force between them, the door may be considered equivalent to a one-plate door. Otherwise, the thickness of the inner plate shall be no less than the minimum calculated thickness of the shell to which the door is fitted and the minimum calculated thickness of the door shall satisfy the relationship shown in the following equation:

$$t = \sqrt{(t_1^2 + t_2^2)} \qquad \ldots 3.15.5.3$$

where

t = minimum calculated thickness of a one-plate door from Equation 3.15.5.2

t_1 = thickness of the inner plate, in millimetres

t_2 = thickness of the outer plate, in millimetres.

3.15.5.4 *Bolting* Studs, bolts, nuts and washers shall comply with Clause 3.21.5.3, except that the minimum size shall be 16 mm.

A door to fit an opening not larger than 225 mm × 180 mm elliptical or 180 mm diameter may be fitted with one stud or bolt. A door for a larger opening shall be fitted with a minimum of two studs or bolts unless otherwise agreed between the parties concerned. Where studs are located at or near the focal points of the ellipse, then only one stud load (W_1) may be used in Equation 3.15.5.2.

The number and size of studs shall provide an adequate gasket seating force (W_{m2}) in accordance with Equation 3.15.5.4(1):

$$W_{m2} = bG_1y \qquad \text{. . . 3.15.5.4(1)}$$

where

W_{m2} = minimum required bolt force for gasket seating, in newtons

b = effective gasket width (see Table 3.21.6.4(B)), in millimetres

G_1 = length of gasket periphery at the mid-point of the contact surface (3.14 times diameter for circular door), in millimetres

y = gasket seating stress from Table 3.21.6.4(A), in megapascals.

NOTE: For high pressures, the gasket may require to be of metal, or metal clad, to resist the internal pressure in the operating condition.

Each stud or bolt shall be fixed to the door by one of the following methods:

(a) The stud may have an integral collar machined on the bearing face which is fitted through the door and riveted over on the inside. The rivet head shall be of standard dimensions and there shall be a countersink under the head.

(b) The stud may have an integral collar machined on the bearing face, be screwed through the door, and be substantially riveted over on the inside or fitted with a nut on the inside or fillet-welded on the inside.

(c) For a door thicker than the stud diameter, the stud may be screwed into the door at least one full stud diameter and shall be lock-welded or where it is essential to unscrew the stud to permit removal of the door, means shall be provided for separately locking the stud.

(d) For a door not exceeding 150 × 100 mm, the stud may be forged solid with the door.

(e) The stud may be welded as shown in Figure 3.15.5.4(c) and (d).

(f) A bolt may be fitted through the door with the head inside, and seal-welded as shown in Figure 3.15.5.4(a) and (b).

(g) A square-headed bolt may also be used in substantial T-slotted lugs securely fastened or welded to the door. Such bolts and slots shall be machine-finished.

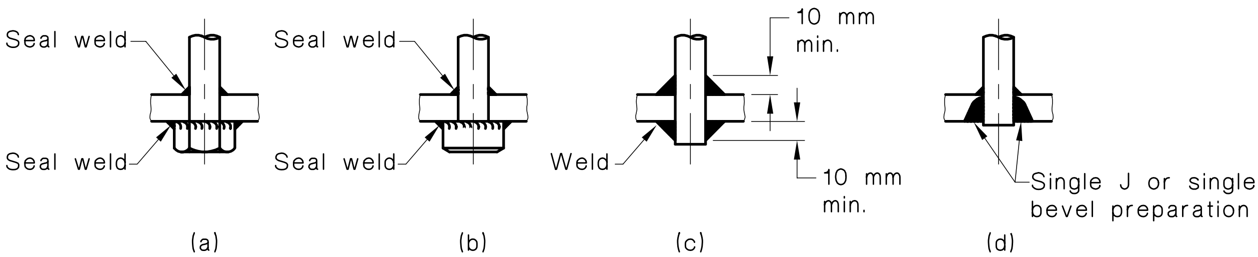


FIGURE 3.15.5.4 ACCEPTABLE METHODS OF FIXING STUDS ON MANHOLE OR HANDLEHOLE DOORS

3.15.5.5 *Bridges or dogs* Bridges or dogs shall be constructed by one of the following methods:

(a) Forged.

(b) Pressed.

(c) Flame cut to shape.

(d) Cast from material complying with AS 1565 alloy C 86300, provided that the vessel does not exceed 400 mm diameter, nor operate at a pressure exceeding 240 kPa.

(e) Fabricated by welding.

The maximum stress calculated as a simple beam of length equal to the centre distance of the bridge supports shall not exceed the stress stated in Table 3.3.1 based on the force (W_1) referred to in Clause 3.15.5.2.

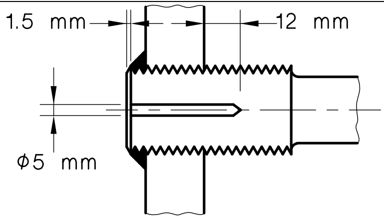
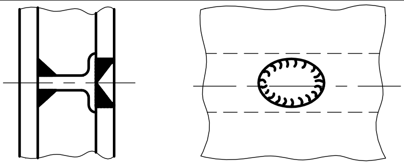
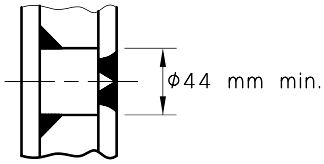
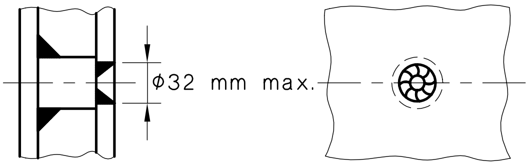
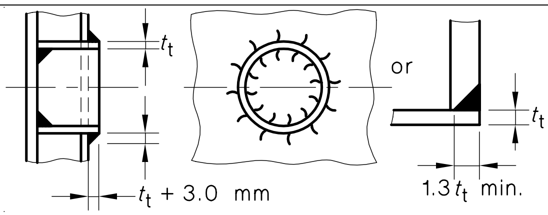
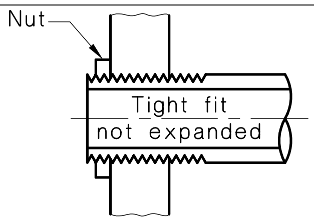
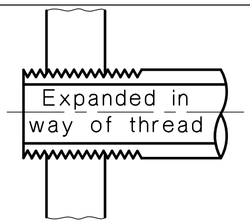
NOTE: In the design of an internally fitted door involving bridges or dogs, it is intended that the bridges or dogs will yield before the studs or the door.

3.16 STAYED FLAT ENDS AND SURFACES

3.16.1 General Stayed and braced flat ends and other surfaces shall be designed in accordance with the requirements of this Clause (3.16). The minimum calculated thickness shall be increased where necessary to carry the additional loads enumerated in Clause 3.2.3 and to meet the requirements of Clauses 3.4.2 and 3.4.3.

Figure 3.16.1 shows some typical methods of staying surfaces.

Where leakage past a stay would be dangerous, as in certain chemical processes, the plate shall not be perforated for supporting stays. Stays of the types shown in Figure 3.16.1(b), (c), (d) or (e) should be used where the process face of a jacketed vessel is provided with corrosion-resistant linings. Alternative configurations are acceptable where provisions of similar strengths and corrosion resistance are available.

Figure	Type	*K* value	Name	Remarks
(a)		3.75	Staybar: screwed and welded (or riveted)	The staybar may be riveted to form substantial head Middle portion of stay should be reduced to the root diameter of the thread
(b)		4.0	Stayblock: welded	2.1 MPa max. Plate thickness ≤ 12 mm. Fillet welds ≤ plate thickness. Inside welds shall be properly inspected before closing plate is attached. spacing of stays determined by Clause 3.16.4.
(c)		4.5	Stayblock: welded	
(d)		4.0	Stayblock: welded	
(e)		5.5	Staytube: welded	Inside diameter of staytube is greater than its length
(f)		5.75	Staytube: screwed and nutted	Tube not less than 5 mm thick at any point. Screwed not finer than 2.3 mm pitch. Stays with plus threads at one end shall be thickened by forging, and annealed. Body of stay may be reduced to bottom of thread.
(g)		4.25	Staytube: screwed	

(*continued*)

FIGURE 3.16.1(in part) TYPICAL STAYING OF SURFACES

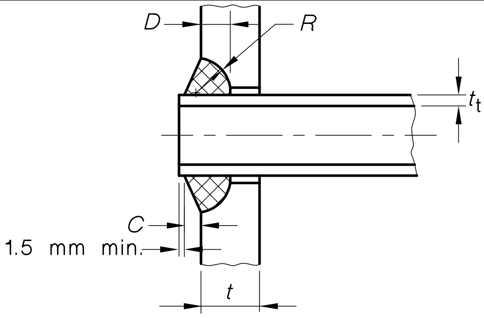
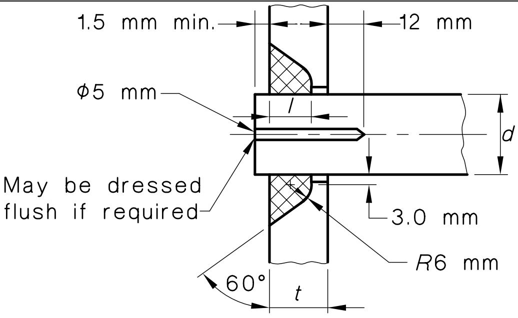
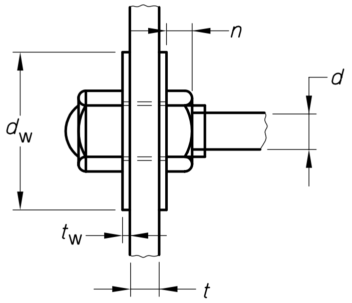
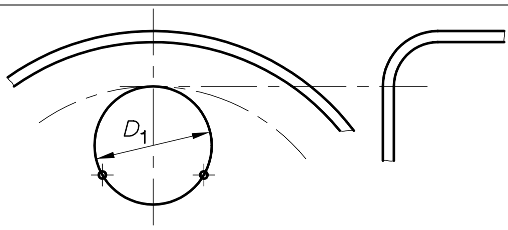
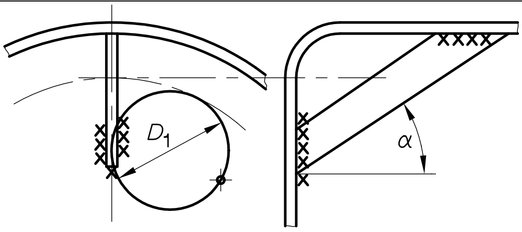
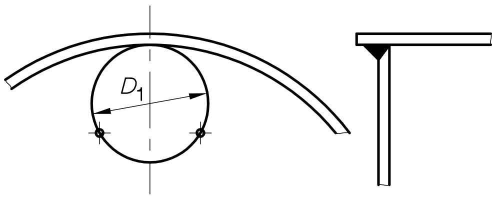
Figure	Type	*K* value	Name	Remarks
(h)		4.25	Staytube: welded	D = t_t min. R = 1 to 1.5 t_t min. C = t_t or 3 mm whichever is greater
(j)		5.05	Staybar: welded	$l = t - 3$ mm; or $0.25d + 3$ mm whichever is the smaller Standard single bevel and J weld are also acceptable
(k)		6.25	Staybar with nuts and small washers	d_w not less than 2.25d t_w not less than 6 mm n not less than 0.66 d Inside washer may be omitted. Middle portion of stay should be reduced to the root diameter of the thread
		6.95	Staybar with nuts and large washers	d_w not less than 3.5d and not less than 0.3D_l(see Figure (l)) t_w not less than 0.66t
(l)		5.0	Flanged support	
(m)		5.0	Welded stay	
(n)		5.5	Flat end welded to shell	

FIGURE 3.16.1(in part) TYPICAL STAYING OF SURFACES

3.16.2 Notation For the purpose of this Clause (3.16), the following notation applies:

t = minimum calculated thickness of stayed plate (exclusive of added allowances, see Clause 3.4.2), in millimetres

P = calculation pressure, in megapascals

f = design strength (see Table 3.3.1) at the maximum temperature at which P is operative (allowance shall be made, if necessary, for thermal stresses caused by temperature gradients), in megapascals

A = distance between rows of stays, in millimetres

B = pitch of stays in rows, in millimetres

D_1 = diameter of the largest circle which can be drawn having a circumference passing through at least three points of support without enclosing any other support, with at least one support located on any semi-circular arc of such circle (see Figure 3.16.2), in millimetres

K = a constant depending upon method of attachment of stay to plate and as given in Figure 3.16.1; where various forms of support are used, the value of K shall be the mean of the three greatest values for support methods used, provided that at least one of these supports is located on any semi-circular arc of the circle with diameter D_1

M_g = flat plate margin, in millimetres

$$= 0.9t\left(\frac{f}{P}\right)^{0.5}$$

3.16.3 Plate thickness The minimum calculated thickness for stayed or braced flat surfaces shall be determined by the following equation:

$$t = \left(\frac{PD_1^2}{fK}\right)^{0.5} \qquad \ldots 3.16.3$$

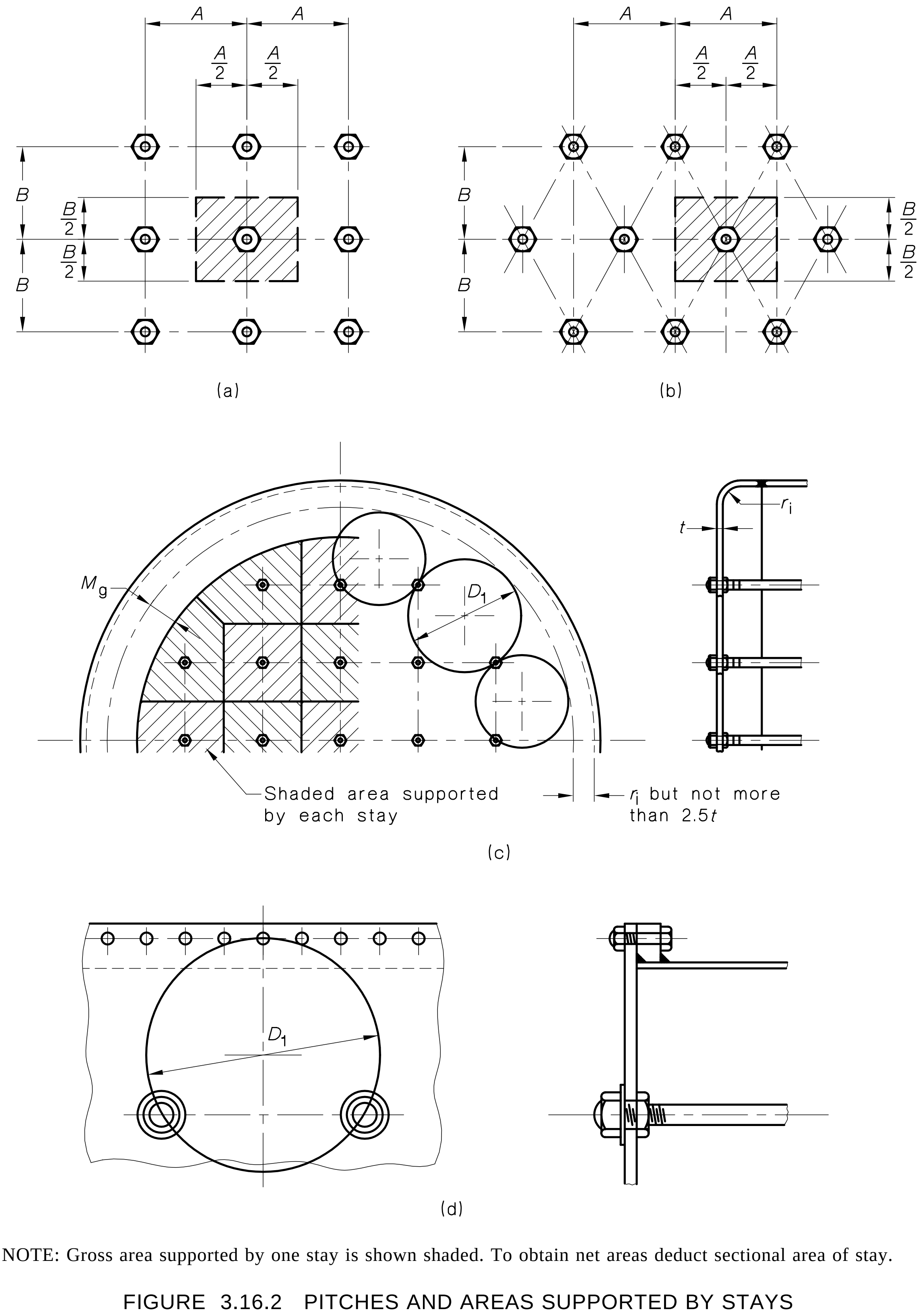
Where tubes are expanded into a stayed plate the thickness of the plate within the tube nest shall be not less than 12 mm where the tube holes do not exceed 50 mm diameter and no less than 15 mm where the tube holes exceed 50 mm diameter.

The minimum thickness of plates to which stays are applied, in other than cylindrical or spherical outer shell plates, shall be 8 mm except for welded construction covered by this Standard.

3.16.4 Minimum pitch of staytubes The centre-lines of the tubes, measured at the tubeplate, shall not be closer together than $1.125d + 12$ mm where d is the outside diameter of the tube in millimetres.

3.16.5 Staybars and staytubes

3.16.5.1 *Material* Each staybar shall be made from rolled bar without weld in its length, except where it is attached to the plate it supports.



NOTE: Gross area supported by one stay is shown shaded. To obtain net areas deduct sectional area of stay.

FIGURE 3.16.2 PITCHES AND AREAS SUPPORTED BY STAYS

3.16.5.2 *Dimensions* The required area of a staybar or staytube at its minimum cross-sectional area (usually taken at the nominal root of the thread) and exclusive of corrosion allowance, shall be obtained by dividing the load on the stay by the allowable stress for the material (see Table 3.3.1), and multiplying the result by 1.10. The load carried by the stay is the product of the area supported by the stay (see Clause 3.16.5.3), the calculation pressure, and the secant of the angle α between the longitudinal axis of the vessel and the stay (see Figure 3.16.1(m)).

Where the length of stay exceeds 14 stay diameters, the factor 1.10 above shall be replaced by 1.34.

3.16.5.3 *Area supported by stay* The area supported by each stay shall be the area enclosed by lines passing midway between the stay and/or adjacent points of support and/or by the flat plate margin as the case may be (see Figure 3.16.2). A deduction may be made for the area occupied by the stay.

3.16.5.4 *Staybars—axial drilling* It is recommended that where practicable, screwed staybars less than 350 mm long and all welded staybars, subject to any bending, be drilled axially with a telltale hole (5 mm diameter) to a depth of 12 mm beyond the inner face of the plate (see Figure 3.16.1(a)).

3.16.5.5 *Attachment* Screwed staybars and staytubes shall, where practicable, be normal to the plate surfaces, but where this is not practicable stays fitted with nuts shall be provided with taper washers to provide a proper bed for the nuts.

Stays screwed through the plates and not normal thereto shall have no less than four engaging threads of which at least two shall be full threads. Holes for screwed stays shall be drilled full size, or punched 6 mm less than full size for plates over 8 mm thick and 3 mm less for plates not exceeding 8 mm thick. After punching, the hole shall be drilled or reamed to full diameter. The holes shall be tapped true with full thread.

The ends of screwed staytubes shall project through the tubeplate by not less than 6 mm and by not more than 10 mm.

Weld dimensions shall be such as will transmit the stay load using a design strength not more than 50 percent of the design strength, f, for the weaker material in the joint.

For other requirements see Figure 3.16.1.

3.16.5.6 *Staybar supports* Horizontal longitudinal through staybars over 5 m long shall be supported at or near the middle of their length.

3.16.6 Gusset and other stays Surfaces may also be stayed with one or more of the following types of stays:

(a) Diagonal staybars.

(b) Diagonal gusset stays.

(c) Diagonal link stays.

(d) Transverse or radial plate stays (or ribs).

(e) Dimpled or embossed plate welded to another like plate or to a plain plate.

Stays of types (a), (b) and (c) above shall be designed in accordance with the requirements of AS 1228, except that fillet welds shall comply with the requirements of Clause 3.5.

Stays of Item (d) above shall be designed as beams supporting a load which is determined in accordance with Clause 3.16.5.2, and with a maximum tensile strength not exceeding that in Table 3.3.1. Alternatively, these stays may be designed to meet the requirements of Clause 3.1.3.

Dimpled and embossed plate of type (Item (e)) shall be designed and manufactured in accordance with the requirements in ANSI/ASME BPV-VIII-1 for dimpled and embossed assemblies except that—

(i) for resistance welded two-plate assemblies, the maximum thickness of any plain plate shall be 10 mm; and

(ii) where the weld attachment is made by fillet welds around holes or slots, the design shall comply with this Clause (3.16).

3.17 FLAT TUBEPLATES

3.17.1 General The design of flat tubeplates in tubular heat exchangers shall comply with AS 3857, or the TEMA Standards.

Clauses 3.17.2 to 3.17.7 Not allocated.

3.17.8 Tubeplate ligament

3.17.8.1 *Minimum ligament* The minimum tubeplate ligament of at least 96 percent of ligaments shall be not less than the nominal ligament minus the ligament tolerance where—

(a) the nominal ligament is the difference between the nominal pitch and the nominal diameter of the tube holes (see Clauses 3.17.9 and 3.17.10 for tube pitch and tube hole);

(b) the ligament tolerance—

(i) equals 2 × drill drift tolerance + 0.5 mm for tubes less than 15 mm OD; or

(ii) equals 2 × drill drift tolerance + 0.8 mm for tubes 15 mm OD and larger;

where drill drift tolerance equals 0.04 t_p/d_o, and t_p is nominal tubeplate thickness.

The minimum tubeplate ligament for the remaining four percent of ligaments shall be not less than $(p - d_o)/2$, rounded to the lower 0.1 mm.

In assessing minimum ligament width no allowance need be made for anchor grooving 0.5 mm deep or less.

3.17.8.2 *Tubes welded to tubeplate* Where tubes are to be fixed to the tubeplate by welding, the ligament width shall be sufficient to permit proper execution of welding and to develop the strength of attachment (see Figure 3.17.11), and shall also comply with the requirements in Clause 3.17.8.1.

3.17.9 Tube pitch Where tubes are fixed by expansion only, the nominal pitch of tubes p shall be no less than the following:

(a) p equals $1.25d_o$ for all exchangers not conforming to Item (b).

(b) p equals $1.17d_o$ for special exchangers where close pitching is required, provided that the consequence of tube joint leakage does not involve any hazard or any unacceptable service difficulties, and that the manufacturer establishes that adequate holding power of the tubes can be maintained. To ensure the maintenance of tube tightness with reduced ligaments, the following requirements should be met:

(i) The maximum difference between temperatures of shell and tube-side fluids does not exceed 20°C.

(ii) The tubes have ends in a condition that the yield stress of the ends is less than 75 percent of the yield stress of the plate (this will normally be met by using non-ferrous tubes in steel tubeplates).

(iii) The maximum fluid temperature should not exceed 65°C where the tube and tubeplate have markedly different thermal expansion coefficients.

3.17.10 Tube holes

3.17.10.1 *Diameter and finish* The tube holes in tubeplates into which tubes are to be expanded shall be machined to a workmanlike finish to comply with the tube hole tolerance and maximum diametral clearance given in Table 3.17.10. The inside edges of tube holes, and the outside edges, where tubes are to be belled or beaded, shall have the sharp edge removed.

Where so specified in Clause 3.17.11.1 tube holes for expanded joints shall be machined with one or more anchor grooves, each approximately 3 mm wide x 0.5 mm deep.

The tube holes in tubeplates into which tubes are to be welded without prior or subsequent expansion may be made by any means, e.g. profile flame cutting, subject to the following:

(a) The maximum diametral clearance shall not exceed—

(i) $\frac{t_t}{2}$; or

(ii) $\frac{d_o}{30}$, whichever is the less,

where

t_t = the wall thickness of tube

d_o = the outside diameter of tube

(b) Significant surface grooves parallel to the hole axis shall be limited to one per tube hole, but shall not extend for more than 50 percent of the depth of the hole. Such grooves are not permitted within 15 degrees of the minimum ligament between holes. This surface groove shall not exceed the following depth:

0.5 mm for tubes ≤ 25 mm OD.

1.0 mm for tubes 32 ≤ OD ≤ 50 mm.

1.2 mm for tubes 63 ≤ OD ≤ 75 mm.

1.5 mm for tubes > 75 mm OD.

The remainder of the tube hole surface shall have a fine finish. Minor repairs by welding and grinding of grooves exceeding these limits are permitted.

(c) Tube holes for vessels operating at pressures exceeding 2.1 MPa, or temperatures above 175°C or below 0°C, shall be finish machined.

(d) The minimum ligament shall comply with the requirements of Clause 3.17.8.

Tubes of outside diameter and tolerances and nominal hole diameters other than listed in Table 3.17.10, may be used provided that—

(i) the maximum diametral clearance (by interpolation if necessary) is not exceeded;

(ii) the nominal tube hole diameter does not exceed the nominal outside diameter of the tube (d_o) by more than 2.5 mm or 0.01 d_o, whichever is greater; or

(iii) as an alternative to Item (ii), a suitably modified value of d_o is used in Clause 3.17.11.4 to allow for any weakening in excess of that permitted for standard tubes.

TABLE 3.17.10

TUBE HOLE DIAMETER, TOLERANCE AND CLEARANCE FOR EXPANDED TUBES

millimetres

Nominal OD of tube d_o	Tolerance on tube OD	Nominal tube hole diameter and tolerance				Maximum nominal diametral clearance (Notes 1 and 2) S		Maximum 'plus' tolerance for 4% of holes
		Standard fit		Special close fit (Note 3)				
		Nom. dia. of hole	Tolerance (Note 1)	Nom. dia. of hole	Tolerance (Note 1)	Standard fit	Special fit	
6	±0.1	6.57	+0.05 −0.1	6.53	±0.05	0.38	0.32	0.18
10	±0.1	9.75	+0.05 −0.1	9.70	±0.05	0.38	0.32	0.18
13	±0.1	12.95	+0.05 −0.1	12.78	±0.05	0.41	0.32	0.2
16	±0.1	16.12	+0.05 −0.1	16.07	±0.05	0.41	0.36	0.25
19	±0.1	19.31	+0.05 −0.1	19.25	±0.05	0.41	0.36	0.25
25	±0.15	25.70	+0.05 −0.1	25.65	±0.05	0.51	0.46	0.25
32	±0.15	32.10	+0.075 −0.15	32.03	±0.075	0.58	0.51	0.25
38	±0.2	38.56	+0.075 −0.13	38.45	±0.075	0.74	0.64	0.25
50	±0.25	51.36	+0.075 −0.18	51.26	±0.075	0.89	0.76	0.25

NOTES:

1 96 percent of tube holes are to meet this requirement. The remaining 4 percent may have a plus tolerance on the hole not exceeding the values listed, and a correspondingly increased clearance.

2 Maximum diametral clearance = maximum hole diameter (nominal + tolerance) − minimum tube diameter (nominal − tolerance).

3 This class of fit may be specified by the purchaser to minimize work-hardening and the resultant loss of resistance to stress corrosion, e.g. in austenitic steel tubes.

3.17.10.2 *Location in welded joints* Tube holes may be machined through double-welded butt joints, provided that the joint for a distance of at least three tube hole diameters on each side of any such hole, complies with the following requirements:

(a) *For Class 1 vessels* The joints meet the requirements for longitudinal welds, i.e. 100 percent radiography or ultrasonic test, and any required postweld heat treatment is carried out before tube welding. The welds are machined at both sides and the surfaces including the hole surface are examined by magnetic particle or penetrant fluid crack detection.

A2

(b) *For Class 2 or 3 vessels* The joints meet the requirements for longitudinal welds, and are examined by magnetic particle or penetrant fluid crack detection, and the appropriate welded joint efficiency has been included in the ligament efficiency when calculating tubeplate thickness.

3.17.11 Tube-to-tubeplate attachment

3.17.11.1 *General* Tubes shall be fixed into the tubeplate by one of the following methods:

(a) Expanding, or expanding followed by beading, by belling, by beading and seal welding, or by belling and seal welding.

(b) Seal welding followed by expanding.

(c) Welding with or without expanding.

(d) Ferrule and packing joint.

(e) Screwing and expanding, with or without seal welding.

(f) Other methods proven to be acceptable by long and satisfactory experience or by tests.

For lethal or flammable fluid applications, tube holes for expanded joints shall be machined with two anchor grooves or shall be seal welded, except where the joint has been proven to be acceptable by evidence of long and satisfactory experience or by tests in accordance with Appendix A, ANSI/ASME BPV VIII-1.

For other applications, where the design pressure is equal to or greater than 2.1 MPa or the temperature is over 175°C, tube holes for expanded joints shall be machined with one anchor groove in tubeplates less that 25 mm thick and with two anchor grooves in tubeplates 25 mm or greater in thickness, except that where the strength of the attachment complies with Clause 3.17.11.4 grooves may be omitted.

Seal welds shall not be considered to contribute to the strength of the attachment but their size shall be sufficient to avoid any cracking. When the weld or heat-affected zone of portion of the tube inside the tubeplate could be subject to significant corrosion, the tube shall also be expanded.

Where tubes are fixed by expanding, the thickness of tubeplates, less any corrosion allowances, shall be not less than 10 mm or $0.125d_o + 8.25$ mm whichever is less, and should be no less than the recommended thickness given in Table 3.17.11.1. Where tubes are fixed by welding, the plate thickness less any corrosion allowances shall be sufficient to enable the attachment to be made satisfactorily.

TABLE 3.17.11.1

RECOMMENDED MINIMUM TUBEPLATE THICKNESS FOR EXPANDED TUBES

Tube outside diameter, d_o mm	Minimum tubeplate thickness, t_p, min. mm
12	12
15	12
20	15
25	20
32	22
38	25
50	32

3.17.11.2 Not allocated.

3.17.11.3 *Expansion of tubes* Where tubes are fixed by expansion only, the tube ends shall be flush with or may project beyond the face of the tubeplate. For non-toxic, non-corrosive applications at design pressures not exceeding 3 MPa and tubes not exceeding 20 mm outside diameter, tubes may be recessed not more than 3 mm below the tubeplate surface provided that the strength of the attachment complies with the requirements of Clause 3.17.11.4.

3.17.11.4 *Strength of attachment of tube* Where tubes are welded into the tubeplate, the calculated load on the tube shall not exceed—

$$\pi d_o \times \text{throat of weld} \times 0.8f \qquad \ldots 3.17.11$$

where

d_o = nominal outside diameter of tube, in millimetres

f = design strength for tube or plate, whichever is the lesser, in megapascals.

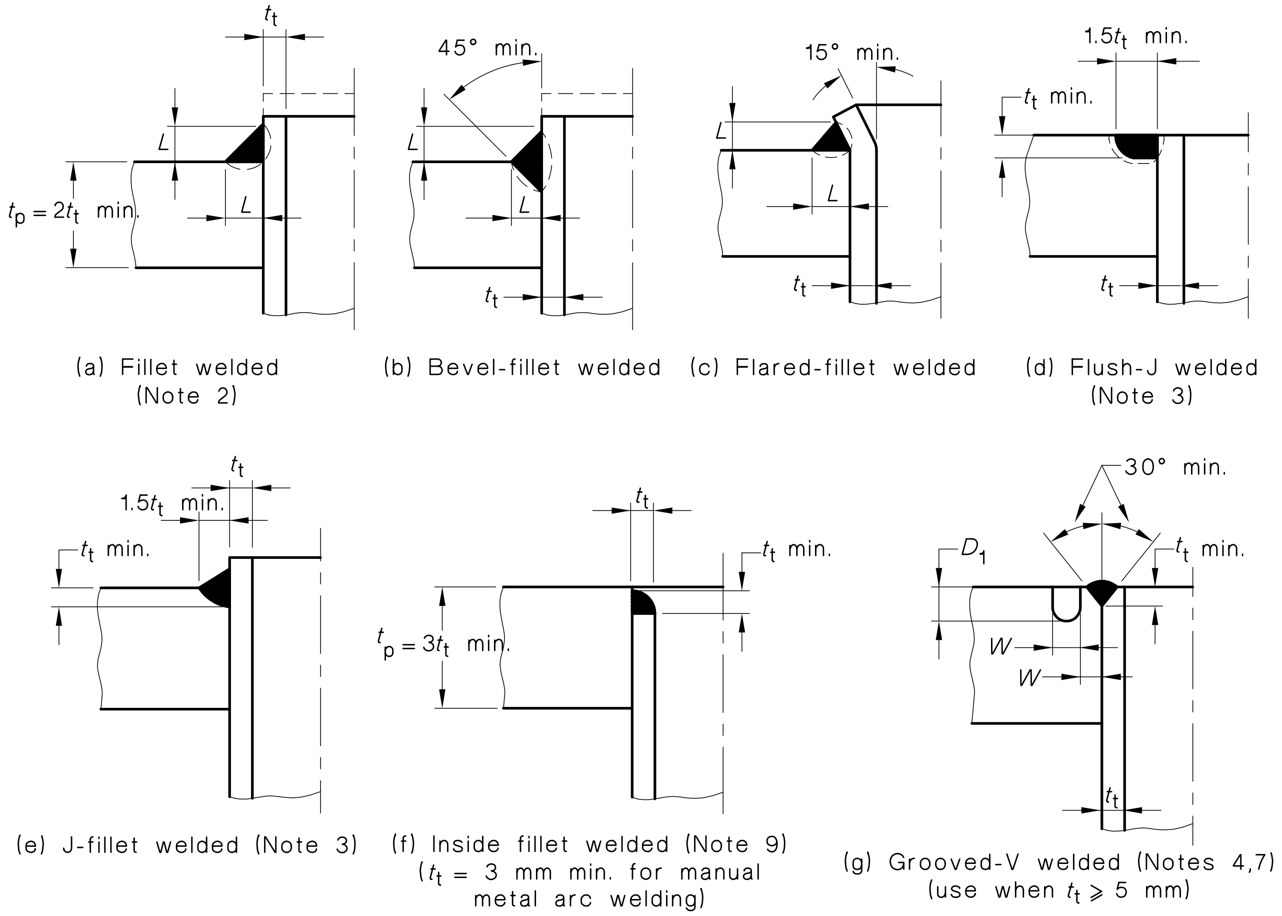
Where tubes are fixed by expanding into the tubeplate, the strength of the attachment shall be established by experience with successful exchangers or by actual tests. A safety factor of four shall be used on loads determined by test.

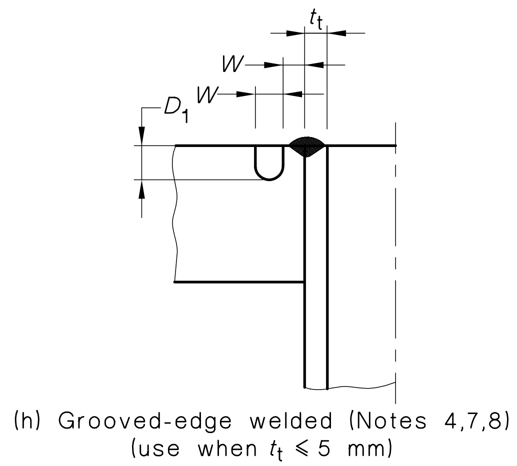
NOTE: For further guidance to allowable tube to tubeplate joint loads refer to Appendix A, ANSI/ASME BPV VIII-1.

3.17.11.5 *Welded attachment of tubes* Where tubes are welded into the tubeplate the welding procedure shall be qualified by suitable tests on simulated joints to ensure adequate penetration and freedom from unacceptable defects. Typical weld preparations and sizes are given in Figure 3.17.11.

NOTE: Light expanding of the tube is recommended after welding, except with austenitic Cr-Ni steel tubes which should be welded without any expansion, as cold work may affect the corrosion performance of these steels.

3.17.12 Attachment of tubeplate to shell The attachment shall be in accordance with Figure 3.17.12, which shows typical attachments, or other methods providing equivalent performance and safety.





NOTES:

1 t_t = nominal thickness of tube
t_p = nominal thickness of tubeplate
$L \geq t_t$
D_1 = $1.5t_t$ to $2.0t_t$
W = t_t

2 Minimum distance between tubes = $2.5t_t$ or 8 mm, whichever is less.

3 This preparation is preferred when there is danger of burning through tube.

4 Tubeplate should be examined for laminations before machining.

5 When conditions are onerous preference should be given to Figure (d) or (e).

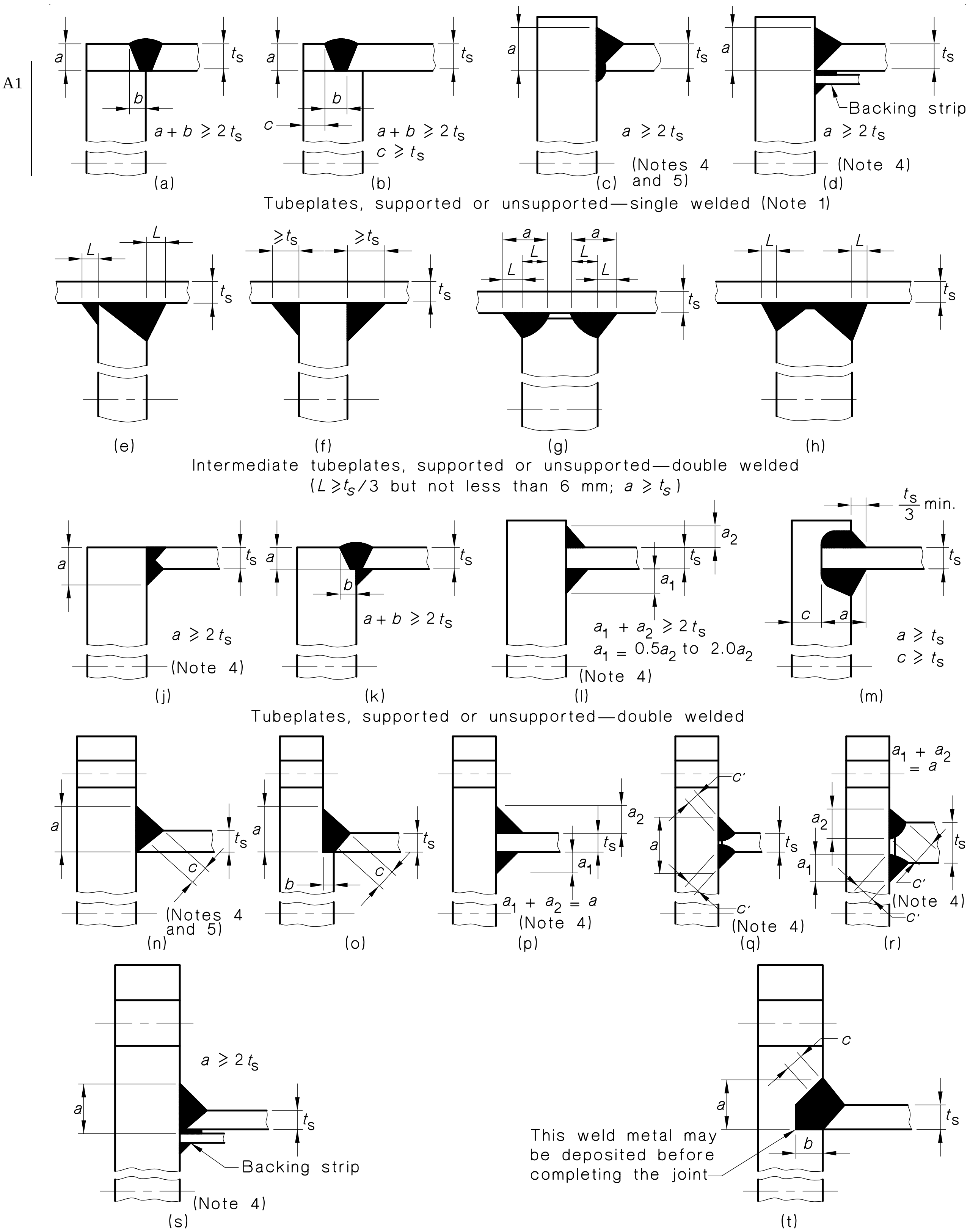
6 See Clauses 3.17.11 for holes and tube expansion.

7 This preparation is preferred where minimum plate distortion is required.

8 This preparation is not suitable for metal-arc welding. Use filler rod where t_t > 1.5 mm (acetylene), or > 2.5 mm (GTAW).

9 This preparation is permissible for low pressure and small temperature fluctuations.

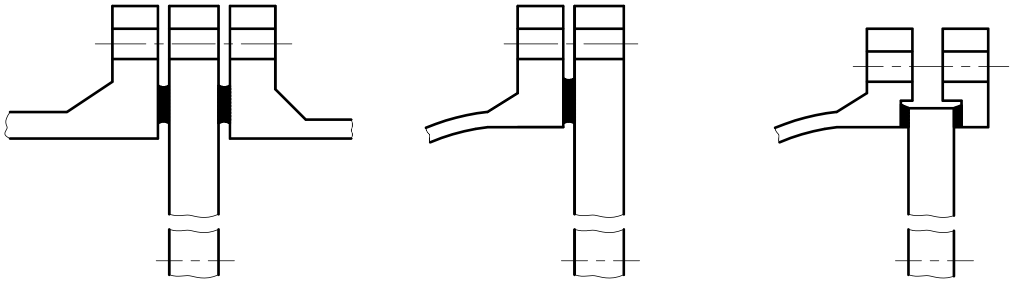
FIGURE 3.17.11 TYPICAL WELDED ATTACHMENT OF TUBES



Tubeplates, supported or unsupported—with bolting flange
Supported : $a + b \geqslant 2t_s$, $c \geqslant 0.7t_s$; $c' \geqslant 0.3t_s$ and 6 mm
Unsupported : $a + b \geqslant 3t_s$, $c \geqslant 1.0\ t_s$; $c' \geqslant 0.5t_s$ and 6 mm

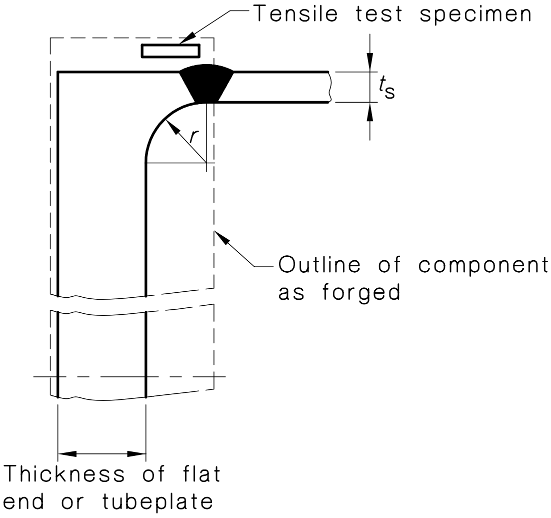
NOTES: See end of this Figure.

FIGURE 3.17.12 (in part) TYPICAL ATTACHMENTS OF TUBEPLATE TO SHELL



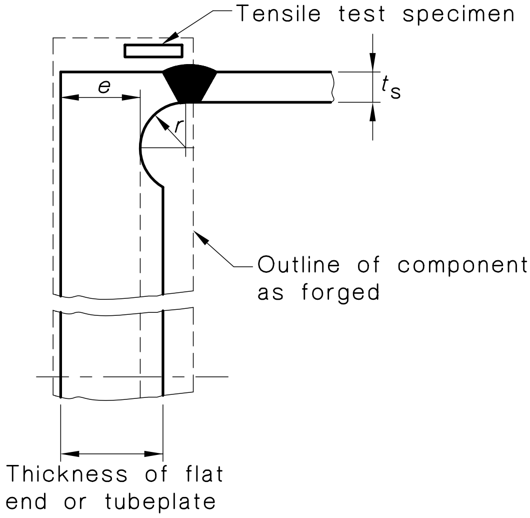
(u) (v) (w)

Clamped tubeplates (joints may be full or narrow face)



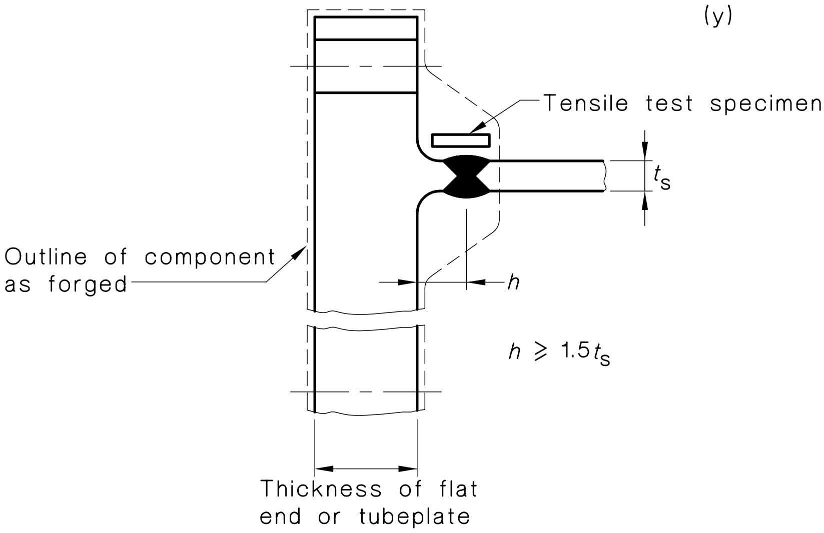
(Notes 6,7,8)

(x)



(Notes 6,7,8)

(y)



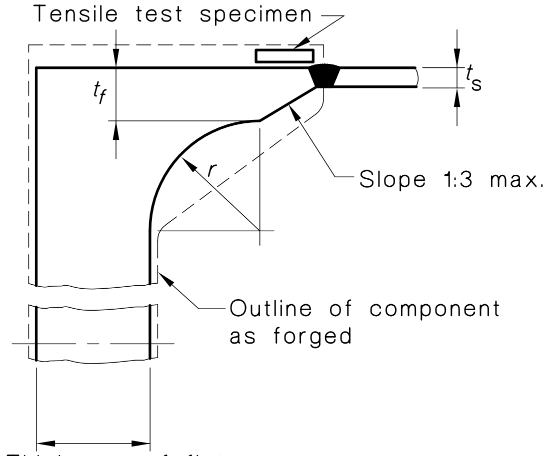
(Notes 6,7,8)

(z)

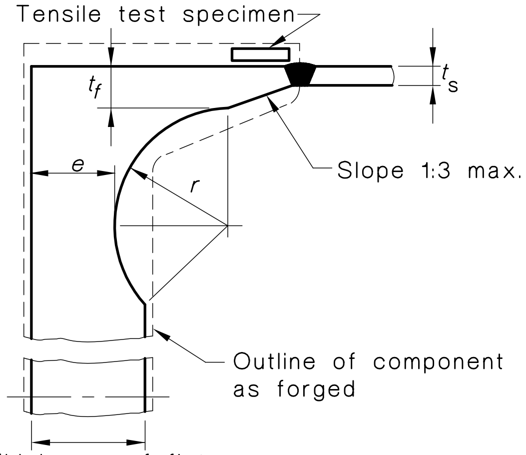
Tubeplates, supported or unsupported forged type with hub (Note 8)

NOTES: See end of this Figure.

FIGURE 3.17.12 (in part) TYPICAL ATTACHMENTS OF TUBEPLATE TO SHELL



(Notes 6,7,8)
(aa)



(Notes 6,7,8)
(bb)

Tubeplates, supported or unsupported— forged type with hub (Note 8)

NOTES TO FIGURE 3.17.12:

1 Supported tubeplate has 80 percent minimum of pressure load on tubeplate carried by tubes.

2 t_s = nominal thickness of shell minus corrosion allowance.

3 For standard weld preparation see Figure 3.19.3(D).

4 Tubeplate must be checked for laminations.

5 Class 3 vessels only.

6 Not permissible, if machined from rolled plate.

7 The tensile test specimen may be located, when possible, inside the forged hub, instead of outside as shown.

8 Attachments shown in (x) to (bb) may be used with or without backing ring provided the weld is constructed to provide a welded joint efficiency of at least 0.9 and is inspected by magnetic particle or penetrant flaw detection methods.

9 Attachments in Group F or Group G steels shall be full penetration butt welds (see Clause 3.5.1.6).

FIGURE 3.17.12(in part) TYPICAL ATTACHMENTS OF TUBEPLATE TO SHELL

3.18 OPENINGS AND REINFORCEMENTS

3.18.1 General The requirements in this Clause (3.18) apply to openings and their reinforcements in cylinders, cones, spheres, and dished and flat ends. They are based on the stress intensification created by the presence of a hole in an otherwise symmetrical section, and reflect experience with vessels designed with safety factors of four and five applied to the tensile strength of the shell material. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors shall be considered when appropriate including unusual designs or under conditions of cyclic loading.

3.18.2 Notation For the purpose of this Clause (3.18), the following notation applies:

t = calculated thickness of a seamless shell or end as defined in Clause 3.18.7.2, or flat end as defined in Clause 3.15 (exclusive of added allowances, see Clause 3.4.2), in millimetres

t_b = calculated thickness of a seamless branch wall required for pressure load plus external loads, if any (exclusive of added allowances, see Clause 3.4.2), in millimetres

T_1 = nominal thickness of the vessel wall, less corrosion allowance, in millimetres

T_{b1} = nominal thickness of branch wall, less corrosion allowance, in millimetres

T_{r1} = nominal thickness or height of reinforcing element, less corrosion allowance (see Figure 3.18.10), in millimetres

d = diameter of the finished opening in the plane under consideration plus twice the corrosion allowance (see Figure 3.18.10), in millimetres

d_m = mean diameter of the finished opening in the plane under consideration plus twice the corrosion allowance (see Figure 3.18.10), in millimetres

D = inside diameter of cylindrical or conical section or sphere, plus twice the corrosion allowance, in millimetres

c = corrosion allowance, in millimetres

h = internal depth of dishing, in millimetres

F = a factor for determining required reinforcement (see Figure 3.18.7 and Clause 3.18.7.2)

f_{r1} = design strength of set through branch divided by design strength of shell or end (but no more than 1.0)

= 1 for a set on branch

f_{r2} = design strength of branch wall extended beyond the shell thickness divided by design strength of shell or end (but no more than 1.0)

f_{r3} = lesser of f_{r2} and f_{r4}

f_{r4} = design strength of compensating plate divided by design strength of shell or end (but no more than 1.0)

A2 η = 1.0 where an opening is in the plate; or

= the joint efficiency obtained from Table 3.5.1.7 where any part of the opening passes through any other welded joint

K_1 = a factor depending on the ratio $D/2h$ and defining equivalent spherical radius (see Table 3.18.7.2)

L = distance from centre of opening to the centre of an adjacent opening, in millimetres

A_1 = area in excess thickness of the vessel wall available for reinforcement, in square millimetres (see Clause 3.18.10)

A_2 = area in excess thickness of the nozzle wall available for reinforcement, in square millimetres (see Clause 3.18.10)

3.18.3 Shape of opening Openings shall preferably be circular, but may be elliptical or obround (i.e. formed by two parallel sides with semi-circular ends).

The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or end, may be considered an elliptical opening for design purposes.

When the long dimension of an elliptical or obround opening exceeds twice the short dimension, the reinforcement across the short dimension shall be increased as necessary to provide against excessive distortion due to any twisting moment.

Openings may be of other shape than given above, provided that all corners have a suitable radius and the vessel is at least as safe as with the above openings. Where the openings are of such proportions that their strength cannot be calculated with sufficient assurance, or where doubt exists as to the safety of a vessel with such openings, the part of the vessel shall be subject to a proof hydrostatic test (see Clause 5.12).

3.18.4 Size of openings

3.18.4.1 *In cylindrical, conical and spherical shells* Properly reinforced openings in cylindrical, conical and spherical shells need not be limited as to size. The application of the requirements in this Standard for the reinforcement of openings is intended to cover the following:

(a) For vessels equal to or less than 1500 mm inside diameter: one-half of vessel diameter but not to exceed 500 mm.

(b) For vessels greater than 1500 mm inside diameter: one-third of vessel diameter but not to exceed 1000 mm.

Where larger openings are required these shall be given special attention and may be reinforced in any suitable manner at least complying with this Standard. It is recommended that the reinforcement provided be distributed close to the junction (a provision of about two-thirds of the required reinforcement within a distance of 0.25d on each side of the finished opening is suggested). It is further recommended that special consideration be given to the fabrication details used and inspection employed on critical openings; reinforcement often may be advantageously obtained by use of heavier shellplate for a vessel course or inserted locally around the opening; welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. Where radiographic examination of welds is not practicable, penetrant flaw examination may be used with non-magnetic materials, and either penetrant flaw or magnetic particle examination with ferromagnetic materials.

The degree to which such measures may be used depends on the particular application and the severity of the intended service. Appropriate proof testing may be advisable in extreme cases of large openings approaching full vessel diameter, openings of unusual shape, and the like.

3.18.4.2 *In dished ends* Properly reinforced openings in dished ends need not be limited as to size, but, when the opening in the end closure of a cylinder is larger than one-half of the inside diameter of the shell, it is recommended that the closure be made by a reversed-curve section, or by a conical section or a cone with a knuckle radius at the large end and/or with a flare radius at the small end. The design shall comply with all the requirements of this Standard for conical sections in so far as these requirements are applicable. See Clauses 3.10 and 3.11 (see also Clause 3.18.6).

3.18.4.3 *In flat ends* No size limits apply to openings in flat ends.

3.18.5 Location of openings

3.18.5.1 *Other than unreinforced openings in accordance with Clause 3.18.6* Openings
A2 shall be located clear of structural discontinuities, e.g. supports, junctions between conical
and cylindrical sections, by at least three times the shell or end thickness except where the
A2 design of the opening is proved adequate as required by Clause 3.1.3. (See also
Clause 3.5.1.3.)

NOTE: This Clause (3.18.5.1) permits openings in the knuckle area, but this is not permitted by AS 1210 Supplement No.1 unless special provisions are agreed.

3.18.5.2 *Orientation of non-circular openings* Non-circular openings in cylindrical or conical shells should be arranged so that the minor axis is coplanar with the longitudinal axis of the shell.

3.18.5.3 *In or adjacent to welds* Openings in or adjacent to welds shall meet the following requirements:

(a) An opening which is fully reinforced in accordance with Clause 3.18.7 may be located in a welded joint.

(b) Unreinforced openings (see Clause 3.18.6) may be located in a butt-welded joint, provided that the openings are machine cut and comply with the requirements for reinforcement in Clause 3.18.7 or Clause 3.18.12, or the welds meet class 1 weld acceptance standards for a length equal to three times the diameter of the opening with the centre of the hole at mid-length. Defects that are completely removed in cutting the hole shall not be considered in judging the acceptability of the weld.

(c) Where more than two unreinforced openings (see Clause 3.18.6) are in line in a welded joint, the requirements for joint and ligament efficiency shall be met or the openings shall be reinforced in accordance with Clause 3.18.7 or 3.18.12.

(d) Unreinforced openings (see Clause 3.18.6) in solid plate shall be placed no closer to the edge of a butt-weld than 13 mm for plates 38 mm thick or less, except when the adjacent weld satisfies the requirements of (b).

3.18.6 Unreinforced openings

3.18.6.1 *Single openings* Single openings on vessels not subject to rapid fluctuations in pressure are not required to have reinforcement other than that inherent in the construction, under the following conditions:

(a) The maximum bore (see Note) of welded or brazed connections is—

(i) where the shell or end nominal thickness is not greater than 10 mm . . . . 90 mm;

(ii) where the shell or end nominal thickness is greater than 10 mm . . . . 65 mm.

NOTE: For the purpose of this Clause, the bore is to be taken as the bore of the actual pipe or component connected to the shell or end. For non-radial connections the bore is to be taken as the greatest opening dimension.

(b) Threaded, studded or expanded connections (see Figure 3.19.6(a), (b) and (c)) in which the opening in the shell or end is not greater than for 65 mm OD pipe.

3.18.6.2 *Multiple openings* Two unreinforced openings may be located in the cylindrical, conical or spherical portion of a vessel, provided that the projected width of the ligament between any two adjacent openings shall be at least equal to the diameter of the larger opening, unless the ligament efficiency has been taken into account in the requirements of Clause 3.7. When more than two unreinforced openings are provided, the ligament efficiency shall comply with the requirements of Clause 3.6.

3.18.7 Reinforcement of single openings in shells and dished ends

3.18.7.1 *General* The requirements of this Clause (3.18.7) apply to all openings other than—

(a) small openings covered by Clause 3.18.6;

(b) openings in flat ends covered by Clause 3.18.9;

(c) openings designed as reducer sections covered by Clauses 3.10 and 3.11; and

(d) large end openings covered by Clause 3.18.4.2.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the centre of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the axis of the shell is the plane of greatest loading due to pressure. For a single opening, not less than one-half of the required reinforcement shall be provided on each side of the centre-line of the opening.

Reinforcement may be in the form of increased thickness of shell or end near the opening; increased thickness of branch; special fittings of increased thickness; reinforcing rings or plates around the opening on the outside and/or inside of the vessel; or by yokes of special design.

NOTE: Reinforcement located nearest the opening is most effective and stress concentration is reduced where the reinforcement is approximately equal on the inside and outside of the vessel wall.

3.18.7.2 *Reinforcement area required in shells, dished ends and cones subject to internal pressure* The total cross-sectional area of reinforcement, A, in square millimetres, required in any given plane for a vessel subject to internal pressure shall be no less than the following equation:

$$A = dtF + 2T_{b1}\, t\, F(1 - f_{r1}) \qquad \ldots 3.18.7.2$$

where

d = the diameter in the given plane of the finished opening plus twice the corrosion allowance, in millimetres

F = a correction factor which compensates for the variation in pressure stresses on different planes taken through the reinforcement at varying angles to the axis of a vessel; a value of 1.0 shall be used for all configurations except that Figure 3.18.7 may be used for reinforced openings in cylindrical shells and cones where the reinforcement is integral with the branch

t = the required thickness of a seamless shell or end calculated in accordance with this Standard for the calculation pressure, in millimetres, except—

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical end, t is the thickness required by Clause 3.7 for a seamless sphere having radius equal to the crown radius of the end;

(b) when the opening is in a cone, t is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone; or

(c) when the opening and its reinforcement are in an ellipsoidal end and are located entirely within a circle the centre of which coincides with the centre of the end and the diameter of which is equal to 80 percent of the shell diameter, t is the thickness required for a seamless sphere of radius K_1D (for K_1 see Table 3.18.7.2).

TABLE 3.18.7.2

VALUES OF SPHERICAL RADIUS FACTOR K_1

$\frac{D}{2h}$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_1	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

NOTE: Values of K_1 for intermediate ratios may be obtained by linear interpolation.

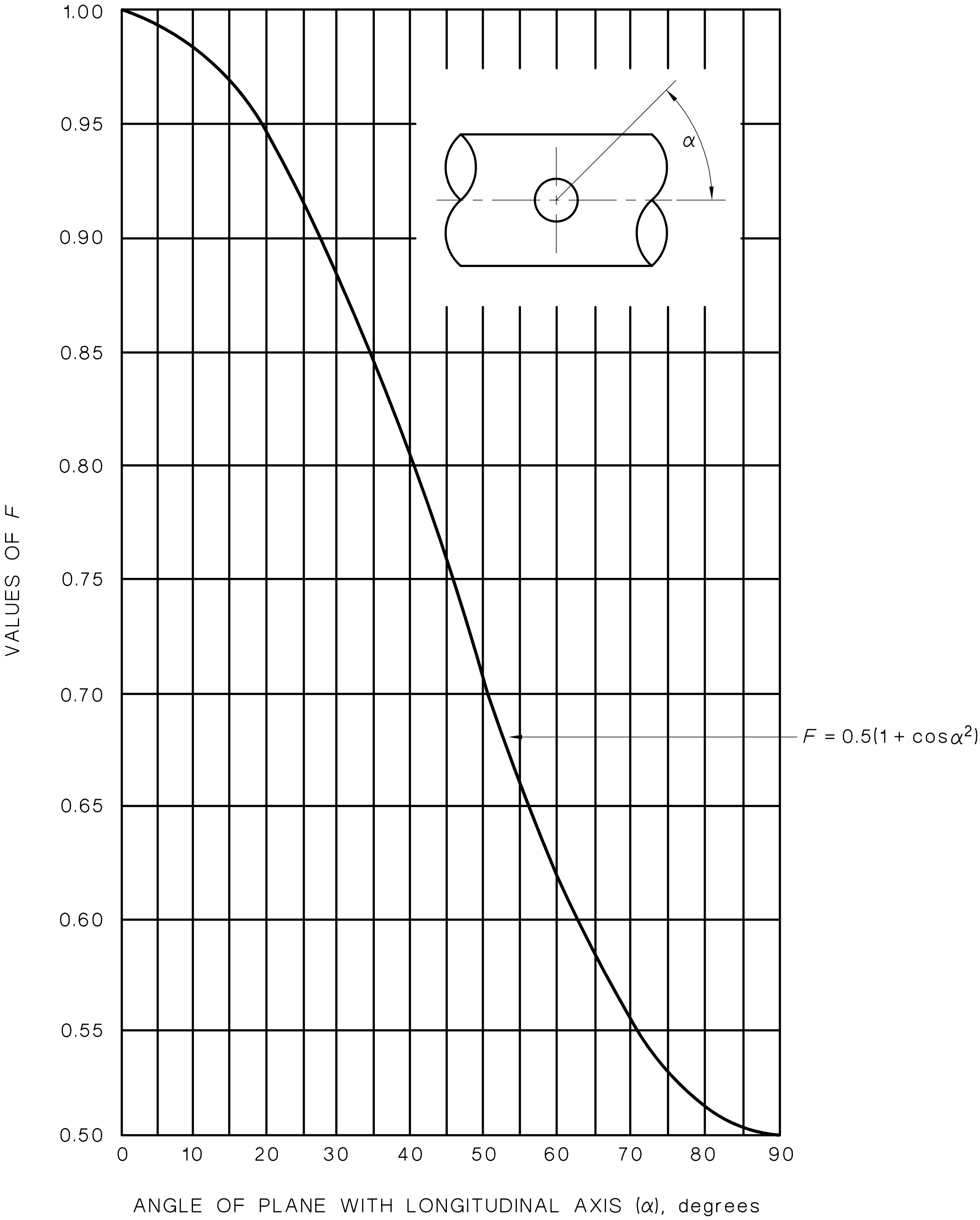


FIGURE 3.18.7 FACTOR *F* FOR REQUIRED REINFORCEMENT AREA

3.18.7.3 *Reinforcement required in shells and dished ends subject to external pressure* In shells and dished ends subject to external pressure—

(a) the reinforcement required for openings in single-walled vessels subject to external pressure need be only 50 percent of that required in Clause 3.18.7.2, where *t* is the wall thickness required by this Standard for vessels subject to external pressure; and

(b) the reinforcement required for openings in each shell of a multiple-walled vessel shall comply with Item (a) when the shell is subject to external pressure, and with

Clause 3.18.7.2 when the shell is subject to internal pressure, regardless of whether or not there is a common branch secured to more than one shell by strength welds, except that when there is pressure in the space between the vessel walls only, the opening in each wall may be assumed to be stayed by the common branch.

3.18.7.4 *Reinforcement required in shells and dished ends subject to alternate internal and external pressures* Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of Clause 3.18.7.2 for internal pressure and of Clause 3.18.7.3 for external pressure applied separately.

3.18.8 Flanged openings in dished ends

3.18.8.1 *Made by inward or outward flanging* Openings in shells and dished ends made by inward or outward flanging of the plate shall meet the requirements of Clause 3.18.6 for unreinforced openings or Clause 3.18.7 for openings which require reinforcement.

3.18.8.2 *Width of bearing surface* For internally fitted manhole doors with flat gaskets see Clause 3.15.5.1 for the width of the bearing surface.

3.18.8.3 *Shell or end thickness to be maintained* Flanging of the opening shall not reduce the shell or end thickness below the minimum thickness required by Clauses 3.7 to 3.13, as appropriate.

3.18.8.4 *Flange thickness* The thickness of the flange may be less than the thickness in Clause 3.18.8.3 but shall be not less than the thickness required for a cylindrical shell having a diameter equal to the major dimension of the opening.

3.18.8.5 *Flange cross-section* The dimensions of the flange at any cross-section shall be in accordance with Figure 3.18.10(c).

3.18.9 Reinforcement required for openings in flat ends

3.18.9.1 *Application* This Clause applies to all openings other than small openings covered by Clause 3.18.6.

3.18.9.2 *Opening less than half of end diameter or shortest span* Flat ends that have an opening with a diameter d in millimetres not exceeding one-half of the end diameter or shortest span, as defined in Clause 3.15, shall have a total cross-sectional area of reinforcement, A, in square millimetres, not less than half that given by Equation 3.18.7.2, where t is the minimum calculated thickness of the unpierced end.

3.18.9.3 *Opening more than half of end diameter or shortest span* Flat ends that have an opening with a diameter exceeding one-half of the end diameter or shortest span, as defined in Clause 3.15, shall be designed as a reverse flange in accordance with Clause 3.21.

3.18.9.4 *Increased thickness* As an alternative to Clause 3.18.9.2, the thickness of flat ends may be increased to provide the necessary opening reinforcement as follows:

(a) In Equations 3.15.3(1) and 3.15.4(1) of Clause 3.15 using $K/2$ or 1.33, whichever is greater, in place of K.

(b) In Equations 3.15.3(2) and 3.15.4(2) of Clause 3.15 by doubling the quantity under the square root sign.

3.18.10 Limits of available reinforcement

3.18.10.1 *Boundaries of area for reinforcement* The boundaries of the cross-sectional area, in any plane normal to the vessel wall and passing through the centre of the opening, within which metal must be located in order to have value as reinforcement, are designated as the limits of reinforcement for that plane (see Figure 3.18.10).

3.18.10.2 *Limits of reinforcement parallel to vessel wall* The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of—

(a) the diameter of the finished opening plus twice the corrosion allowance, i.e. d on Figure 3.18.10; and

(b) the radius of the finished opening plus the corrosion allowance plus the corroded thickness of the vessel wall, plus the thickness of the nozzle wall, i.e. $(0.5d + T_1 + T_{b1})$ -from Figure 3.18.10.

3.18.10.3 *Limits of reinforcement normal to vessel wall* The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the smaller of—

(a) 2.5 times the nominal shell thickness less corrosion allowance; and

(b) 2.5 times the nozzle-wall thickness less corrosion allowance, plus the thickness of added reinforcement exclusive of weld metal on the side of the shell under consideration.

Except that the limits from Items (a) and (b) may be exceeded provided it is not in excess of—

$$0.8(dT_{b1})^{0.5} + T_{r1} \qquad \text{. . . 3.18.10.3}$$

For flanged-in openings in dished ends, the maximum depth which may be counted as reinforcement is $(dT_1)^{1/2}$ as shown in Figure 3.18.10(c).

3.18.10.4 *Reinforcing metal* Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(a) Metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the equations—

$$A_1 = (\eta T_1 - Ft)d - 2T_{b1}\,(\eta T_1 - Ft)(1 - f_{r1}) \qquad \text{. . . 3.18.10.4(1)}$$

$$A_1 = 2(\eta T_1 - Ft)(T_1 + T_{b1}) - 2T_{b1}\,(\eta T_1 - Ft)(1 - f_{r1}) \qquad \text{. . . 3.18.10.4(2)}$$

(b) Metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the equations—

$$A_2 = (T_{b1} - t_b)5T_1\,f_{r2} \qquad \text{. . . 3.18.10.4(3)}$$

$$A_2 = (T_{b1} - t_b)(5T_{b1} + 2T_{r1})\,f_{r2} \qquad \text{. . . 3.18.10.4(4)}$$

except that this limit may be exceeded, provided that it is not in excess of—

$$A_2 = (T_{b1} - t_b)\{1.6(dT_{b1})^{1/2} + 2T_{r1}\}f_{r2} \qquad \text{. . . 3.18.10.4(5)}$$

All metal in the nozzle wall extending inside the vessel wall and within the limits of Clause 3.18.10.3 above may be included after proper deduction for corrosion allowance on all the exposed surface is made and adjusted by factor f_{r2} (see A_3 in Figure 3.18.10). No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress in the shell around the opening.

(c) Metal added as reinforcement, and metal in attachment welds (see A_5 and A_4 respectively in Figure 3.18.10).

NOTES:

1 A_4 shall be adjusted by factor f_{r3} for outside shell (or compensating plate) to nozzle weld, by a factor f_{r4} for outside compensating plate to shell weld by factor f_{r2} for inside shell to nozzle weld.

2 A_5 shall be adjusted by factor f_{r4}.

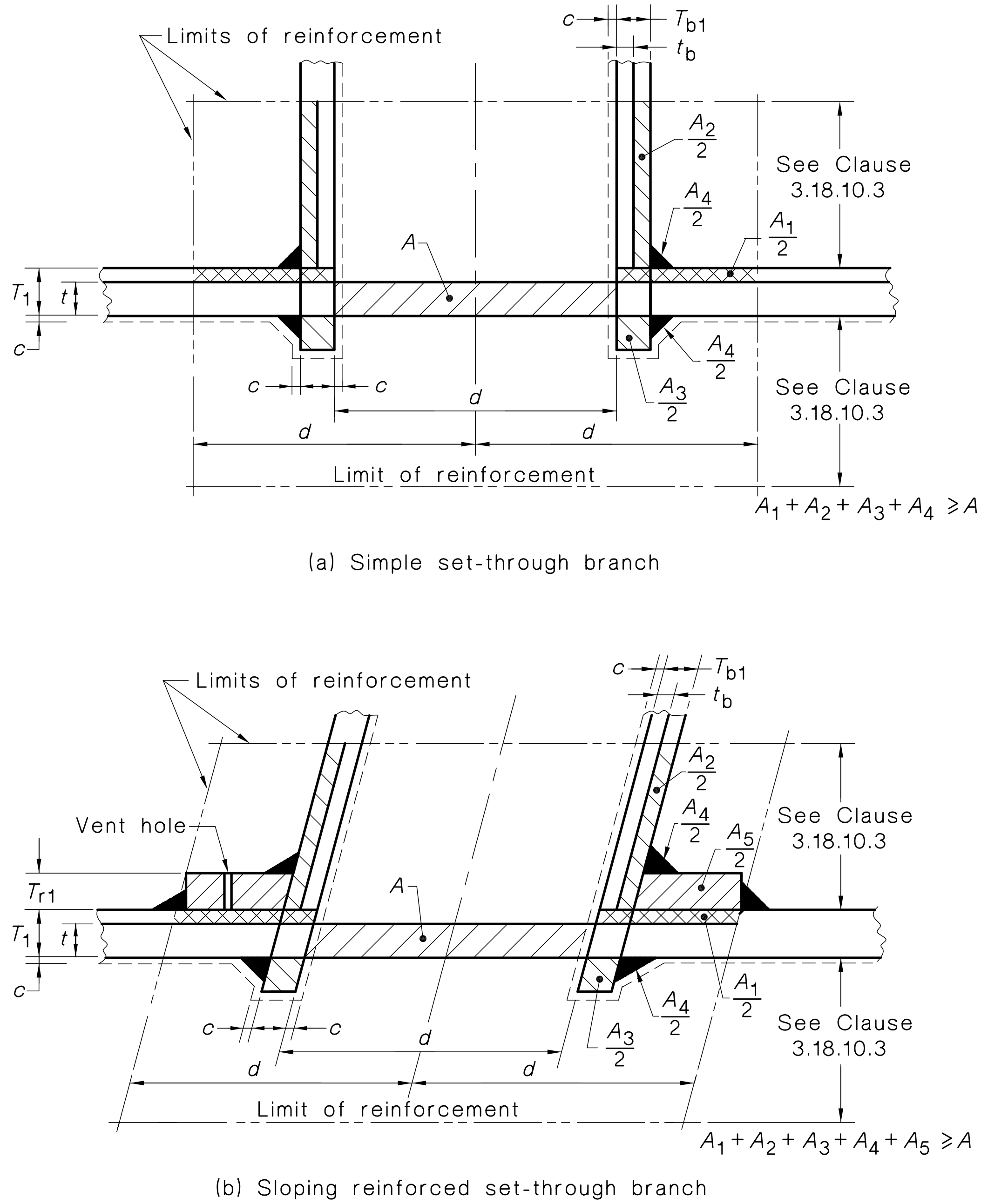
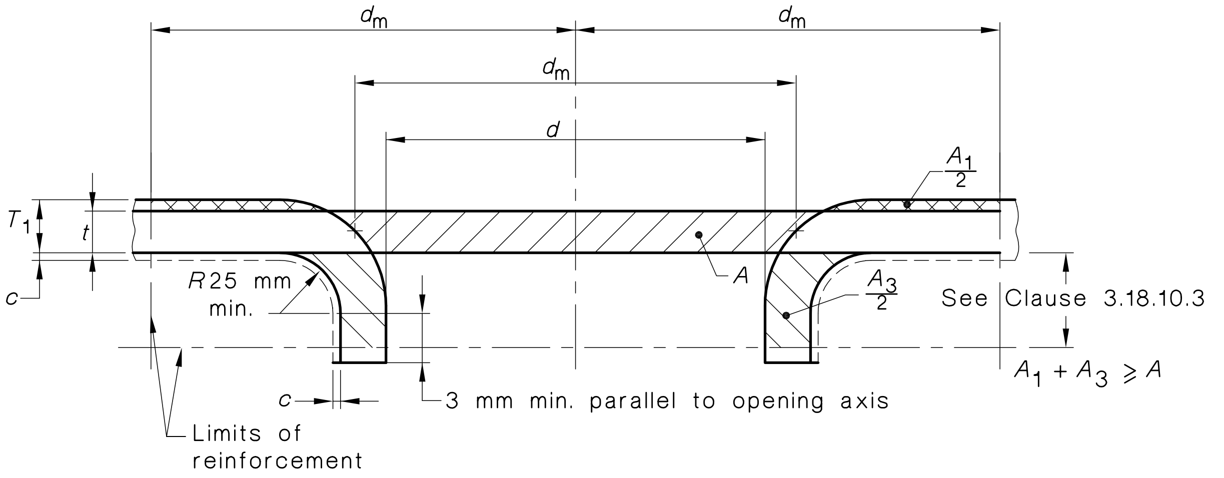
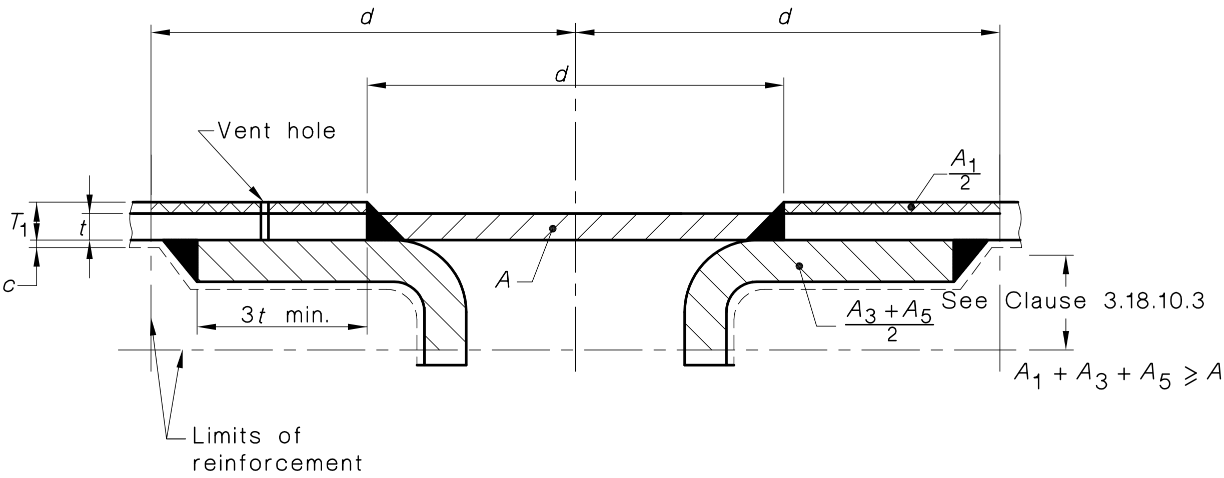


FIGURE 3.18.10 (in part) REINFORCEMENT AREAS AND LIMITS FOR OPENINGS



(c) Inwardly flanged opening



(d Inwardly flanged and welded opening

NOTE: For definition of symbols see Clause 3.18.2

FIGURE 3.18.10 (in part) REINFORCEMENT AREAS AND LIMITS FOR OPENINGS

3.18.11 Strength of reinforcement

3.18.11.1 *General* Material used for reinforcement shall have a design strength equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used. The strength reduction factors f_{r1}, f_{r2}, f_{r3} and f_{r4} are to take account of different strength materials, but in no case are these to exceed 1.0.

All pressure parts at openings and branches in vessels constructed of Group F or Group G steels shall be made of material whose specified minimum tensile strength is equal to or greater than that of the shell material, except that pipe flanges, pipe or communicating chambers may be of carbon steel, low alloy steel or high alloy steel welded to branch necks of the required material provided that—

(a) the joint is a circumferential butt weld located no less than $(rt)^{½}$ measured from the limit of reinforcement as defined in Clause 3.18.10 where *r* is the inside radius of the nozzle neck, and *t* is the thickness of the nozzle at the joint;

(b) the design of the nozzle neck at the joint is made on the basis of the allowable stress value of the weaker material;

(c) the slope of the nozzle neck does not exceed 3:1 for at least a distance of 1.5*t* from the centre of the joint; and

(d) the diameter of the nozzle neck does not exceed the limits given in Clause 3.18.4.1.

3.18.11.2 *Requirements* Strength of attachments and detailed requirements for welded and brazed reinforcement are given in Clause 3.19.

3.18.12 Reinforcement of multiple openings

3.18.12.1 *Two adjacent openings* Where two adjacent openings are spaced at less than twice their average diameter so that their limits of reinforcement overlap, the two openings (or similarly a greater number of openings) shall be reinforced in accordance with Clause 3.18.7 with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for the separate openings. No portion of the cross-section shall be considered as applying to more than one opening, or be evaluated more than once in a combined area (see Figure 3.18.12).

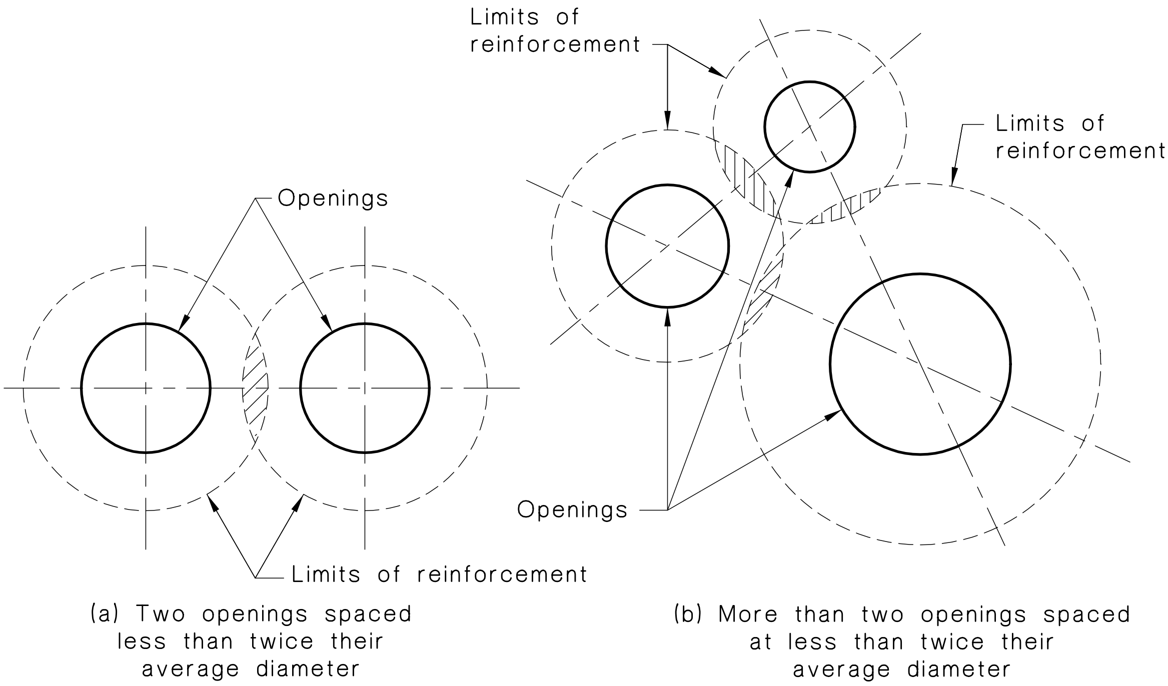


FIGURE 3.18.12 EXAMPLES OF MULTIPLE OPENINGS

3.18.12.2 *More than two adjacent openings* Where more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centres of any two of these openings should be at least 1.33 times their average diameter and the area of reinforcement between them shall be at least equal to 50 percent of the total required for these two openings.

3.18.12.3 *Reinforcement not credited* Where two adjacent openings as considered under Clause 3.18.12.2 have a distance between centres less than 1.33 times their average diameter, no credit for reinforcement shall be given for metal in the vessel wall between the openings.

3.18.12.4 *Number and arrangement unlimited* Any number of closely spaced adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings.

3.18.12.5 *Reinforcement by thicker section* Where a group of openings is reinforced by a thicker section butt-welded into the shell or end, the edges of the inserted section shall be tapered as prescribed in Clause 3.5.1.8.

3.18.12.6 *Series of tube openings* Where there are a series of tube openings in a pressure vessel and it is impracticable to reinforce each opening, the ligaments between openings shall be calculated in accordance with Clause 3.6.

3.19 CONNECTIONS AND BRANCHES

3.19.1 General Pipes, branches and fittings shall be connected to the vessel shells and ends in accordance with this Clause (3.19). For bolted flanged connections, see Clause 3.21.

Screwed and expanded connections shall not be used for vessels with lethal contents (see Clause 1.7.1).

3.19.2 Strength of attachment The strength of attachment of connections shall meet the following requirements:

NOTE: Welded connections which comply with Figures 3.19.3, 3.19.4, 3.19.6 or 3.19.9 meet these requirements and accordingly do not require further checking unless this requirement is shown in the relevant figure.

(a) On each side of the plane defined in Clause 3.18.10.1, the strength of the attachment joining the vessel wall and reinforcement or parts of the attached reinforcement shall be at least equal to the smaller of—

  (i) the strength in tension of the cross-section of the element of reinforcement being considered; and

  (ii) the strength in tension of the area defined in Clause 3.18.7 less the strength in tension of the reinforcing area which is integral in the vessel wall as permitted by Clause 3.18.10.4(a).

(b) The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in Clause 3.18.10. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the centre of the semi-circular end of the opening.

(c) Figure 3.19.2 shows some paths of failure which should be checked for strength by the following equations:

$$\text{Strength of attachment} = \frac{\pi}{2}\left(d_{ro}t_{fo} + d_{ri}t_{fi}\right) f_w \qquad \ldots 3.19.2(1)$$

where

f_w = design strength in weld (see Clause 3.19.3.5), in megapascals, and other symbols are as given in Figure 3.19.2;

and this shall be no less than the following:

$$\text{Strength of element} = A_5 f_r \qquad \ldots 3.19.2(2)$$

where

f_r = design strength in reinforcement ring or plate (see Clause 3.18.11 and Table 3.3.1), in megapascals

A_5 = cross-sectional area of reinforcement ring or plate, in square millimetres.

3.19.3 Welded branch connections and reinforcement

3.19.3.1 *Application* Arc or gas-welded connections may be used to attach branches, pads and reinforcement rings or plates to weldable materials.

Where thermal gradients are high, welds with full penetration should be used, and reinforcement plates and similar construction avoided.

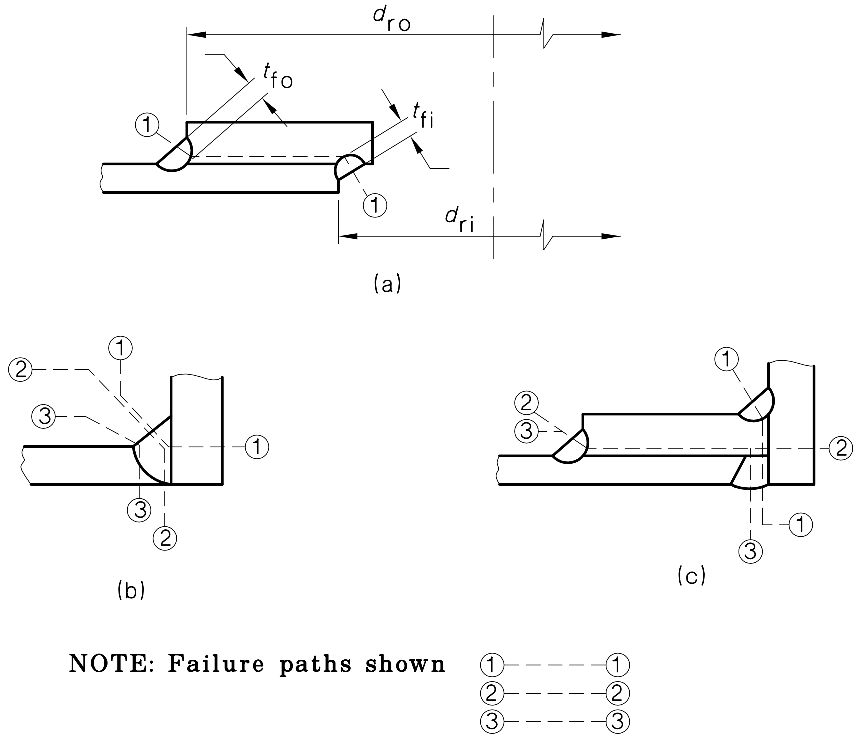


FIGURE 3.19.2 TYPICAL PATHS OF FAILURE OF WELDED CONNECTIONS

3.19.3.2 *Methods of attachment* Some acceptable forms of attachment of branches and reinforcement are given in Figure 3.19.3.

Reinforcement rings or plates may be located on either or both the outside or inside of the vessel and shall closely fit the vessel wall.

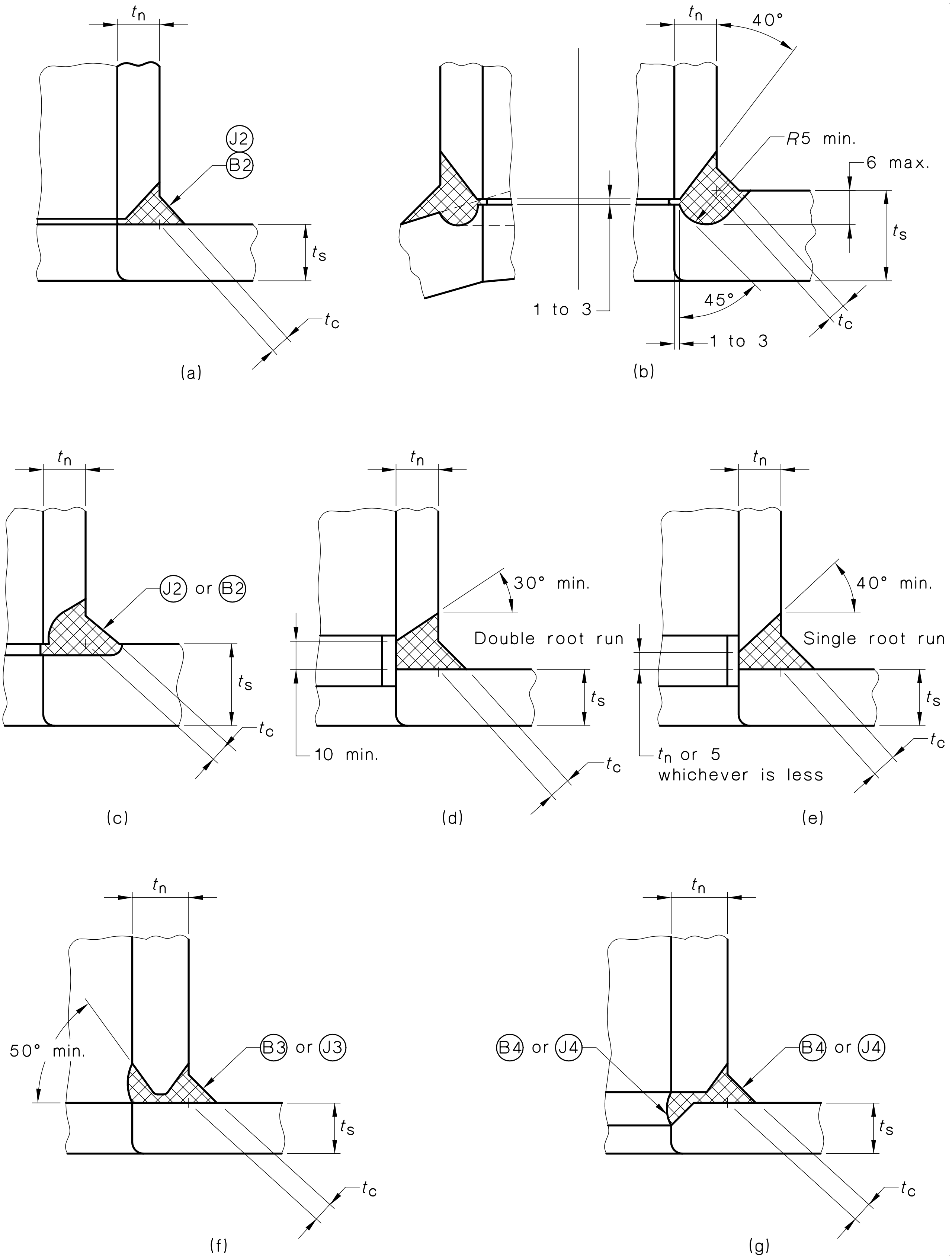
The overall length of any obround, set-in pad attached to the shell by double fillet welds shall not exceed one-half the inside diameter of the vessel.

Connections involving Group F steel shall be attached with full penetration butt welds and the radius at nozzle entry equal to $t/4$ or 20 mm, whichever is the lesser.

Connections involving Group G steel shall be full penetration butt welds in accordance with Figure 3.19.9 excluding figures (a) and (b).

3.19.3.3 *Hole for inserted connections* The diameter of the hole cut through a shell or end for an inserted pad or branch shall not exceed the diameter of the pad or branch by more than 6 mm. The pad or branch shall be centrally located in the opening before welding.

Where the surface of the hole will not be fused during welding, the hole shall not be punched and the surface shall have a smooth finish free from sharp crevices.



LEGEND and NOTES: See end of Figure 3.19.3(C).

DIMENSIONS IN MILLIMETRES

FIGURE 3.19.3(A) (in part) SOME ACCEPTABLE BRANCH CONNECTIONS—SET-ON TYPE

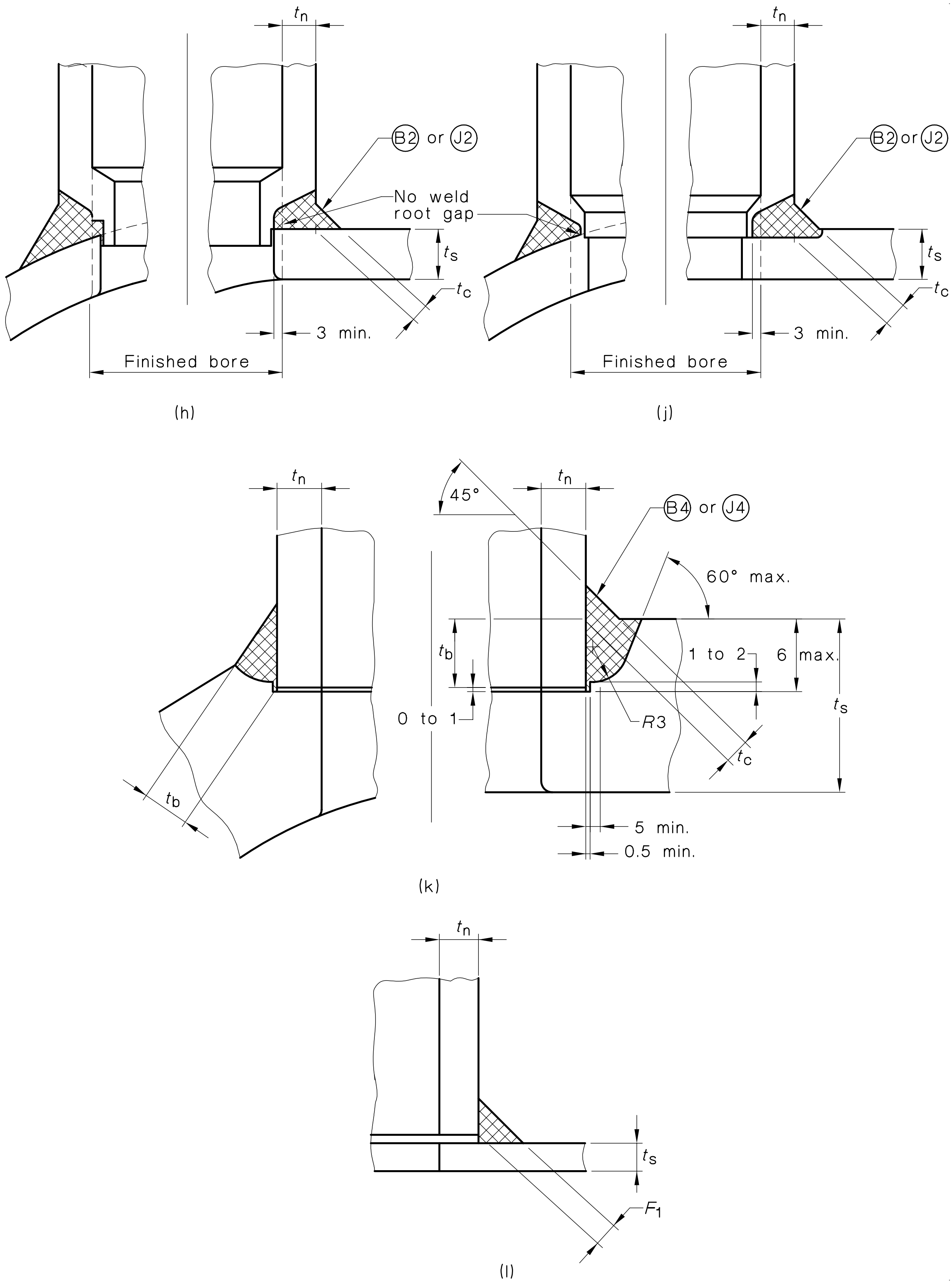
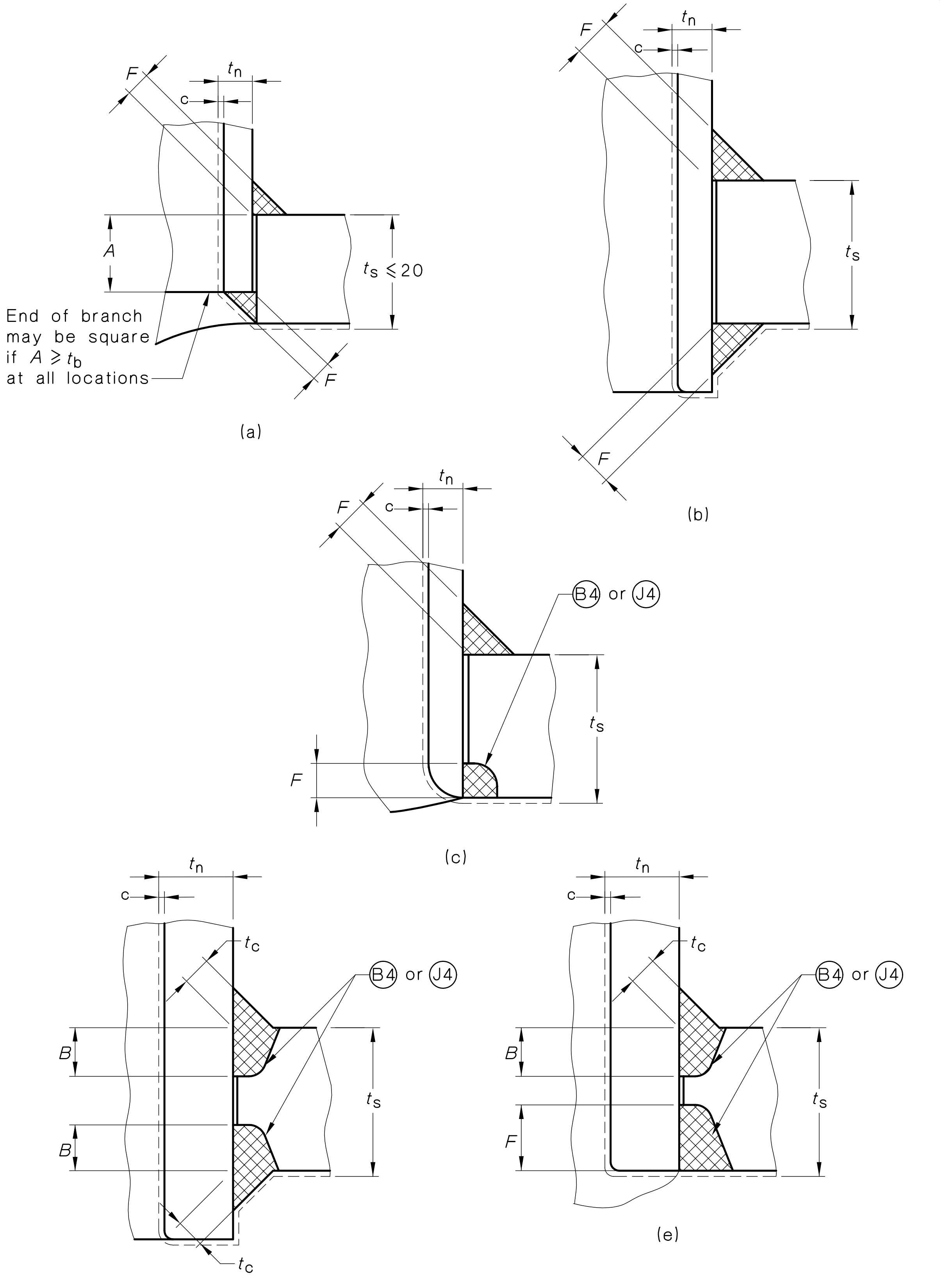


FIGURE 3.19.3(A) (in part) SOME ACCEPTABLE BRANCH CONNECTIONS—SET-ON TYPE



LEGEND and NOTES: See end of Figure 3.19.3(C).

DIMENSIONS IN MILLIMETRES

FIGURE 3.19.3(B) (in part) SOME ACCEPTABLE BRANCH CONNECTIONS—SET-IN TYPE

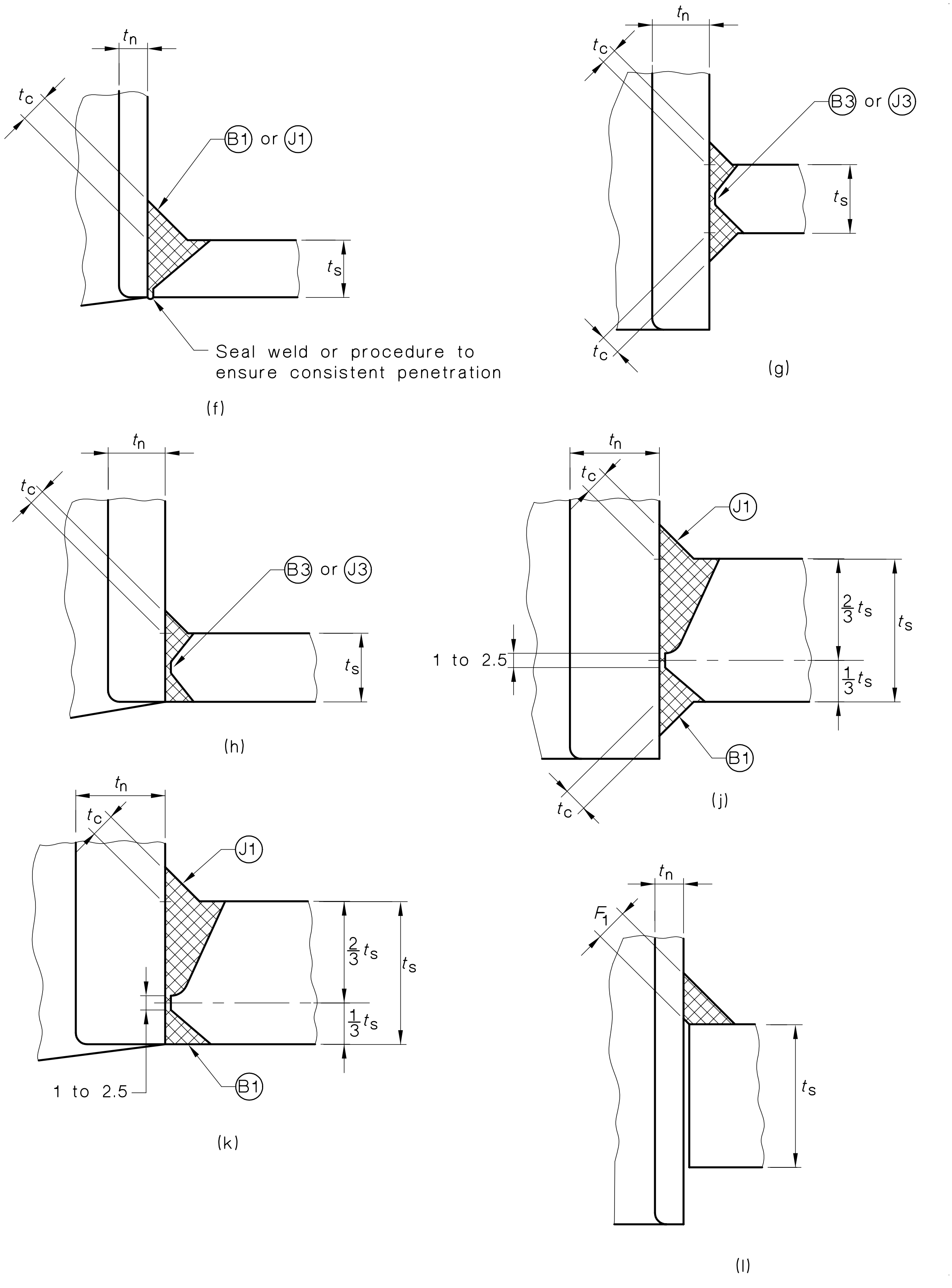
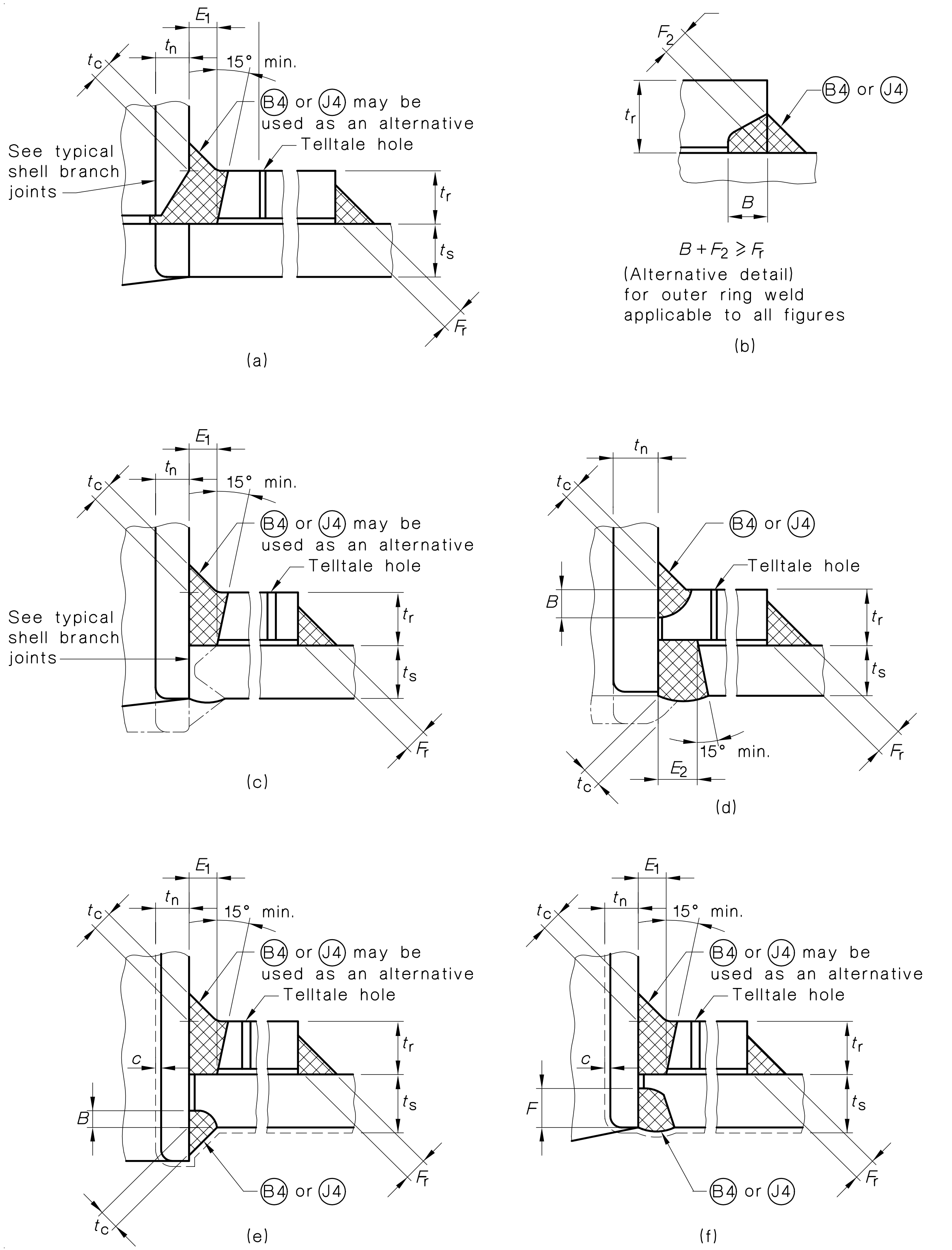


FIGURE 3.19.3(B) (in part) SOME ACCEPTABLE BRANCH CONNECTIONS—SET-IN TYPE



LEGEND and NOTES: See end of this Figure 3.19.3(C).

DIMENSIONS IN MILLIMETRES

FIGURE 3.19.3(C) SOME ACCEPTABLE BRANCH CONNECTIONS WITH COMPENSATING RINGS

LEGEND TO FIGURES 3.19.3(A), 3.19.3(B), and 3.19.3(C):

t_s	=	nominal thickness of vessel wall, in millimetres
t_n	=	nominal thickness of branch wall, less specified under tolerance, in millimetres
c	=	corrosion allowance, in millimetres
t	=	$t_s - c$ mm
t_b	=	$t_n - c$ mm
t_c	≥	$0.7t$, $0.7t_b$ or 6 mm, whichever is least
t_r	=	nominal thickness or height of reinforcing element, in millimetres
$B + t_c$	≥	t_b (NOTE: B may = 0)
E_1	≥	$\frac{t_r}{2}$ or 10 mm, whichever is less
E_2	≥	$\frac{t}{2}$ or 10 mm, whichever is less
F	≥	$0.7t$, $0.7t_b$ or 12 mm, whichever is least
F_1	≥	1.25 t or 1.25 t_b, whichever is less
F_r	≥	$0.5t_r$, 0.5 t, or 10 mm, whichever is least, but sufficient to comply with Clause 3.19.3.5

NOTES TO FIGURES 3.19.3(A), 3.19.3(B) AND 3.19.3(C):

1 See Figure 3.19.3(D) for standard branch weld details. Recommended departures in weld preparation angle from these details are shown on applicable sketches.

2 Backing rings must fit closely and shall be removed after welding except where otherwise agreed between the parties concerned.

3 Blank.

4 Connections (c),(h), (j) of Figure 3.19.3(A) are generally used for small branch to shell diameter ratios.

5 Connections (b) and (k) of Figure 3.19.3(A) are suitable for thick shells but (k) is not suitable for corrosive conditions.

6 In all set-on branch connections the shell plate around the hole shall be examined visually for laminations prior to welding and where practicable, for lamellar type tearing after welding.

7 Radius or chamfer all sharp corners.

8 Connections (1) of Figure 3.19.3(A) and (1) of Figure 3.19.3(B) are limited to Class 3 vessels with opening in shell or end not greater than maximum permitted unreinforced opening (see also Clause 3.19.5) and are not suitable for corrosive conditions.

9 The use of partial penetration welds and connections in Figures 3.19.3(C) should be avoided where cyclic stresses are likely to occur, where thermal gradients may overstress attachments welds, where the branch or shell thickness exceeds 50 mm or where high strength materials are used.

10 For all set on branch conditions, and set-in partial penetration connections, see AS 4458 for edge finish of unwelded openings.

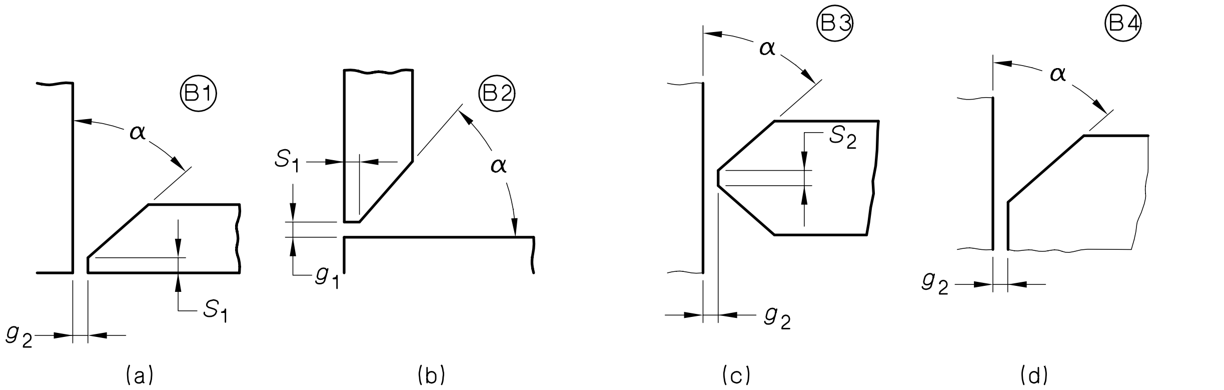
11 Where weld preparations (B4) or (J4) of Figure 3.19.3(D) are used for the attachment of reinforcing plates in Figure (a), (c), (e) and (f) of Figure 3.19.3(C), paths of failure shall be checked for strength when $t_b + E < t_r$.

12 The dashed lines indicate corrosion allowance on those joints which would require additional weld sizes for this purpose.

13 The figures show a 45° fillet weld as typical. This should not exceed 50° on the weld toe at the thinner member in Group D to J steels or where fatigue, shock, brittle fracture or exceptional external loads are important considerations.

14 Connection (k) of Figure 3.19.3(A) is permitted for branches up to and including 150 mm nominal bore and t_n up to and including 7 mm; it is not suitable for corrosive conditions.

15 The connections as detailed in Figure 3.19.3(C) may have the compensating rings on either or both sides of the vessel wall, with corrosion allowance added to rings on the inside wall and tell-tale holes venting to atmosphere.



LEGEND

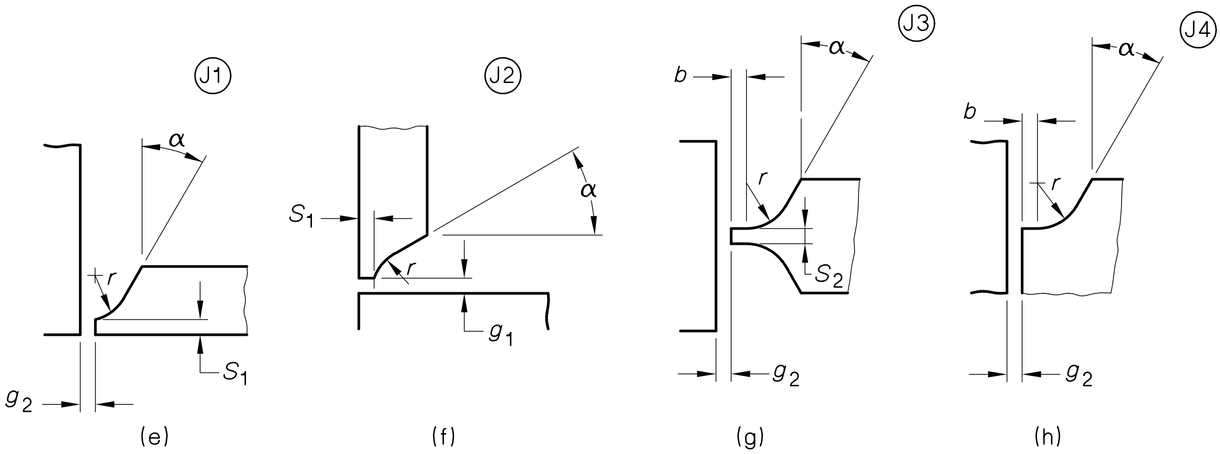
α = 50° min.

S_1 = 1.5 to 2.5 mm

S_2 = 0 to 3 mm

g_1 = 1.5 to 2.5 mm when $t_b < 10$ mm
1.5 to 4.0 mm when $t_b \geqslant 10$ mm

g_2 = See Note 2



LEGEND

α = 15° to 35°

S_1 = 1.5 to 3.0 mm

S_2 = 1.5 to 3.0 mm

g_1 = 1.5 to 3.0 mm

g_2 = See Note 2

b = 0 to 3.0 mm

r = 6 to 12 mm

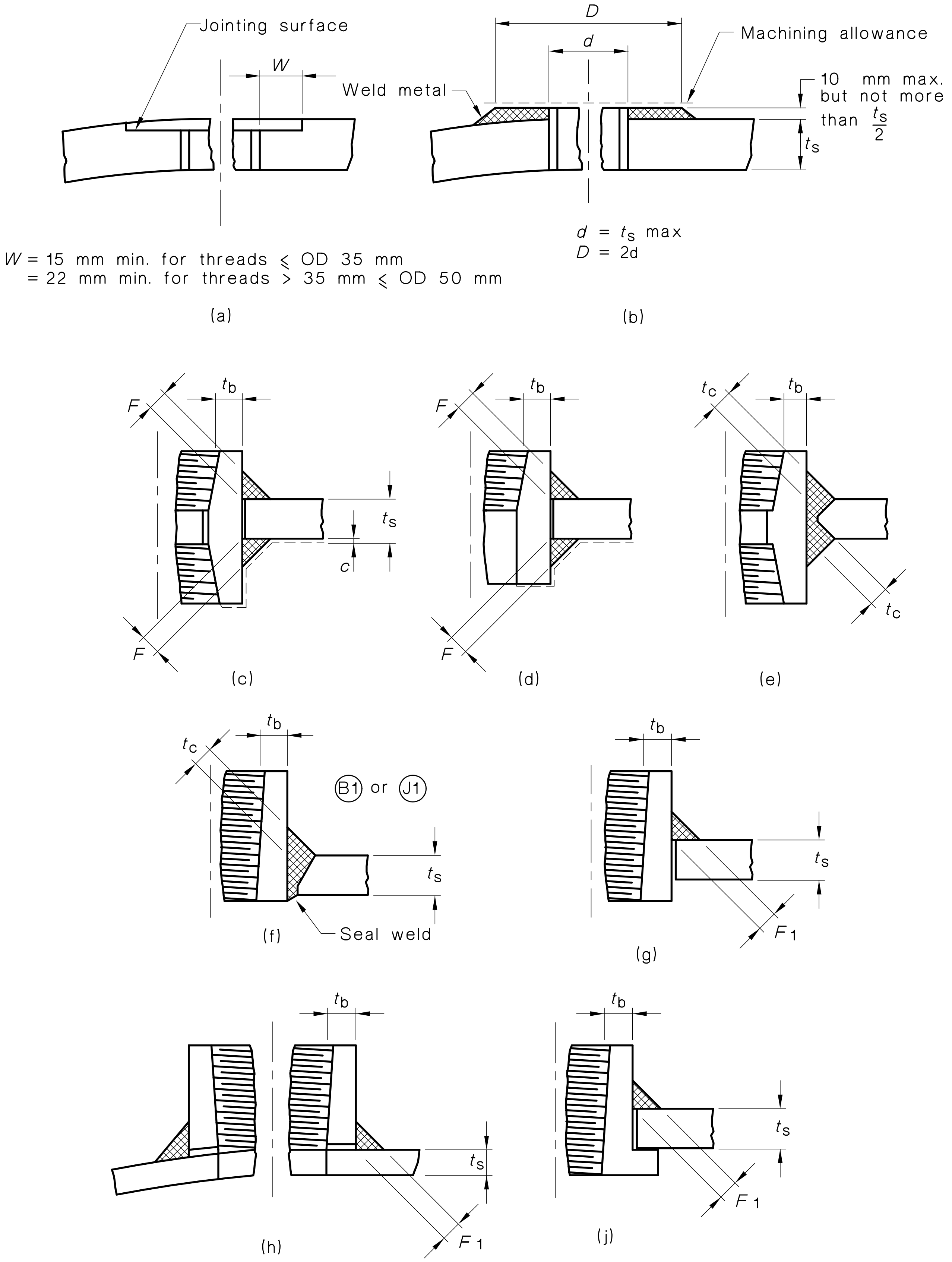
NOTES:

1 Weld preparations shown are regarded as prequalified preparations. Other preparations may be used, provided that the manufacturer demonstrates to the satisfaction of the Inspector that welds of the required size and quality can be obtained. Discretion must be used in apply the maximum and minimum dimensions quoted which are subject to variation according to the welding procedure employed (e.g. size and type of electrodes) also the position in which the welding is carried out.

2 It is recommended that in no case should the gap between branch and shell exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases. For welding of this sections by gas tungsten arc welding (GTAW) the gap is to be further reduced.

3 The use of minimum angle should be associated with the maximum radius or gap and conversely the minimum radius or gap should be associated with the maximum angle.

FIGURE 3.19.3(D) STANDARD WELD DETAILS FOR BRANCH CONNECTIONS



DIMENSIONS IN MILLIMETRES

FIGURE 3.19.4 (in part) SOME ACCEPTABLE SCREWED AND SOCKET WELDED CONNECTIONS

A3

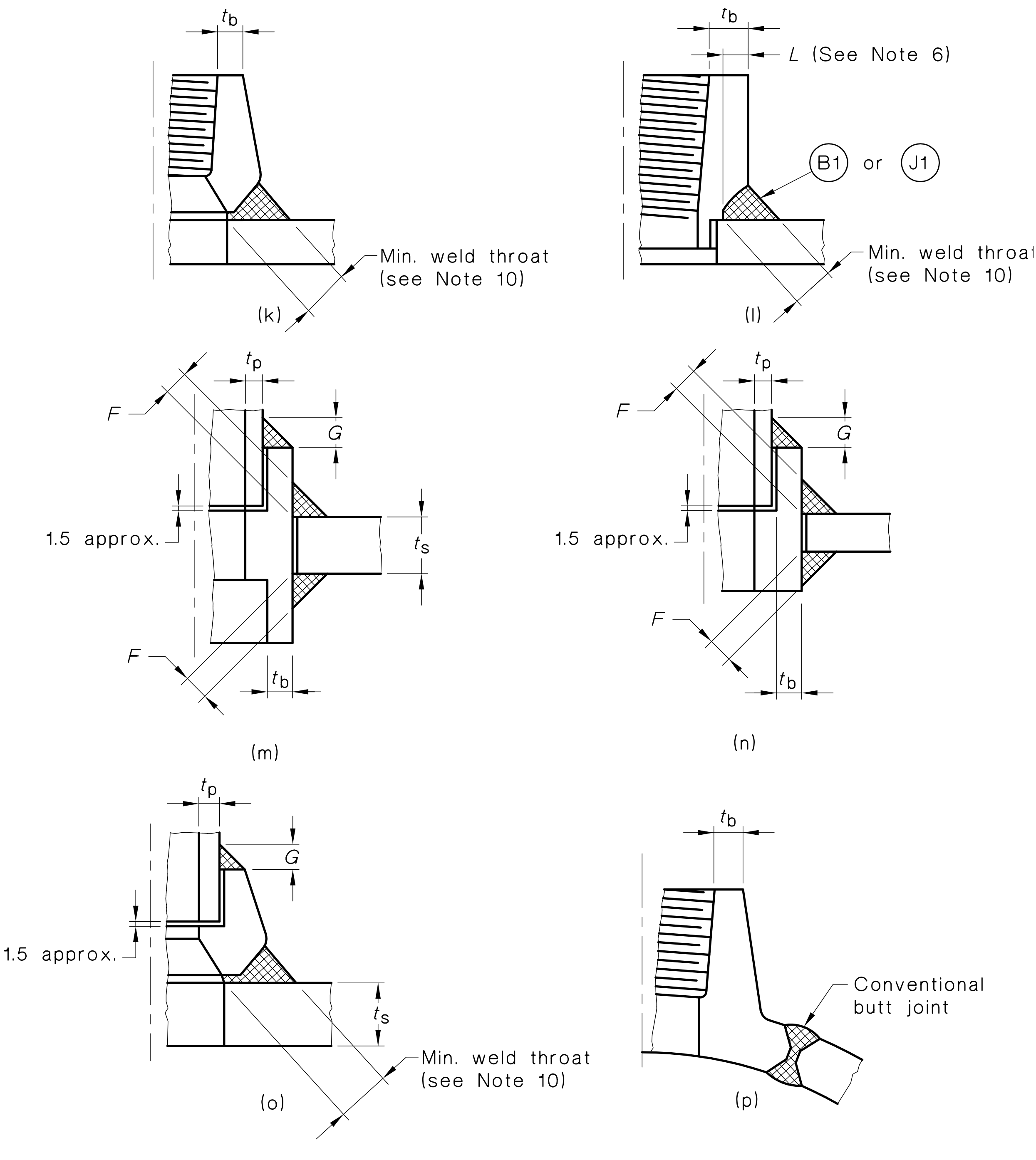


FIGURE 3.19.4 (in part) SOME ACCEPTABLE SCREWED AND SOCKET WELDED CONNECTIONS

NOTES TO FIGURE 3.19.4:

1 For weld preparations and weld sizes not shown, see Legend and Notes to Figures 3.19.3(A) to (D).

2 All screwed connections shall have the required length of thread.

A3 3 c = corrosion allowance, in millimetres

t_p = nominal pipe thickness, in millimetres

t_s = nominal thickness of vessel wall, in millimetres

t_b = 0.5 (outside diameter of socket minus largest major diameter of thread), in millimetres

4 In all set-on connections, the shell plate around the hole shall be examined visually for laminations prior to welding and where practicable, for lamellar tearing after welding.

5 Connections (g), (h), (j) are limited to Class 3 vessels with opening in shell or end not greater than maximum permitted unreinforced opening and t_s = 10 max. See also Clause 3.19.5 for limitations on use.

6 L = thickness of ANSI B36.10 pipe of schedule 160 wall thickness and bore equal to nom. opening size.

7 See Figure 3.19.3(D) for standard branch weld details.

8 In connections (m), (n), (o) diametrical clearances = 1 max. and $G = 1.25t_p$, but not less than 3 (see also Clause 3.19.5).

9 For all set-on connections and set-in partial penetration welds, see AS 4458 for edge finish of unwelded opening.

A3 10 The weld shall fill the weld preparation provided on the fitting unless otherwise specified by the designer.

3.19.3.4 *Tell-tale holes* Reinforcement plates and rings and similar constructions which may have chambers sealed by welding shall have at least one tell-tale hole per chamber that may be tapped to 15 mm major diameter (maximum), for testing of the welding sealed off by the reinforcing ring, and for venting during any heat treatment. For flanged joints or similar applications the end of the hole shall be clear of contact surfaces. After testing, the hole shall be exposed to atmosphere to prevent pressure build-up in the event of leakage through the attachment welds. However, the hole may be filled with a material which will exclude moisture.

NOTE: In some instances, such as underground vessels, it may be counterproductive to include tell-tale holes since they may admit moisture between the plate and vessel forming a corrosion pocket.

3.19.3.5 *Strength of welded connections* (see Note to Clause 3.19.2). Branches, other connections and their reinforcements attached to pressure parts, shall have sufficient welding on either side of a line, through the centre of the opening, parallel to the longitudinal axis of the shell, to develop the strength of the reinforcing parts as required by Clause 3.19.2, through shear or tension in the weld whichever is applicable.

The strength of a weld shall be based on the nominal throat of the weld times the length of the weld measured on its inner periphery times the maximum allowable stress for the weld. The allowable stress in the weld and in the component which may be included in the possible path of failure shall be the following percentage of the design tensile strength for the appropriate material (see Table 3.3.1):

A1, A3 (a) Fillet weld in end shear equals 70 percent.

(b) Butt weld in tension equals 74 percent.

(c) Butt weld in shear equals 60 percent.

(d) Components (e.g. branch wall) in shear equals 70 percent.

Where the load on a weld varies from side to end shear or shear to tension, the lower of the above values shall be used.

3.19.4 Screwed and socket welded connections

3.19.4.1 *General* Screw-threaded joints other than for screwed flanges may be used for the connection of pipes and fittings to pressure vessels within the limits set out in the following clauses. Such joints are not recommended where the connection is to be broken and remade frequently or is subject to continuous vibration; nor with toxic or flammable contents. Some acceptable types are shown in Figure 3.19.4.

3.19.4.2 *Pipe threads* Threads shall be in accordance with AS 1722.1, AS 1722.2, ANSI B1.20.1 or API Std 5B, or equivalent Standard.

Threads shall be right hand and may be taper-to-taper, parallel-to-parallel or taper-to-parallel.

Threads shall be true to their full length and depth and shall comply with any gauging requirements of the relevant specification.

3.19.4.3 *Size limitation* Threaded joints other than for screwed flanges shall not exceed 65 mm OD, except that threaded joints up to and including 90 mm OD may be used provided that—

(a) a taper-to-taper joint is used;

(b) the depth of engagement is not less than 25 mm; and

(c) any socket is a heavy wall type with gauged threads .

For threaded openings in forged ends see AS 4458.

3.19.4.4 *Temperature and pressure limits* Threaded joints other than for screwed flanges shall be limited to a maximum metal temperature of 260°C where temperature fluctuations could cause relaxation of the joint.

Threaded joints using steel heavy pipe with ordinary sockets, both of which conform to the dimensions of AS 1074 or BS 1740 shall be limited to the maximum pressure given in Table 3.19.4.

NOTE: AS 1074 and BS 1740 materials are not acceptable for integral pressure parts of vessels.

Notwithstanding the above requirements, threaded joints of taper-to-taper in accordance with API Std 5B or ANSI B1.20.1, or parallel-to-parallel type made with components which comply with any of the following Standards, may be used for temperatures and pressures up to the maximum permitted by that Standard for the component having the lower pressure/temperature rating:

BS 3799 BS 5154 BS 5352

or other equivalent Standards.

TABLE 3.19.4

MAXIMUM ALLOWABLE PRESSURE FOR THREADED JOINTS OTHER THAN SCREWED FLANGES

Outside diameter of pipe mm	Maximum allowable pressure, MPa		
	Taper-to-parallel joint	Parallel-to-parallel joint	Taper-to-taper joint
≤ 35	1.2	1.2	2.1
> 35 ≤ 50	1.05	1.05	1.75
> 50 ≤ 65	0.86	0.86	1.55
> 65 ≤ 90	—	—	1.55

3.19.4.5 *Sealing* Where threaded joints are likely to seize or corrode, sealing shall be arranged to prevent threads from coming in contact with the contained fluid. Where a sealing gasket is used, it shall be fitted so that inadvertent blockage of a passageway is not possible thereby.

To facilitate tightening during assembly and to promote long-time pressure tightness of threaded joints, the use of a material having lubricating, sealing and adequately stable properties for the intended service, is recommended.

NOTE: Where PTFE sealing and anti-seize tape is used, care may be necessary to avoid rupture of thin-walled fittings.

Where parallel threads are used and sealing is to be made on a curved surface, a joint face shall be provided in accordance with Figure 3.19.4(a).

3.19.4.6 *Length of thread engagement* The length of thread engagement shall be in accordance with the appropriate Standard, shall develop adequate strength against blowout, and shall in no case have less than four pitches of complete thread (see also Clause 3.19.4.3).

3.19.4.7 *Attachment* Screwed pipe and mountings may be attached to the vessel wall by screwing direct or by use of screwed sockets, branches or pad connections.

Screwed sockets shall—

(a) have a body thickness measured at the major diameter of the thread in accordance with Clause 3.19.10.2(b);

NOTE: Additional thickness in the body of the socket should be provided to limit distortion during welding.

(b) meet the reinforcement requirements of Clause 3.18;

(c) be welded in accordance with Figure 3.19.4 (see Clause 3.19.3.5); and

(d) for connection involving Groups F and G steels, be made with full penetration butt welds and be connections of the following types only:

  (i) For Group F steel—Figures 3.19.4(e), (f), (k) or (p)

  (ii) For Group G steels—Figure 3.19.4(p).

Where the plate thickness is insufficient to provide the specified length of thread engagement, a pad may be used. Pads of weld metal shall have a finished thickness not exceeding 50 percent of plate thickness with a maximum of 10 mm and the outside diameter should be approximately twice the hole diameter (see Figure 3.19.4(b)).

Screwed nipples may be attached using welded connections similar to those in Figure 3.19.4, with the minimum thickness measured at the minor diameter of the thread.

Where welded pads are used, the attachment of the pads shall be in accordance with Clause 3.19.3.

3.19.4.8 *Socket welded connections* Socket welded joints may be used for connecting pipes and fittings to pressure vessels within the limits set out in Clauses 3.19.4.1 and 3.19.5, but shall not be used for fittings for pipes exceeding 50 mm nominal ID.

Some acceptable types of socket welded connections are shown in Figures 3.19.4(m), (n) and (o).

3.19.5 Single fillet-welded connections Single fillet-welded connections should be avoided where cyclic stresses are likely to occur, where thermal gradients may overstress the attachment welds, and where corrosive conditions may occur.

3.19.6 Studded connections

3.19.6.1 *General* Studded connections may be used for jointing branches or fittings to the vessel wall either directly to a flat surface machined on the vessel wall or on a welded built-up pad or on a properly attached pad or fitting.

3.19.6.2 *Types of connection* Some acceptable types of connections are shown in Figure 3.19.6, except that connections involving Groups F and G steels shall be attached with full penetration welds only in accordance with —

(a) for Group F steels—Figure 3.19.6(g), (h) or (j); and

(b) for Group G steels—Figure 3.19.6(g).

Where the connection is made direct to wall as shown in Figure 3.19.6(a) and (b), the diameter of the hole shall not exceed 75 mm.

It is recommended that dimensions comply with standard flange drillings and facings.

3.19.6.3 *Studs* The material, dimension and number of studs shall comply with Clause 3.21.

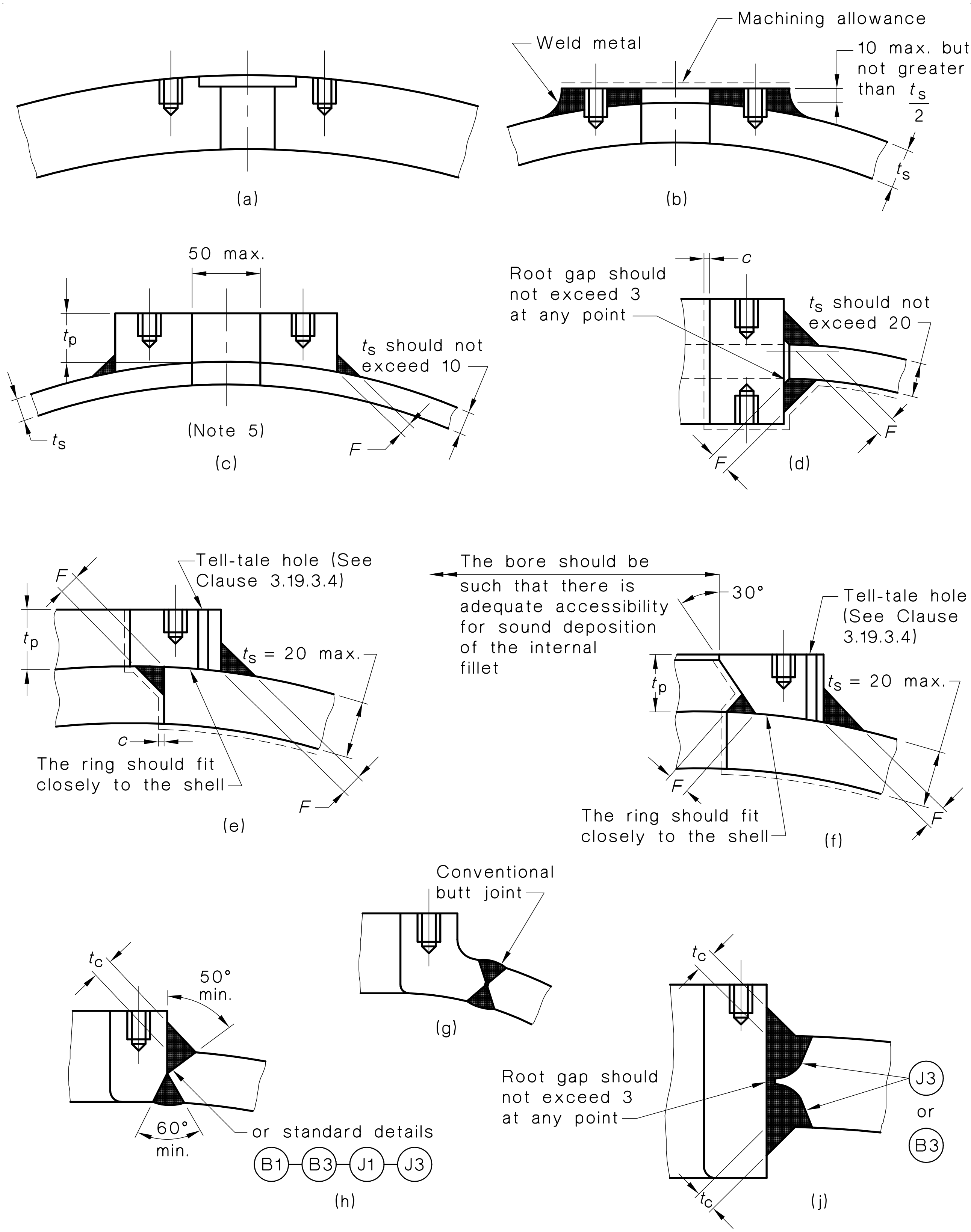
3.19.6.4 *Stud holes* Stud holes in pad type openings such as those shown in Figure 3.19.6 (excluding (e) and (f)) shall be drilled without piercing the pressure-retaining surface unless the pierced surface is suitably sealed. The thickness below the unpierced hole shall exceed the required corrosion allowance by an amount sufficient to retain pressure and withstand piercing by the stud.

The sealant for a pierced surface shall not be corrodible by the contents of the vessel or shall be at least as thick as the thickness required under unpierced holes.

Stud holes in pad type openings such as those shown in Figures 3.19.6(c), (e) and (f) shall not pierce the pad or ring, but, if they do, arrangement shall be made to prevent damage to attachment welds or the vessel wall due to tightening of the stud.

NOTE: Where bolts are fitted to pierced holes using a sealing compound which is compatible with the contents of the vessel and suitable for the service temperature range specified, no additional sealing is required.

The full threaded portion of stud holes and thread shall comply with Clause 3.21. For aluminium and its alloys, threaded inserts should be used where steel studs are used.



DIMENSIONS IN MILLIMETRES

FIGURE 3.19.6 SOME ACCEPTABLE STUDDED CONNECTIONS

NOTES TO FIGURE 3.19.6:

A3 1 Connections (c), (d), (e), (f) are not recommended if the vessel is subjected to pulsating loads.

2 For weld symbols and weld sizes not shown, see Legend and Notes to Figures 3.19.3(A) to (C). Additionally, the sizes of fillet welds in (c), (d), (e) and (f) shall comply with the requirements of Clause 3.19.2.

3 In connections (g), (h), (j) special precautions should be taken in the welding procedure to minimize the stresses induced by welding.

4 See Figure 3.19.3(D) for standard branch weld details.

5 Permitted for Class 3 vessels only. For limitations on use see Clause 3.19.5.

6 In all set-on connections, the shell plate around the hole shall be examined visually for laminations prior to welding and where practicable for lamellar type tearing after welding.

7 For all set-on connections and set-in partial penetration welds, see Clause 4.1.6.6 for edge finish of unwelded opening.

8 t_s = nominal thickness of vessel wall, in millimetres.

3.19.7 Expanded connections

3.19.7.1 *Application* A pipe, tube or forging for connection of pipes and fittings to pressure vessels may be attached to the vessel wall by inserting through an opening and expanding into the wall, provided that the outside diameter is not greater than 65 mm when fitted in an unreinforced opening, or not greater than 150 mm when fitted in a reinforced opening. For connections in flat tubeplates see Clause 3.17.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable or toxic gases and liquids unless the connections are seal welded.

3.19.7.2 *Methods of attachment* Such connections shall be—

(a) firmly expanded and beaded;

(b) expanded, beaded and seal-welded around the edge of the bead;

(c) expanded and flared not less than 2.5 mm over the diameter of the hole;

(d) expanded, flared and welded; or

(e) rolled and welded without flaring or beading, provided that—

  (i) the ends extend at least 6 mm but not more than 10 mm through the shell; and

  (ii) the throat of the weld is at least 5 mm but not more than 8 mm.

Where the outside diameter of the tube or pipe does not exceed 38 mm, the shell may be chamfered or recessed to a depth at least equal to the thickness of the tube or pipe and the tube or pipe may be rolled into place and welded. In no case shall the end of the tube or pipe extend more than 10 mm beyond the shell.

3.19.7.3 *Tube holes* Tube holes shall meet the requirements of Clause 3.17.10.

Where the tubes are not normal to vessel wall there shall be a neck or belt of parallel seating of at least 12 mm in depth measured in a plane through the axis of the tube at the holes.

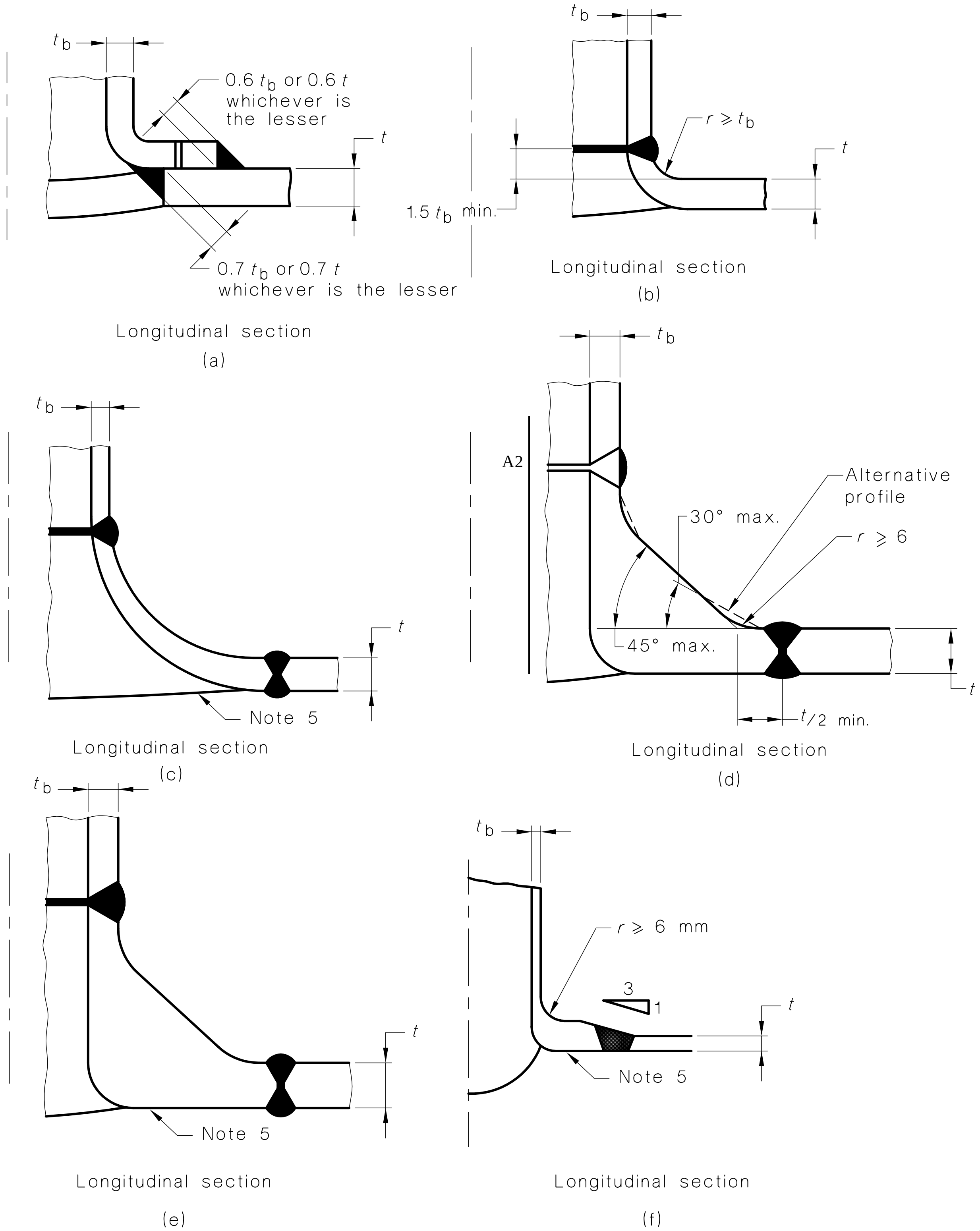
3.19.7.4 *Expansion* The expansion of tubes shall comply with Clause 3.17.11.

3.19.8 Brazed connections Connections such as saddle-type fittings and fittings inserted into openings formed by outward flanging of the vessel walls, in sizes not exceeding 90 mm outside diameter, may be attached to vessels by lap joints of brazed construction. Sufficient brazing shall be provided on either side of the line through the centre of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcement as specified in Clause 3.19.2 through shear in the brazing.

Openings for nozzles and other connections shall be far enough away from any main brazed joint so that the joint and the opening reinforcement do not interfere with one another.

3.19.9 Special connections Methods of connections using forged components or forging a short branch in the vessel (see Figure 3.19.9) may be used.

For special connections through jacketed vessels see Clause 3.23.



NOTES:

1 Conventional butt joints are used to connect the forging to the shell and branch and may therefore be of other forms than that shown.

2 These forgings connecting branches to shells are used with various forms of profile.

3 See Figure 3.19.3(D) for standard butt weld details.

4 t_b and t are nominal thickness minus corrosion allowance.

5 See Clause 3.19.3.2 for additional limitations when using Group F or Group G steels.

DIMENSIONS IN MILLIMETRES

FIGURE 3.19.9 SOME ACCEPTABLE FORGED BRANCH CONNECTIONS

3.19.10 Branches

3.19.10.1 *Design basis* Branches shall be designed to provide—

(a) adequate thickness to withstand the design pressure and any corrosion;

(b) adequate thickness to withstand external forces when so specified by the purchaser (see Clause 3.2.3. and Appendix E);

(c) suitable connection to the vessel (see other requirements to this Clause (3.19)); and

(d) where necessary, added reinforcement of the opening.

3.19.10.2 *Branch thickness* The minimum thickness of the branch after fabrication, up to the connection to external piping shall be the greater of—

A3 (a) the thickness to withstand both the calculation internal or external pressure and other loadings plus corrosion; and

A2,A3 (b) the smaller of the required thickness of the vessel wall due to the larger of the design internal pressure and the design external pressure with this pressure applied as an internal pressure, including allowances in Clause 3.4.2 at the point of attachment, and the following thickness plus corrosion:

Outside diameter, mm	21.3	26.7	33.4	48.3	60.3	88.9	114.3	168.3	219.1	273	>273
DN	15	20	25	40	50	80	100	150	200	250	>250
Minimum thickness, mm	2.4	2.5	2.9	3.2	3.4	4.8	5.2	6.2	7.1	8.1	8.3

Intermediate values may be derived by interpolation.

The thickness required by Item (b) does not apply for access openings or openings for inspection only and may be reduced where suitable protection or support are provided.

It is recommended that advantage be taken of increased branch thickness where reinforcement is required.

NOTE: Reinforcement of the hole in the shell of a vessel is obtained more efficiently by a thick branch pipe than by a thin one with a reinforcing ring.

3.19.10.3 *Inclination* Branches may be inclined provided that the reinforcement is adequate. This will be achieved by using the major dimension of the resultant opening in applying the requirements for reinforcement.

3.20 INSPECTION OPENINGS

3.20.1 General All vessels, except those permitted by Clauses 3.20.5 and 3.20.6, shall be provided with suitable inspection openings to permit visual examination and cleaning of internal surfaces. Internal access equipment shall be provided where required. Consideration shall be given to the proposed method and frequency of, and accessibility for, inspection (see AS/NZS 3788).

Manholes shall be positioned to allow easy ingress by an inspector and safe and ready recovery of an incapacitated person.

Clause 3.20.2 Not allocated.

Clause 3.20.3 Not allocated.

3.20.4 General purpose vessels Vessels other than special vessels covered by Clauses 3.20.5 and 3.20.6 shall be fitted with inspection openings in accordance with Table 3.20.4, or openings shall be located to permit closer inspection of areas most subject to deterioration.

TABLE 3.20.4

INSPECTION OPENINGS FOR GENERAL PURPOSE VESSELS

A2

Inside diameter of vessel mm	Minimum clearance size of openings (Note 1) mm	Minimum number of openings (Note 2)	Location of openings
≤315	30 dia.	One for shells up to and including 900 mm long	In end, or where this is not practicable, in the shell near end.
		Two for shells over 900 mm long	—
>315 ≤460	40 dia.	Two for shells of any length	One in each end, or where this is not practicable, in the shell near each end
>460 ≤920	50 dia.		
>920 ≤1500†	Handhole 150 diameter or 180 × 120	Two for shells up to 3000 mm long (Note 3)	One in each end or in the shell near each end
	Headhole 290 diameter	One for shells up to 3000 mm long (Note 3)	In the central third of the shell (Note 4)
>1500	Elliptical mahole or equivalent*	One for shells of any length	In the shell or end to give ready ingress and egress

* See Table 3.20.9

† Either handhole or headhole option may be selected.

NOTES:

1 Size openings for jackets of jacketed vessels need not exceed 65 mm OD.

2 The length of shell is measured between the welds attaching the ends to the cylindrical shell.

3 For shells longer than 3000 mm, the number of openings shall be increased so that the maximum distance between handholes does not exceed 2000 mm and that of headholes 3000 mm.

4 For shells up to 2000 mm long, a single headhole in one end may be used.

3.20.5 Vessels not subject to corrosion Vessels which are not subject to internal corrosion, abrasion or erosion; and which are—

(a) used for static services (i.e. stationary, or normally stationary but are transported at infrequent intervals, and are not subject to severe shock or fatigue loadings), and have a water capacity not exceeding 60 m^3;

A2 (b) used for other than static service, and have a water capacity not exceeding 5 m^3; or

A2 (c) burried or mounded, and have a water capacity not exceeding 15 m^3;

shall be fitted with inspection openings in accordance with Table 3.20.5. Vessels exceeding the limits of Item (a) or Item (b) shall be fitted with a manhole, except where the process or nature of the vessel contents or the design of the vessel renders undesirable the installation of a manhole. For vacuum-insulated vessels where a manhole is provided in the inner vessel, but not in the outer vessel, the manufacturer shall clearly mark the outer vessel with the words ‘Manhole Here’ opposite the inner manhole.

For the purposes of this Standard, vessels not subject to corrosion include vessels for refrigerants, liquefied petroleum gas and other substances which from tests and past experience are known to have no harmful effect on the vessel material.

TABLE 3.20.5

INSPECTION OPENINGS IN VESSELS NOT SUBJECT TO CORROSION

Inside diameter of vessel mm	Minimum clearance size of opening, mm (Notes 2 and 3)	Minimum number and location of openings (Note 1)
≤160	Not required	—
>160 ≤250	25	For shell ≤3000 mm: one opening in end (or in shell near end)
>250 ≤400	30	For shells >3000 mm: two openings: one in each end (or in shell near each end)
>400 ≤775	35	
>775	40	

NOTES:

1 A greater number of smaller openings may be used provided that—
   (a) the minimum opening is 25 mm clearance diameter;
   (b) the sum of the diameters is at least equal to that required by Table 3.20.5;
   (c) the openings are suitably located to facilitate inspection.

2 These openings may be provided by—
   (a) removal of valves, fittings or pipe;
   (b) cutting of branch pipes near the shell;
   (c) special inspection branches with seal welded closures.

3 As an alternative to openings in these vessels, inspection may be provided by—
   (a) cutting of shells;
   (b) having no openings and using non-destructive examination methods (other than visual) see Clause 3.20.6(b). Refer to Appendix E.

3.20.6 Vessels not requiring openings Vessels need not have the prescribed inspection openings where—

(a) they are designed, constructed and installed so as to be readily dismantled to permit visual examination and cleaning of all internal surfaces subject to stress; or

(b) they are of such design and usage that visual examination is not practicable and an alternative approved means of assessing deterioration is applicable.

3.20.7 Manholes for vessels containing an unsafe atmosphere Vessels which, at the time a person may be required to enter the vessel, are liable to contain an unsafe atmosphere, i.e. contaminated or oxygen deficient, shall be fitted with at least one manhole of the following minimum size:

(a) For stationary vessels—not less than 450 mm × 400 mm (elliptical) or 450 mm (circular).

(b) For transportable vessels—not less than 400 mm × 300 mm (elliptical) or 400 mm (circular).

NOTE: The means of ingress to and egress from a vessel need to be kept free from encumbrances. Accordingly, where the atmospheric contaminants or the nature of the work to be performed in a vessel may require power lines, hoses, ventilation ducts or similar to pass through a manhole, consideration should be given to the provision of a second manhole. (See
A3 also AS 2865 and AS/NZS 3788.)

3.20.8 Alternative openings Openings may alternatively be provided as follows:

(a) Where the vessel shape is not cylindrical, the openings required by Clause 3.20.4 need not apply, but sufficient openings of suitable size and location shall be provided to give access equivalent to that required by this Clause (3.20).

(b) Where a manhole is prescribed but the shape or use of the vessel makes the provision of manhole impracticable, sufficient inspection openings each 150 mm × 100 mm or 125 mm diameter, or larger, shall be provided. One opening shall be located in each end or in the shell near the end and in other positions to permit examination of all areas liable to deterioration.

(c) Vessels which are 315 mm inside diameter or less may use pipe or fitting connections in place of the required inspection openings, provided that they are in suitable locations, can be readily dismantled and will provide the necessary number and size of openings.

(d) Core openings in cast vessels having internal passages may be used in place of inspection openings, provided that their closures are readily removable and replaceable and are located to permit adequate inspection.

(e) Removable ends or cover plates may be used in place of inspection openings, provided that they are at least equal to the minimum size required for such openings. A single removable end or cover plate may be used in lieu of all other inspection openings where the size and location of such opening permits a general view of the interior at least equal to that obtained with the inspection openings otherwise required.

3.20.9 Size of openings The preferred sizes of inspection openings are given in Table 3.20.9.

TABLE 3.20.9

SIZE OF INSPECTION OPENINGS

millimetres

Type	**Circular openings— (diameter)**	**Equivalent elliptical openings— (major × minor axes)**	**Maximum depth of opening (see Note 1)**
Sighthole	30 40 50	— — —	30 40 50
Handhole	75 100 125 150 200	90 × 63 115 × 90 150 × 100 180 × 120 225 × 180	50 } Pads 50 } Pads 63 } Pads 75 100
Headhole	300 max. 290 min.	320 × 220 max. 310 × 210 min.	100
Manhole	400 (Note 2) 450 500	400 × 300 (Note 2) 450 × 400 —	150 245 300

NOTES:

1 The depth of the opening is the shortest distance from the outside face of the opening to the inside face of the opening. Linear interpolation of the depth of the opening is permitted. A greater depth may be permitted only where the tabulated depth is impractical.

2 A 400 mm × 300 mm elliptical manhole or 400 mm diameter circular manhole may be used only where larger manholes are impractical and within the following limitations (see also Clause 3.20.7(b)):

(a) Vessels for steam, water, air or other applications were it can be ensured that, at the time of any entry to the vessel, the contents will be life supporting.

(b) For stationary vessels, the diameter of the vessel is not greater than 1530 mm.

(c) For horizontal vessels, the manhole is in the end with the major axis of the ellipse horizontal. (See also Clause 3.20.1).

(d) For vertical vessels, the manhole is in the shell within 700 mm to 900 mm of the bottom of the vessel or a platform within the vessel, and with the major axis of the ellipse horizontal.

3.20.10 Design of inspection openings The design of inspection openings shall be in accordance with the requirements for openings and branches (see Clauses 3.18 and 3.19).

Screwed plugs with parallel threads may be used for closure of inspection openings up to and including 65 mm outside diameter, provided that they have a joint face and the connection is in accordance with Clause 3.19.3 or approved method which will permit removal and replacement from time to time with ease and safety. The screw plug shall be
A2 of material suitable for the pressure and temperature conditions.

3.20.11 Ingress to vessels Unless precluded by process equipment or other circumstances, provision shall be made inside the vessel so that a safe landing place or the top rung of a ladder leading thereto is located adjacent to and not more than 1 m below any manhole intended for ingress. Suitable hand grips shall be provided where practicable.

3.21 BOLTED FLANGED CONNECTIONS

3.21.1 General This Clause (3.21) deals with the design of bolted flanged connections in pressure vessels, including inspection covers, blind flanges, bolted flat ends, sections of shells, and branch connections.

It provides only for hydrostatic end-forces and gasket seating. Where the component is subjected to moments or other forces from external sources, these shall also be taken into consideration.

Bolted flanged connections shall comply with the requirements of this Clause (3.21) or a
A2 recognized Standard for flanges. Flanges conforming to ANSI/ASME B16.5, ANSI/ASME B16.47, AS 2129, AS 4087, AS/NZS 4331 Parts 1 to 3, BS 3293 or BS 4504 may be used and in such cases the calculations required in this Clause need not be carried out. The above standard pipe flanges shall only be used within the size and pressure-temperature rating permitted in the relevant Standard.

Attention is drawn to potential problems of large diameter flanges which may rotate more than small diameter flanges designed to these rules. Such flanges can leak particularly those sealed with non self-energizing gaskets under cyclic loading.

NOTE: Flanges and bolting complying with AS 2129 used at maximum conditions permitted by that Standard may result in high stresses and risk of leakage, particularly under hydrostatic test. These flanges should not be used with lethal contents or where risk of leakage cannot be tolerated. AS 2129 flanges with full-face joints may be used only within the limits of Clause 3.21.2(b).

3.21.2 Types of flanged connection For design purposes flanges are divided into the following types:

(a) *Narrow-face flanges*—flanges in which the joint ring or gasket does not extend beyond the inside of the bolt holes as shown in Figure 3.21.2(b), (c), (d).

(b) *Flanges with full-face joint*—flanges in which the joint ring or gasket extends over the full width of the flange face as shown in Figure 3.21.2(a). These are suitable only when used with comparatively soft jointings and are not recommended for pressures exceeding 2.1 MPa or temperatures exceeding 260°C. Where the inside diameter exceeds 600 mm a maximum of 1.4 MPa is recommended.

(c) *Reverse flanges*—flanges where the shell is attached to the outer edge of the flange as shown in Figure 3.21.12.2.

NOTE: Care must be taken to avoid the incorrect mating of full-face flanges with narrow-face flanges, particularly where the full-face flange is made from weaker material, e.g. standard full-face cast iron flanges should not be connected to standard narrow-face steel flanges.

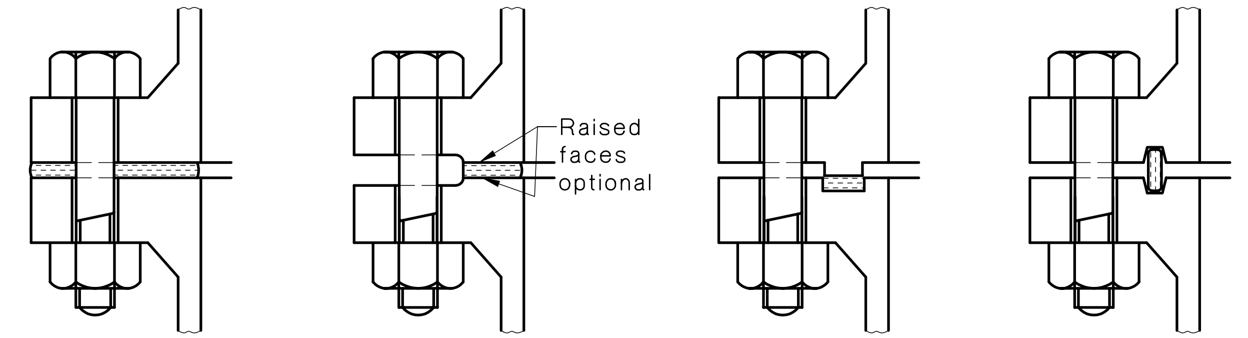


FIGURE 3.21.2 TYPES OF BOLTED FLANGE JOINT

3.21.3 Attachment of flanges

3.21.3.1 *Types of attachment* Various types of flange attachment are shown in Figure 3.21.3.

Typical flange attachments, as shown in Figure 3.21.3, may be used for reverse flanges, adjusted as appropriate for the location of the flange inside the shell and, usually, with provision for studs in place of bolt holes.

3.21.3.2 *Strength of attachment* Flanges shall be attached to the vessel or branch in accordance with the dimensions shown in Figure 3.21.3.

Threaded flanges where used shall be provided with ample depth and length of thread to withstand loads and moments. and shall be screwed home hard on the branch pipe or vessel shell. Threads on the branch pipe or vessel shall vanish at a point just inside the back or hub of the flange, except where a parallel-to-parallel threaded attachment is used. In this latter attachment ample provision shall be made for sealing and locking.

3.21.3.3 *Limits of use of welded flange attachments* Welded flange attachments shown in Figure 3.21.3 are limited to the following maximum calculation pressures and temperatures:

Attachments (a) to (d) inclusive and (1)—no limits provided that full penetration welds are used for Group F and Group G steels.

Attachments (e) to (g) inclusive—8.3 MPa at 50°C for carbon steel and equivalent ratings
A1 except temperature shall not exceed 425°C, e.g. Table R of AS 2129.

Attachments (h) and (j)—4.9 MPa at 50°C for carbon steel and equivalent ratings; except
A1 that the temperature shall not exceed 425°C, e.g. Table J of AS 2129.

Attachments (b), and (d) to (j) inclusive shall be avoided where thermal gradient may cause overstress in welds or where many large temperature cycles are expected, particularly where the flange is uninsulated.

Attachments (e), (h) and (j) are not recommended for corrosive conditions.

Slip-on and socket-welded flanges are not recommended for service below −45°C.

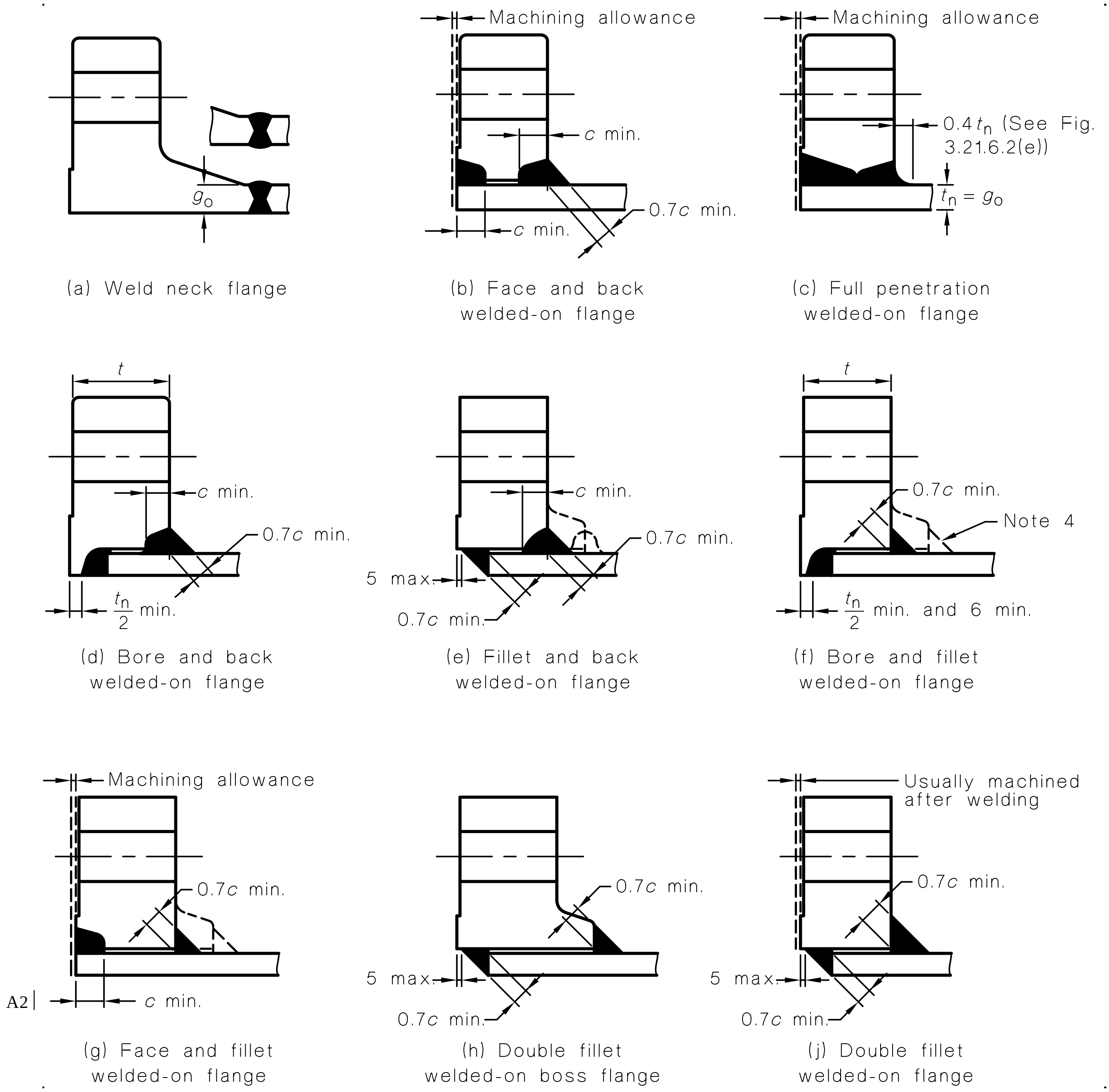
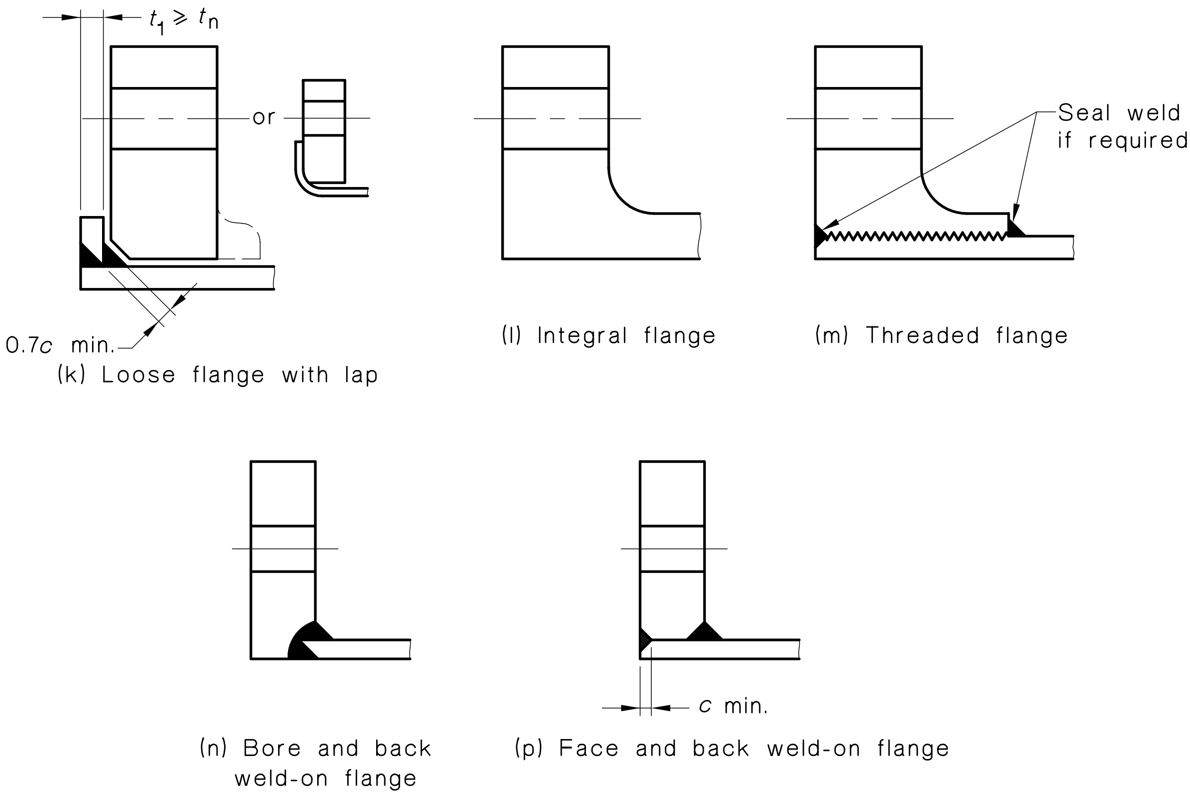


FIGURE 3.21.3 (in part) TYPICAL FLANGE ATTACHMENTS



NOTES:

1 c = t_n or t_x, whichever is less, where t_x is as in Clause 3.21.6.2.

2 t_n = nominal thickness of shell or branch, less corrosion allowance.

3 See Figure 3.19.3 for standard weld preparations. Where weld preparations are shown as J type on this Figure (3.21.3), B type preparations may be used.

4 The gap between flange and wall should not exceed 3 mm. Wide gaps increase the tendency to cracking during welding, particularly as the thickness of the parts joined increases. For welding of thin sections by gas tungsten-arc welding (GTAW) process, the gap is to be small.

5 For thin shells it may be desirable to fit a short length of thickened shell to facilitate flange attachment.

6 For flange dimensions not shown, see Figure 3.21.6.2.

FIGURE 3.21.3 (in part) TYPICAL FLANGE ATTACHMENTS

3.21.3.4 *Limits of use of threaded flanges* The pressure and temperature limits of use of threaded flanges in which the tightness of the joint depends upon the tightness of the threads, are given in Table 3.21.3.4.

Threaded flanges are not recommended for severe cyclic service, or for corrosive service unless sealed on the face, or for service below −50°C for ferritic steels.

Threaded flanges in which the tightness of the joint depends on the tightness of the threads and which contain—

(a) corrosive material; or

(b) flammable or toxic fluids or fluids which are difficult to contain;

shall be of weldable quality and shall be seal welded. In the case of (a) the seal weld shall be on the contact face, and in the case of (b) on the back of the flange.

3.21.4 Basis of design (see Clause 3.21.6.2 for notation).

3.21.4.1 *General* The design of a bolted flanged connection involves the selection of gasket (material, type and dimensions), flange facing, bolting, hub proportions, flange width and flange thickness. The methods given in the following clauses generally require a preliminary selection of these details followed by a trial and error procedure.

Flange dimensions shall be such that the stresses in the flange calculated in accordance with this Clause (3.21.4) do not exceed the allowable flange stresses permitted in Clause 3.21.6.7. All calculations shall be made with dimensions in the corroded condition, i.e. by allowing for loss of metal equal to the corrosion allowance.

In the design of a bolted flange connection, complete calculations shall be made for two separate and independent sets of conditions. which are defined in Clauses 3.21.4.2 and 3.21.4.3.

NOTE: It is recommended that the bolt spacing on unproven flange designs be not greater than the dimension obtained from the following equations (see Clause 3.21.6.2 for notation):

$$P_b \text{ max.} = 2D_b + \frac{6t}{m + 0.5} \quad \text{for narrow face flanges; or}$$

$$P_b \text{ max.} = 2D_b + \frac{6t}{m + 0.5}\left(\frac{E}{200\ 000}\right)^{1/4} \quad \text{for flanges with full face gaskets.}$$

If bolt spacing, P_b exceeds $2D_b + \dfrac{6t}{m + 0.5}$, the total flange moments shall be increased by a

A1 factor equal to $\left[P_b/(2D_b + \dfrac{6t}{(m + 0.5)})\right]^{0.5}$

The minimum bolt spacing will be determined by consideration of the space necessary to apply a wrench to the nuts and possible interference from gussets and other obstructions.

TABLE 3.21.3.4

LIMITS OF USE OF THREADED FLANGES

Material	Method of attachment	Maximum pressure Mpa	Maximum temperature °C
Carbon and carbon-manganese steels	Threaded and expanded	3.1	371
	Taper to taper	2.1	260
	Taper to parallel	0.86	260
Alloy steels	Threaded and expanded	4.2	482
Cast irons	Taper to taper	1.05	180
	Taper to parallel	0.86	178
Copper and copper alloys	Threaded	Refer to AS 2129	

3.21.4.2 *Operating conditions* The operating conditions shall be taken as those required to resist the hydrostatic end-force of the design pressure tending to part the joint, and to maintain on the gasket or joint-contact-surface sufficient compression to ensure a tight joint all at the design temperature. The minimum force is a function of the design pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure, as determined by Equation 3.21.6.4.1(1), and determines one of the two requirements for the amount of bolting area A_{m1}. This force is also used for the design of the flange, as determined by Equation 3.21.6.4.4(1).

3.21.4.3 *Gasket seating conditions* The gasket seating conditions shall be taken as those existing when the gasket or joint-contact surface is seated by applying an initial force with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial force considered to be adequate for proper seating is a function of the gasket material, and the effective gasket or contact area to be seated, as determined by Equation 3.21.6.4.1(2), and determines the other of the two requirements for the amount of bolting area A_{m2}. For the design of the flange this force is modified in accordance with Equation 3.21.6.4.4(2), to take account of the operating conditions, when these govern the amount of bolting area required, A_m, as well as the amount of bolting area actually provided, A_b.

3.21.5 Materials and components

3.21.5.1 *General* Materials for bolted flanged connections shall comply with the requirements of Table 3.3.1 and Clause 2.2 (as applicable).

3.21.5.2 *Flanges* Flanges made from ferritic steel and designed in accordance with this Clause (3.21.5) shall be given a normalizing or full-annealing heat treatment where the thickness of the flange section before machining exceeds 75 mm.

Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure in AS/NZS 3992 is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35 percent. All welding on flange connections shall comply with the requirements for postweld heat treatment given in AS 4458.

Fabricated hubbed flanges may be machined from a hot-rolled or forged billet or forged bar. The axis of the finished flange shall be parallel to the long axis of the original billet or bar. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric).

Hubbed flanges (except as permitted above) shall not be machined from plate or bar stock material unless the material has been formed into a ring, and provided that:

(a) In a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange (this is not intended to imply that the original plate surface be present in the finished flange).

(b) The joints in a ring are welded butt-joints that conform to the requirements of this Standard. Thickness to be used to determine stress-relief and radiography shall be the lesser of:

$$t \text{ and } \frac{(A - B)}{2} \quad \ldots 3.21.5.2$$

where these symbols are as defined in Clause 3.21.6.2.

(c) The back of the flange and the outer surface of the hub are inspected by non-destructive methods such as magnetic particle inspection or penetrant flaw inspection to ensure that these surfaces are free from defects.

3.21.5.3 *Bolting*

3.21.5.3.1 *General* Material used for bolting shall be suitable for use at all temperatures and conditions of the intended service.

Precautions shall be taken to avoid over-stressing of small diameter bolting during tightening and to avoid binding of threads. To prevent over-stressing, torque spanners or other means should be used for bolting up to 38 mm. To prevent binding, nuts and bolts should be manufactured from different materials or from materials having differing levels of strength or hardness. See Appendix D for corrosion of dissimilar metals.

Bolting materials of a similar nature to the flange material and of adequate strength are likely to avoid corrosion difficulties.

3.21.5.3.2 *Bolts, screws, studs and stud-bolts*

The following requirements shall be met:

(a) Materials for bolts including screws, studs and stud-bolts shall comply with the specifications listed in Table 3.21.5 which also gives design strengths.

(b) When bolts are machined from heat-treated hot-rolled, or cold-worked material and are not subsequently hot-worked or annealed, design strength shall be based on the condition of the material selected (see Table 3.21.5).

(c) When bolts are fabricated by hot-heading, the design strength for annealed material in Table 3.21.5 shall apply unless the manufacturer can furnish adequate control data to show that the tensile properties of hot-rolled bars or hot-finished forgings are being met, in which case the design strength for the material in the hot-finished condition may be used.

(d) When bolts are fabricated by cold-heading, the design strength for annealed material in Table 3.21.5 shall apply unless the manufacturer can furnish adequate control data to show that higher design strengths, as agreed upon, may be used. In no case shall such stresses exceed the design strength given in Table 3.21.5 for cold-worked bar stock.

(e) Bolts and studs shall be suitably protected from corrosion but where some corrosion is possible an increase in size or change in material is recommended.

(f) All bolts shall be made forged, pressed or machined from one piece, except that for 'T' or eye bolts the bolt may be welded to the cross part or eye, provided that the material has good weldability, the bolt is normalized after welding, and the joint is
A3 a complete penetration weld, fully radiographed.

(g) Where metal temperatures exceed 400°C stud-bolts shall be used. Such stud-bolts shall be threaded full length or with the unthreaded portion reduced to the bottom of the thread. The surface finish shall be at least equal to R_a 0.8 µm.

(h) High strength and alloy bolts shall be marked to facilitate material identification.

A3 (i) Clamp assemblies shall have the appropriate load carrying capacity and shall be distributed around the flange as specified in the design.

3.21.5.3.3 *Nuts* The following requirements shall be met:

(a) Nuts shall be suitable for the service conditions and made of a material listed in Table 3.21.5 or made of a carbon-molybdenum steel in accordance with BS 4882, Grade 4, 4B or 4L, or ASTM A 194 Grade 4.

(b) Nuts shall be used within the limits given in Table 3.21.5. Carbon-molybdenum steel nuts Grades 4 and 4B to BS 4882 shall not be used at operating temperatures exceeding 600°C nor below −29°C. Carbon-molybdenum steel nuts which meet the impact test requirements of the Standards in (a) above may be used at temperatures down to −100°C.

Nuts may be made of material to the same specification as for the bolting to which they are fitted, but for operating temperatures over 290°C the hardness (or strength) of ferritic nuts should differ from that of the bolts.

(c) Nuts shall be of standard design but may be of any practical shape including those with holes or ring for 'tommy bar' or similar, provided that the depth of the threaded portion is not less than the diameter of the thread and shall engage the bolt or stud by at least the same amount.

(d) The thrust face of nuts shall be machined where the operating temperature exceeds 400°C.

(e) Cap or blind nuts shall have a threaded portion with a length not less than 1.5 times the diameter of the thread.

A3 (f) Nuts for swing bolt closures shall have thread engagement as per Clause 3.21.5.3.7.

A3 (g) Nuts requiring welded attachments shall be made of suitable material for good weldability.

Thread fit and condition of the nuts after welding shall comply with the relevant Standard.

3.21.5.3.4 *Washers* The use of washers is optional. When used they shall be of wrought materials and shall be of approximately the same hardness and composition as the nuts when used with carbon or alloy steel bolts and studs.

3.21.5.3.5 *Threads* Threads on bolts which are to be frequently unscrewed are recommended to be trapezoidal and the nut shall have a threaded portion with a length not less than 1.5 times the diameter of the thread. For bolts with full shank the length of thread under the nut should be at least equal to the bolt diameter.

The bolt and nut combination shall be a medium or closer fit.

3.21.5.3.6 *Size* Bolts and studs shall have a nominal diameter not less than 12 mm except where manufactured of high strength material in which event the minimum nominal diameter should be 8 mm. Bolts smaller than these sizes or larger than 50 mm nominal diameter require special tightening techniques and should be avoided where possible.

Where bolting is to be unscrewed frequently or where only one or two bolts hold the joint together, an increase in bolting size is recommended.

NOTE: Bolt data is to be obtained from the relevant bolt Standard. The core area (cross-sectional area at root of thread) for bolts to AS/NZS 1110 is as follows:

Nom. dia	M8	M10	M12	M16	M20	M24	M30	M36
Core area, mm^2	32.8	52.3	76.2	144	225	324	519	759

For other bolts with metric threads, refer to AS 1275 or AS 1721. For bolts with other threads, refer to the appropriate Standard.

3.21.5.3.7 *Stud attachment* Where tapped holes are provided for studs, and the like, the threads shall be full and clean and shall engage the stud for a length no less than the larger of d_s and—

$$0.75d_s \times \frac{\text{design strength of stud material at design temperature}}{\text{design strength of tapped material at design temperature}}$$

in which d_s is the diameter of the stud, except that the thread engagement need not exceed $1.5d_s$.

A3 See Clause 3.19.6.4.

A3

TABLE 3.21.5

DESIGN TENSILE STRENGTH (MPa) FOR FLANGE BOLTING

Material					Notes	MDMT °C	For design temperatures not exceeding −°C (Note 1)																			
Type	**Specification**	**Grade**	**Temper**	**Dia. or size (mm)**			**Min. temp. to 50**	**100**	**150**	**200**	**250**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**	**625**	**650**
CARBON STEELS																										
	AS/NZS 1110 AS B148 AS 2465	4.6 Clause 2 A, B		All All All		−30	60	60	60	60	50															
	AS/NZS 1110	5.8		All		−30	100	100	100	100	100	100	100	100												
	AS 2465	P		All		−30	85	85	85	85	85	85	85	85												
	AS/NZS 1110	8, 8		All		−30	160	160	160	160	160	160	160	160												
	AS 2465 AS 1252	S —		All All		−30	130	130	130	130	130	130	130	130												
ALLOY STEELS																										
A3 1Cr-0.2Mo	ASTM A 320	L7		≤ 65	2,3	−100	172	172	172	172	172	172	172	172	172											
	ASTM A 193	B7		≤ 65 > 65 ≤ 102	2,3	−45	172 159	172 159	172 159	172 159	172 159	172 159	172 159	172 159	172 159	163 153	145 138	121 115	93 92	69 69	43 43					
5Cr-1/2Mo	ASTM A 193	B5		≤ 102	2,3,9	−30	138	138	138	138	138	138	138	138	138	138	129	104	78	59	45	34	26	19	13	8,6
1Cr-1/2Mo-V	ASTM A 193	B16		≤ 65 > 65 ≤ 102	2,3	−30	172 152	172 152	172 152	172 152	172 152	172 152	172 152	172 152	172 152	172 152	172 152	163 146	147 131	121 113	92 90	61 61	35 35			
HIGH ALLOY STEELS																										
13Cr	ASTM A 193	B6(410)		≤ 102	2,9	−30	146	146	146	146	146	146	146	146	146	146	134	107	89							
18Cr-8 Ni	ASTM A 193	B8(304)		All	2,4,5, 7,8	−200	129	106	96	88	85	79	78	77	76	75	73	71	70	69	68	67	65	59	53	42
18Cr-8Ni-Ti	ASTM A 193	B8T		All	2,4,5, 6,8	−200	129	109	97	89	84	79	77	76	75	75	74	73	73	73	72	68	58	45	34	25
18Cr-9Ni-Nb	ASTM A 193	B8C (347)		All	2,4,5, 8	−200	129	118	110	104	98	94	92	90	89	88	88	87	87	87	87	84	78	59	42	30
18Cr-12Ni-2Mo	ASTM A 193	B8M (316)		All	2,4,5, 7,8	−200	129	110	101	92	87	83	80	79	78	77	76	75	75	74	74	73	72	69	64	51
Material					**Notes**	**MDMT**	**For design temperatures not exceeding −°C (Note 1)**																			
Type	**Specification**	**Grade**	**Temper**	**Dia. or size (mm)**			**Min. temp. to 50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**450**	**500**	**550**	**600**	**650**
NICKEL AND NICKEL ALLOYS (Note 10)																										
Nickel	ASTM B 160	200	Annealed	All			26	26	26	26	26	26	26	26	26	26	26									
		200	Hot finished	All			26	26	26	26	26	26	26	26	26	25	24									
		200	Cold drawn	All			69	66	66	66	66	66	66	66	65	65	64									
Low C Nickel	ASTM B 160	201	Annealed or hot finished	All			17	17	17	16	16	16	16	16	16	16	16	16	16	16	16	15	14	13	11	8

(*continued*)

TABLE 3.21.5 (*continued*)

Material					Notes	MDMT °C	For design temperatures not exceeding −°C (Note 1)																			
Type	**Specification**	**Grade**	**Temper**	**Dia. or size (mm)**			**Min. temp. to 50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**450**	**500**	**550**	**600**	**650**
NICKEL AND NICKEL ALLOYS (*continued*) (Note 10)																										
Nickel-Copper	ASTM B 164	400-405	Annealed	All			43	40	39	37	36	35	34	34	34	34	34	34	34	34	34	33				
		400	Hot finished	All except hexagons > 54			69	67	66	66	65	64	62	61	59	59	59	59	59	59	58	45				
		400	Hot finished	Hexagons > 54			52	51	51	50	49	48	47	46	45	45	45	45	45	44	43	36				
		405	Hot finished	Rounds ≤ 76			61	60	59	58	57	56	55	54	53	52	52	52	52	52	51	41				
		400	CD Stress rel.	All	13		86	83	82	80	79	79	78	78	78											
		400	CD Stress equalized	Rounds ≤ 90	13		121	118	116	114	112	109	107	107	106											
		400	CD Stress equalized	Other sizes, shapes	13		95	91	89	88	87	86	86	85	85											
		400	Cold drawn	All	13		95	91	89	88	87	86	86	85	85											
		405	Cold drawn	All	13		86	84	82	81	79	78	77	77	77											
Nickel-Chromium Iron	ASTM B 166	600	Annealed	All			60	57	56	55	54	54	53	53	52	52	52	51	51	50	50	48	47	41	20	14
		600	Hot finished	Rounds > 76 Shapes, all sizes			60	59	58	57	56	56	55	55	55	55	55	55	55	55	54	52	51	50	48	38
		600	Hot finished	Rounds ≤ 76			69	67	65	64	64	63	63	63	63	63	63	62	62	61	61	60	59	56	49	38
		600	Cold drawn	All	13,14		69	67	65	64	64	63	63	63	63											
Nickel Molyb-denum	ASTM B 335	B	Annealed	All			79	72	69	68	68	65	63	62	61	60	58	57	57	57	57					

(*continued*)

TABLE 3.21.5 (*continued*)

Material					Notes	MDMT °C	For design temperatures not exceeding −°C (Note 1)																			
Type	**Specification**	**Grade**	**Temper**	**Dia. or size (mm)**			**Min. temp. to 50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**450**	**500**	**550**	**600**	**650**
COPPER AND COPPER ALLOYS																										
Copper	AS 1567	102A, 110A, 120C, 122A	O	All			17	15	14	13	13	11	11													
Copper-Silicon	AS 1567	655A	O	6 ≤ 70	12		26	26	26	26	26	24														
				6 ≤ 20	12		65	65	64	62	61	59														
			M	20 ≤ 50	12		60	60	59	57	56	54														
Aluminium-Bronze	AS 1567	623B	M	6 < 50			55	55	55	55	54	54	53	52	52											
ALUMINIUM AND ALUMINIUM ALLOYS						Note 10																				
Al-4Cu-Mn-Si	ASTM B211	2014	T6	3 ≤ 200	11		90	83	78	70	50	31	21													
—	ASTM B211	2024	T4	12 ≤ 110	11		72	70	68	65	54	43	34													
Al-4Cu-1.5Mn	AS 1865	6061, 6262	T6	10 ≤ 150	11		52	Not Available																		
				< 10	11		58	56	54	51	43	34	24													
	ASTM B211	6061, 6262	T6 welded	3 ≤ 200	11		58	56	54	51	43	34	24													
				3 ≤ 200	—		33	32	31	30	27	24	19													

NOTES TO TABLE 3.21.5:

1 Stresses at intermediate temperatures may be obtained by linear interpolation.

2 These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints, where freedom from leakage over a long period of time without re-tightening is required, lower stress values may be necessary as determined from the relative flexibility of the flange and bolts, and corresponding relaxation properties.

3 Between minimum temperature shown and 200°C, stress values equal to the lower of the following will be permitted: 20 percent of the specified tensile strength, or 25 percent of the specified minimum yield strength.

4 These stresses are permitted for material which has been carbide-solution treated.

5 At temperatures over 525°C, these stress values apply only when the carbon is 0.04 percent or higher.

6 For temperatures above 525°C, these stress values may be used only if the material has been heat treated at a temperature of 1075°C minimum.

7 For temperatures above 525°C, these stress values may be used only if the material has been heat treated at a temperature of 975°C minimum.

8 Austenitic steel bolts for use in pressure joints should not be less than 10 mm diameter.

9 These materials are normally used because of their corrosion resistance.

10 No lower temperature limit for materials below.

11 The stress values given for this material are not applicable when either welding or thermal cutting is employed.

12 Copper-silicon alloys are not always suitable when exposed to certain media and high temperatures, particularly steam above 100°C. The user should satisfy himself that the alloy selected is satisfactory for the service for which it is to be used.

13 The maximum operating temperature is arbitrarily set at 250°C, because harder temper adversely affects design strength in the creep-rupture temperature range.

14 Design strengths for the cold-drawn temper based on hot-rolled properties until required data on cold drawn is available.

3.21.5.4 *Gaskets* Gaskets shall be made of materials which are not seriously affected by the contained fluid under all anticipated operating conditions. Non-metallic gaskets shall not be used above 400°C calculation temperature, and shall not be used in non-confining (flat or raised face) flanged joints for the following conditions—

(a) with toxic or flammable material at or above 8.3 MPa pressure at ambient temperature or equivalent flange rating; and

(b) with non-toxic and non-flammable material at or above 12.5 MPa pressure at ambient temperature or equivalent flange rating.

Gasket materials should be used within the service conditions recommended by the gasket manufacturer.

Self-equalizing types of gasket (O-ring, delta-ring and lens types) are frequently used for high-pressure application. Joints of this kind do not require mechanical loading for gasket seating and, since the gasket reaction can be considered negligible, the total bolting is only that necessary to retain the hydrostatic end-force.

3.21.6 Narrow-face flanges with ring-type gaskets.

3.21.6.1 *Scope* The flange design methods outlined in this Clause (3.21.6) together with Clauses 3.21.1 to 3.21.5, are applicable to circular flanges under internal pressure with gaskets which are entirely within the circle enclosed by the bolt holes and with no contact outside this circle. Modifications are given in Clauses 3.21.7 and 3.21.8 for the design of split and non-circular flanges and in Clauses 3.21.9 for flanges subject to external pressure.

3.21.6.2 *Notation* The notation described below is used in the equations for the design of flanges (see also Figures 3.21.6.2 and 3.21.12.2). Additional and modified notation for flanges with full-face gaskets and reverse flanges is given in Clauses 3.21.11.2 and 3.21.12.2, respectively.

A = outside diameter of flange, or, where slotted holes extend to the outside of the flange, the diameter to the bottom of the slots, in millimetres

A_b = actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, in square millimetres

A_m = total required cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2}, in square millimetres

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions, in square millimetres

$$= \frac{W_{m1}}{S_b}$$

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, in square millimetres

$$= \frac{W_{m2}}{S_a}$$

B = inside diameter of flange, in millimetres; when B is less than $20g_1$, it will be optional for the designer to substitute B_1 for B in the equation for longitudinal stress S_H

B_1 = $B + g_1$ for loose-type hub flanges and also for integral-type flanges when f is less than 1

= $B + g_o$ for integral-type flanges when f is equal to or greater than 1

b = effective gasket or joint-contact-surface seating width, in millimetres (see Note, Clause 3.21.6.4.1(a))

$2b$ = effective gasket or joint-contact-surface pressure width, in millimetres (see Note, Clause 3.21.6.4.1(a))

b_o = basic gasket seating width, in millimetres (from Table 3.21.6.4(B))

C = bolt circle diameter, in millimetres

c = basic dimension used for the minimum sizing of welds, equal to t_n or t_x, whichever is less, in millimetres

D = diameter of bolt hole, in millimetres

D_b = bolt outside diameter, in millimetres

d = factor, in millimetres to the 3rd power

for integral-type flanges = $\frac{U}{V} h_o g_o^2$

for loose-type flanges = $\frac{U}{V_L} h_o g_o^2$

E = modulus of elasticity of flange material at operating temperature (see Table 3.3.7), in megapascals

e = factor, in millimetres to the power of minus 1

for integral flanges = F/h_o

for loose-type flanges = F_L/h_o

F = factor for integral-type flanges (from Figure 3.21.6.6(B))

F_L = factor for loose-type flanges (from Figure 3.21.6.6(D))

f = hub stress-correction factor for integral flanges from Figure 3.21.6.6(F) (when greater than 1, this is the ratio of the stress in the small end of hub to the stress in the large end) (for values below limit of figure use $f = 1$)

G = diameter at location of gasket-force, in millimetres; except as noted in Figure 3.21.6.2(a) it is defined as follows:

For flanges covered by this Clause (3.21.6) (see Table 3.21.6.4(B))–

when $b_o \leq 6$ mm, G = mean diameter of gasket contact-face

when $b_o > 6$ mm, G = outside diameter of gasket contact-face minus $2b$

g_o = thickness of hub at small end, in millimetres

g_1 = thickness of hub at back of flange, in millimetres

H = total hydrostatic end-force, in newtons

= $0.785G^2P$

H_D = hydrostatic end-force on area inside of flange, in newtons

= $0.785B^2P$

H_G = for flanges covered by this Clause (3.21.6), gasket-force (difference between flange design bolt-force and total hydrostatic end-force), in newtons

= $W - H$

H_p = total joint-contact surface compression force, in newtons

= $2b\pi GmP$

H_T = difference between total hydrostatic end-force and the hydrostatic end-force on area inside of flange, in newtons

= $H - H_D$

h = hub length, in millimetres

h_D = radial distance from the bolt circle to the circle on which H_D acts, as described in Table 3.21.6.5, in millimetres

h_G = radial distance from gasket-force reaction to the bolt circle as described in Table 3.21.6.5, in millimetres

h_o = factor = $\sqrt{(Bg_o)}$

h_T = radial distance from the bolt circle to the circle on which H_T acts as described in Table 3.21.6.5, in millimetres

K = ratio of outside diameter of flange to inside diameter of flange

= A/B

L = factor = $\dfrac{te+1}{T} + \dfrac{t^3}{d}$

M_D = component of moment due to H_D, in newton millimetres

= $H_D h_D$

M_G = component of moment due to H_G, in newton millimetres

= $H_G h_G$

M_o = total moment acting upon the flange, for operating conditions or gasket seating as may apply, in newton millimetres (see Clause 3.21.6.5); this notation applies to flanges covered by Clauses 3.21.6 to 3.21.9 inclusive and Clause 3.21.12.

M_T = component of moment due to H_T, in newton millimetres

= $H_T h_T$

m = gasket factor, obtained from Table 3.21.6.4(A) (see Note, Clause 3.21.6.4.1(a))

N = width used to determined the basic gasket seating-width b_o, based upon the possible contact width of the gasket (see Table 3.21.6.4(B)), in millimetres

n = number of bolts

P = calculation pressure, in megapascals; for flanges subject to external pressure see Clause 3.21.9

P_b = centreline-to-centreline bolt spacing, in millimetres

S_a = design strength for bolt at atmospheric temperature (given in Table 3.21.5 as f), in megapascals

S_b = design strength for bolt at design temperature (given in Table 3.21.5 as f), in megapascals

S_f = design strength for material of flange at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply (given in Clause 3.3.1 as *f*), in megapascals

S_H = calculated longitudinal stress in hub, in megapascals

S_n = design strength for material of nozzle neck, vessel or pipe wall, at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply (given in Clause 3.3.1 as *f*), in megapascals

S_R = calculated radial stress in flange, in megapascals

S_T = calculated tangential stress in flange, in megapascals

T = factor involving K (from Figure 3.21.6.6(A))

t = flange thickness, in millimetres

t_n = nominal thickness of shell or nozzle wall to which flange or lap is attached, minus corrosion allowance, in millimetres

t_x = two times the thickness g_o, when the design is calculated as an integral flange, or two times the thickness of shell or branch wall required for internal pressure, when the design is calculated as a loose flange, but not less than 6 mm, in millimetres

U = factor involving K (from Figure 3.21.6.6(A))

V = factor for integral-type flanges (from Figure 3.21.6.6(C))

V_L = factor for loose-type flanges (from Figure 3.21.6.6(E))

W = flange design bolt-force, for the operating conditions or gasket seating, as may apply, in newtons (see Clause 3.21.6.4.4 for flanges covered by this Clause (3.21.6)

W_{m1} = minimum required bolt-force for operating conditions (see Clause 3.21.6.4), in newtons

For flange pairs used to contain a tube sheet for a floating head for a U-tube type of heat exchanger, or for any other similar design, W_{m1} shall be the larger of the values as individually calculated for each flange, and that value shall be used for both flanges.

W_{m2} = minimum required bolt-force for gasket seating (see Clause 3.21.6.4), in newtons

w = width used to determine the basic gasket seating width b_o, based upon the contact width between the flange facing and the gasket (see Table 3.21.6.4(B)), in millimetres

Y = factor involving K (from Figure 3.21.6.6(A))

y = gasket or joint-contact-surface seating stress (see Note in Clause 3.21.6.4.1), in megapascals

Z = factors involving K (from Figure 3.21.6.6(A))

3.21.6.3 *Circular flange types* For purposes of calculation, there are three types:

(a) *Loose-type flanges* This type covers those designs in which the flange has no direct connection to the nozzle neck, vessel, or pipe wall, and designs where the method of attachment is not considered to give the mechanical strength equivalent of integral attachment. See Figure 3.21.3(f), (g), (h), (j), (k) and (m) for typical loose-type flanges and Figure 3.21.6.2 for location of the forces and moments.

(b) *Integral-type flanges* This type covers designs where the flange is cast or forged integrally with the nozzle neck, vessel or pipe wall, butt-welded thereto, or attached by other forms of arc or gas welding of such a nature that the flange and nozzle neck, vessel, or pipe wall is considered to be the equivalent of an integral structure. In welded construction, the nozzle neck, vessel, or pipe wall is considered to act as a hub. See Figure 3.21.3(a), (c), (l), for typical integral-type flanges and Figure 3.21.6.2 for location of the forces and moments.

(c) *Optional-type flanges* This type covers designs where the attachment of the flange to the nozzle neck, vessel, or pipe wall is such that the assembly is considered to act as a unit, which shall be calculated as an integral flange, except that for simplicity the designer may calculate the fabrication as a loose-type flange provided that none of the following values is exceeded:

$$g_o = 16 \text{ mm}; \ \frac{B}{g_o} = 300; \ P = 2.1 \text{ MPa};$$

design temperature = 370°C

See Figure 3.21.3(b), (d) and (e) for typical optional-type flanges.

3.21.6.4 *Bolt-forces*

3.21.6.4.1 *Bolt-forces for non-self-energizing type gaskets*

(a) *Force for operating conditions* The required bolt-force for the operating conditions, W_{m1}, shall be sufficient to resist the hydrostatic end-force H, exerted by the calculation pressure on the area bounded by the diameter of gasket reaction, and, in addition, to maintain on the gasket or joint-contact-surface a compression-force H_p. which experience has shown to be sufficient to ensure a tight joint, all at the design temperature. (This compression force is expressed as a multiple m of the internal pressure (see Tables 3.21.6.4(A) and 3.21.6.4(B)); its value is a function of the gasket material and its facing (See Note).

NOTE: Tables 3.21.6.4(A) and 3.21.6.4(B) give a list of many commonly used gasket materials and contact facings, with suggested values of m, b, and y that have proved satisfactory in actual service. These values are suggested only and are not mandatory. Values that are too low may result in leakage at the joint, without affecting the safety of the design. The primary proof that the values are adequate is the hydrostatic test.

The required bolt-force for the operating conditions, W_{m1}, is determined in accordance with Equation 3.21.6.4.1(1):

$$W_{m1} = H + H_p$$

$$= 0.785G^2P + 2b\pi GmP \quad \text{. . . 3.21.6.4.1(1)}$$

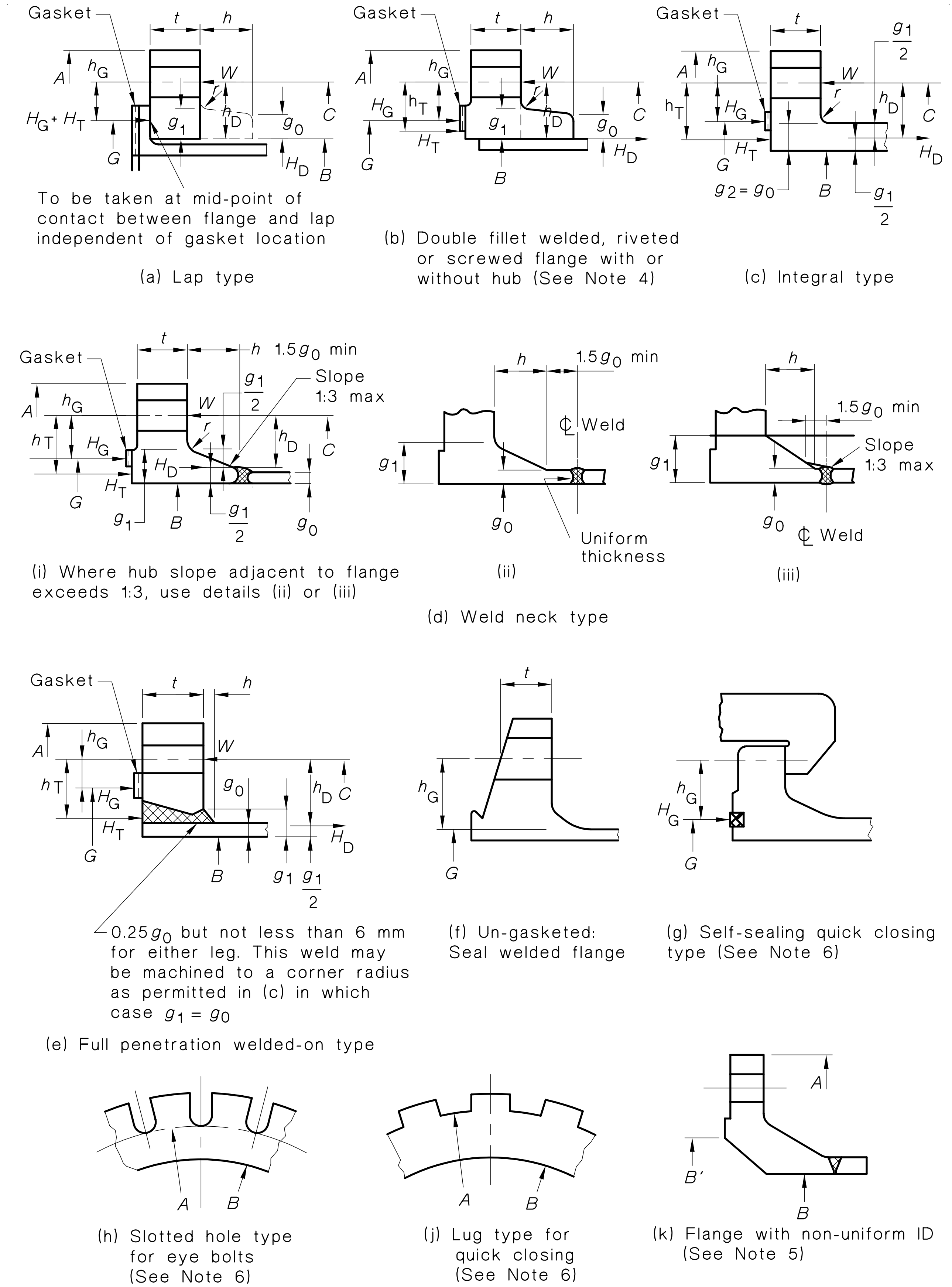


FIGURE 3.21.6.2 FLANGE NOTATION

NOTES TO FIGURE 3.21.6.2:

1 For hub tapers 6 degrees or less, use $g_o = t_n$.

2 Fillet radius r to be at least 0.25_{gl} but not less than 5 mm.

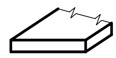
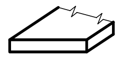
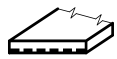
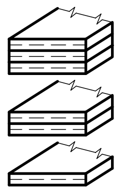
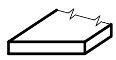
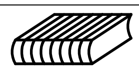
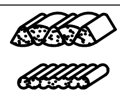
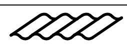
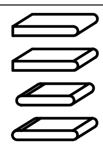
3 Raised, tongue-groove, male and female, and ring joint facings shall be in access of the required minimum flange thickness t.

A3 4 The vessel or pipe wall shall not be considered to have any value as a hub for this attachment or where the back weld is a fillet weld only.

A3 5 In calculation, use $K = A/B'$ in place of $K = A/B$.

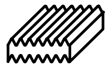
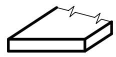
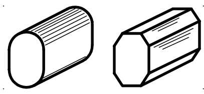
6 Closure elements shall comply with Clause 3.27(viii) to (xi).

TABLE 3.21.6.4(A)
GASKET MATERIALS AND CONTACT FACINGS

	Gasket factor (*m*) for operating conditions and minimum design seating strength (*y*) (see Note 1)					Refer to Table 3.21.6.4(B)	
	Gasket material (see Note 2)		**Gasket factor** *m*	**Min. design seating stress** *y* **(MPa)**	**Sketches and notes**	**Use facing sketch**	**Use column**
A1	*Self-energizing types:* O-rings, metallic, elastomer other gasket types considered as self-sealing		0	0	—	—	—
	Elastomers without fabric or a high percent of asbestos fibre Below 75 Shore Durometer 75 or higher Shore Durometer		 0.50 1.00	 0 1.4		1 (a, b, c, d,) 4, 5	II
A3	Asbestos with a suitable binder for the operating conditions or PTFE (see Note 4)	3 mm thick 1.5 mm thick 1 mm thick	2.00 2.75 3.50	11.0 25.5 45.0			
	Elastomers with cotton fabric insertion		1.25	2.8			
	Elastomers with asbestos fabric insertion, with or without wire reinforcement (see Note 3)	3-ply 2-ply 1-ply	2.25 2.50 2.75	15.2 20.0 25.5			
	Vegetable fibre		1.75	7.6			
A1	Spiral-wound metal, asbestos filled (see Note 4)	Carbon Stainless or monel	2.50 3.00	69.0 69.0		1 (a, b)	
	Corrugated metal, asbestos inserted or Corrugated, metal, jacketed asbestos filled	Soft aluminium Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	2.50 2.75 3.00 3.25 3.50	20.0 25.5 31.0 38.0 45.0			
	Corrugated metal	Soft aluminium Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	2.75 3.00 3.25 3.50 3.75	25.5 31.0 38.0 45.0 52.5		1 (a, b, c, d)	
A3	Flat metal jacketed asbestos filled	Soft aluminium Soft copper or brass Iron or soft steel Monel 4-6% chrome Stainless steels	3.25 3.50 3.75 3.50 3.75 3.75	38.0 45.0 52.5 55.5 62.0 62.0		1 (a, b, c, d), 2. For 1 (c, d), 2, see Note 3	

(*continued*)

TABLE 3.21.6.4(A) (*continued*)

Gasket factor (*m*) for operating conditions and minimum design seating strength (*y*) (see Note 1)					Refer to Table 3.21.6.4(B)	
Gasket material (see Note 2)		**Gasket factor** ***m***	**Min. design seating stress** ***y*** **(MPa)**	**Sketches and notes**	**Use facing sketch**	**Use column**
Grooved metal	Soft aluminium Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	3.25 3.50 3.75 3.75 4.25	38.0 45.0 52.5 62.0 70.0		1 (a, b, c, d) 2,3	II
Soft flat metal	Soft aluminium Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	4.00 4.75 5.50 6.00 6.50	61.0 90.0 124.0 151.0 180.0		1 (a, b, c, d) 2, 3, 4, 5	I
Ring joint	Iron or soft steels Monel or 4-6% chrome Stainless steels	5.50 6.00 6.50	124.0 151.0 180.0		6	

NOTES:

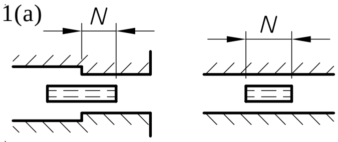
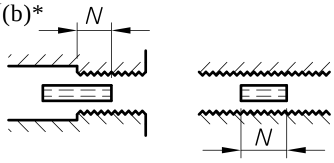
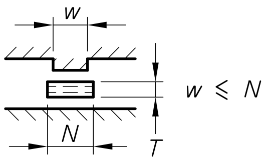
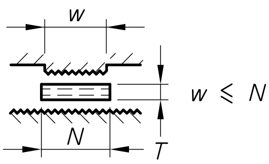
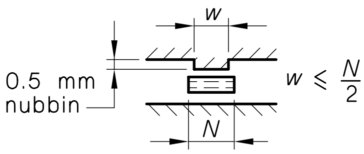
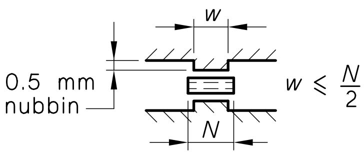
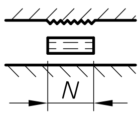
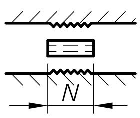
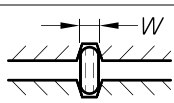
1 This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of *m* and *y* that have generally proved satisfactory in actual service when using effective gasket seating width *b* given in Table 3.21.6.4(B). The design values and other details given in this table are suggested only and are not mandatory.

2 Asbestos-type gaskets may not be permitted in some applications.

3 The surface of a gasket having a lap should not be against the nubbin.

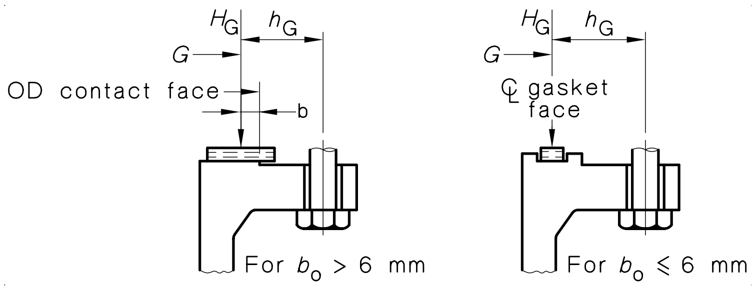
4 The values given in this Table for asbestos-based gaskets may not apply for gaskets constructed of non-asbestos fibre substitutes (e.g. aramid, carbon/aramid, glass/aramid). The gasket manufacturer should be consulted for guidance on the gasket choice, gasket factors, seating stress, chemical and thermal resistance and contact facing. If special bolt tightening procedures are required, these shall be communicated to the purchaser.

TABLE 3.21.6.4(B)
EFFECTIVE GASKET WIDTH (See Clause 3.21.4.3)

Facing sketch (exaggerated)	Basic gasket seating width b_o	
	Column I †	**Column II †**
1(a) 	$\frac{N}{2}$	$\frac{N}{2}$
1(b)* 		
1(c) 	$\frac{w+T}{2}$ but not to exceed $\frac{w+N}{4}$	$\frac{w+T}{2}$ but not to exceed $\frac{w+N}{4}$
1(d)* 		
2 	$\frac{w+N}{4}$	$\frac{w+3N}{8}$
3 	$\frac{N}{4}$	$\frac{3N}{8}$
4* 	$\frac{3N}{8}$	$\frac{7N}{16}$
5* 	$\frac{N}{4}$	$\frac{3N}{8}$
6 	$\frac{w}{8}$	

(*continued*)

TABLE 3.21.6.4(B) (*continued*)

EFFECTIVE GASKET SEATING WIDTH *B*	
$b = 2.52\sqrt{b_o}$, when $b_o > 6$ mm	$b = b_o$, when $b_o \leq 6$ mm
LOCATION OF GASKET FORCE REACTION	
	NOTE: The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

A3 * Where serrations do not exceed 0.5 mm width spacing, sketches 1 (b) and 1 (d) shall be used.

† See Table 3.21.6.4(A).

NOTE: The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

(b) *Gasket seating-force* Before a tight joint can be obtained it is necessary to seat the gasket or joint-contact-surface properly by applying a minimum initial force (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt-force required for this purpose, W_{m2}, shall be determined in accordance with Equation 3.21.6.4.1(2)—

$$W_{m2} = \pi b G y \qquad \text{. . . 3.21.6.4.1(2)}$$

For flange pairs used to contain a tube sheet for a floating head for a U-tube type of heat exchanger, or for other similar design, and where the flanges or gaskets (or both) are not the same, W_{m2} shall be the larger of the values obtained from Equation 3.21.6.4.1(2) as individually calculated for each flange and gasket, and that value shall be used for both flanges.

The need for providing sufficient bolt-force to seat the gasket or joint-contact-surfaces in accordance with Equation 3.21.6.4.1(2) will prevail on many low-pressure designs and with facings and materials that require a high seating-force and where the bolt-force calculated by Equation 3.21.6.4.1(1) for the operating conditions is insufficient to seal the joint. Accordingly, it is necessary to furnish bolting and to pre-tighten the bolts to provide a bolt-force sufficient to satisfy both of these requirements, each one being individually investigated. When Equation 3.21.6.4.1(2) governs, flange proportions will be a function of the bolting instead of internal pressure.

3.21.6.4.2 *Bolt-forces for self-energizing type gaskets* Bolt-forces for self-energizing type gaskets shall comply with the following:

(a) *Force for operating conditions* The required bolt-force for the operating conditions W_m, shall be sufficient to resist the hydrostatic end-force H, exerted by the calculation pressure on the area bounded by the outside diameter of the gasket. H_p is to be considered as zero (0) for all self-energizing gaskets except that certain seal configurations which generate axial forces shall be considered.

(b) *Gasket seating-forces* Self-energizing gaskets may be considered to require an inconsequential amount of bolting-force to produce a seal, i.e. W_{m2} = 0. Bolting, however, shall be pretightened to provide a bolt-force sufficient to withstand the hydrostatic end-force H.

3.21.6.4.3 *Total required and actual bolt areas A_m and A_b* The total cross-sectional area of bolts A_m, required for both the operating conditions and gasket seating is the greater of the values for A_{m1} and A_{m2} where $A_{m1} = W_{m1}/S_b$ and $A_{m2} = W_{m2}/S_a$. A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts A_b, will not be less than A_m.

3.21.6.4.4 *Flange design bolt-forces W* The bolt-forces used in the design of the flange shall be the values obtained from Equations 3.21.6.4.4(1) and 3.21.6.4.4(2):

For operating conditions—

$$W = W_{m1} \quad \ldots 3.21.6.4.4(1)$$

For gasket seating—

$$W = \frac{(A_m + A_b)\,S_a}{2} \quad \ldots 3.21.6.4.4(2)$$

In addition to the minimum requirements for safety, Equation 3.21.6.4.4(2) provides a margin against abuse of the flange from overbolting. Since the margin against such abuse is needed primarily for the initial bolting-up operation which is done at atmospheric temperature and before application of internal pressure, the flange design is required to satisfy this loading only under such conditions (see Note).

NOTE: Where additional safety against abuse is desired, or where it is necessary that the flange be suitable to withstand the full available bolt-force $A_b \times S_a$, the flange may be designed on the basis of this latter quantity.

3.21.6.5 *Flange moments* In the calculation of flange stresses, the moment of force acting on the flange is the product of the force and its moment arm. The moment arm is determined by the relative position of the bolt circle with respect to that of the force producing the moment (see Figure 3.21.6.2). No credit shall be taken for the reduction in moment arm due to cupping of the flanges or due to inward shifting of the line of action of the bolts as a result thereof.

For the operating conditions, the total flange moment M_o, is the sum of the three individual moments M_D, M_T, and M_G, as defined in Clause 3.21.6.2 and based on the flange design bolt-force of Equation 3.21.6.4.4(1) with moment arms as given in Table 3.21.6.5.

For gasket seating, the total flange moment M_o, is based on the flange design bolt-force of Equation 3.21.6.4.4(2), which is opposed only by the gasket force in which case—

$$M_o = Wh_G \quad \ldots 3.21.6.5$$

TABLE 3.21.6.5

MOMENT ARMS FOR FLANGE FORCES UNDER OPERATING CONDITIONS

Type of flange	Values		
	h_D	h_T	h_G
Integral-type flanges (see Figure 3.21.3(a), (c) and (l))	$\frac{C - B - g_1}{2}$	$\frac{C - B}{4} + \frac{h_G}{2}$	$\frac{C - G}{2}$
Loose-type; except lap-joint flanges (see Figure 3.21.3(f), (g), (h), (j) and (m)), and optional-type flanges (see Figure 3.21.3(b), (d) and (e)).	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap-joint flanges (see Figure 3.21.3(k))	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$
Reverse-type flange (see Figure 3.21.12.2(a))	$\frac{C - B + g_1 - 2g_o}{2}$	$0.5\ (C - \frac{B + G}{2})$	$\frac{C - G}{2}$

3.21.6.6 *Calculation of flange stresses* The stresses in the flange shall be determined for both the operating conditions and gasket seating, whichever controls, in accordance with the following:

(a) *For integral-type flanges and all hub-type flanges*:

Longitudinal hub stress—

$$S_H = \frac{fM_o}{Lg_1^2 B} \quad \ldots 3.21.6.6(1)$$

Radial flange stress—

$$S_R = \frac{(1.33te + 1)M_o}{Lt^2 B} \quad \ldots 3.21.6.6(2)$$

Tangential flange stress—

$$S_T = \frac{YM_o}{t^2 B} - ZS_R \quad \ldots 3.21.6.6(3)$$

(b) *For loose-type ring flanges (including optional-type calculated as loose-type) having a rectangular cross-section*:

Tangential flange stress—

$$S_T = \frac{YM_o}{t^2 B} \quad \ldots 3.21.6.6(4)$$

and $S_R = 0$; $S_H = 0$

NOTE: See Table 3.21.6.6(A) for values of Y and Z.

3.21.6.7 *Flange design strengths* The flange stresses calculated by the equations in Clause 3.21.6.6 shall not exceed any of the following values:

(a) Longitudinal hub stress S_H not greater than S_f for cast iron (see Note) and, except as otherwise limited by (b) and (c), not greater than $1.5S_f$ for materials other than cast iron.

NOTE: When the flange material is cast iron, particular care should be taken when tightening the bolts to avoid excessive stress that may break the flange; an attempt should be made to apply no greater wrenching effort than is needed to ensure tightness in the hydrostatic test.

(b) Longitudinal hub stress S_H not greater than the smaller of $1.5S_f$ and $1.5S_n$ for optional-type flanges designed as integral (Figure 3.21.3(b),(d), and (e)), also integral type (Figure 3.21.3(c)) where the neck material constitutes the hub of the flange.

(c) Longitudinal hub stress S_H not greater than the smaller of $1.5S_f$ and $2.5S_n$ for integral-type flanges with hub welded to the neck, pipe or vessel wall (Figure 3.21.3 (a)).

(d) Radial flange stress S_R no greater than S_f.

(e) Tangential flange stress S_T no greater than S_f.

(f) Also $\dfrac{S_H + S_R}{2}$ no greater than S_f and

$\dfrac{S_H + S_T}{2}$ no greater than S_f.

For hub flanges attached as shown in Figure 3.21.3(f), (g), (h), (j) and (m), the nozzle neck, vessel or pipe wall shall be considered to have no value as a hub.

In the case of loose-type flanges with laps, as shown in Figure 3.21.3(k), where the gasket is so located that the lap is subjected to shear, the shearing stress shall not exceed $0.8S_n$ for the material of the lap, as defined in Clause 3.21.6.2. In the case of welded flanges shown in Figure 3.21.3(b), (c), (d), (e), (f), (g), (h) and (j), where the nozzle neck, vessel or pipe wall extends near to the flange face and may form the gasket contact face, the shearing stress carried by the welds shall not exceed $0.8S_n$. The shearing stress shall be calculated on the basis of W_{m1} or W_{m2}, as defined in Clause 3.21.6.2, whichever is greater. Similar cases where flange parts are subjected to shearing stress shall be governed by the same requirements.

TABLE 3.21.6.6(A)

VALUES *T U*, *Y*, *Y′* AND *Z* (TERMS INVOLVING *K*)

K	*T*	*Z*	*Y*	*Y′*	*U*
1.001	1.91	1000.50	1899.43	13.82	2078.85
1.002	1.91	500.50	951.81	13.73	1052.80
1.003	1.91	333.83	637.56	13.65	700.80
1.004	1.91	250.50	478.04	13.57	525.45
1.005	1.91	200.50	383.67	13.49	421.72
1.006	1.91	167.17	319.71	13.40	351.42
1.007	1.91	143.36	274.11	13.32	301.30
1.008	1.91	125.50	239.95	13.24	263.75
1.009	1.91	111.61	213.40	13.17	234.42
1.010	1.91	100.50	192.19	13.09	211.19
1.011	1.91	91.41	174.83	13.01	192.13
1.012	1.91	83.84	160.38	12.93	176.25
1.013	1.91	77.43	148.06	12.86	162.81
1.014	1.91	71.93	137.69	12.78	151.30
1.015	1.91	67.17	128.61	12.70	141.33
1.016	1.90	63.00	120.56	12.63	132.49
1.017	1.90	59.33	111.98	12.56	124.81
1.018	1.90	56.06	107.36	12.48	118.00
1.019	1.90	53.14	101.72	12.41	111.78
1.020	1.90	50.51	96.73	12.34	106.30
1.021	1.90	48.12	92.21	12.27	101.33
1.022	1.90	45.96	88.04	12.20	96.75
1.023	1.90	43.98	84.30	12.13	92.64
1.024	1.90	42.17	80.81	12.06	88.81
1.025	1.90	40.51	77.61	11.99	85.29
1.026	1.90	38.97	74.70	11.92	82.09
1.027	1.90	37.54	71.97	11.85	79.08
1.028	1.90	36.22	69.43	11.78	76.30
1.029	1.90	34.99	67.11	11.72	73.75
1.030	1.90	33.84	64.91	11.65	71.33
1.031	1.90	32.76	62.85	11.58	69.06
1.032	1.90	31.76	60.92	11.52	66.94
1.033	1.90	30.81	59.11	11.46	63.95
1.034	1.90	29.92	57.41	11.39	63.08
1.035	1.90	29.08	55.80	11.33	61.32
1.036	1.90	28.29	54.29	11.26	59.66
1.037	1.90	27.54	52.85	11.20	58.08
1.038	1.90	26.83	51.50	11.14	56.59
1.039	1.90	26.15	50.21	11.08	55.17
1.040	1.90	25.51	48.97	11.02	53.82
1.041	1.90	24.90	47.81	10.96	53.10
1.042	1.90	24.32	46.71	10.90	51.33
1.043	1.90	23.77	45.64	10.84	50.15
1.044	1.90	23.23	44.64	10.78	49.05
1.045	1.90	22.74	43.69	10.72	48.02
1.046	1.90	22.05	42.75	10.66	46.99
1.047	1.90	21.79	41.87	10.60	46.03
1.048	1.90	21.35	41.02	10.55	45.09
1.049	1.90	20.92	40.21	10.49	44.21
1.050	1.89	20.51	39.43	10.43	43.34
1.051	1.89	20.12	38.68	10.38	42.51
1.052	1.89	19.74	37.96	10.32	41.73
1.053	1.89	19.38	37.27	10.27	40.96
1.054	1.89	19.03	36.60	10.21	40.23
1.055	1.89	18.69	35.96	10.16	39.64
1.056	1.89	18.38	35.34	10.10	38.84
1.057	1.89	18.06	34.74	10.05	38.19
1.058	1.89	17.76	34.17	10.00	37.56
1.059	1.89	17.47	33.62	9.95	36.95
1.060	1.89	17.18	33.64	9.89	36.34
1.061	1.89	16.91	32.55	9.84	35.78
1.062	1.89	16.64	32.04	9.79	35.21
1.063	1.89	16.40	31.55	9.74	34.68
1.064	1.89	16.15	30.61	9.69	34.17
1.065	1.89	15.90	30.61	9.64	33.65
1.066	1.89	15.67	30.17	9.59	33.17
1.067	1.89	15.45	29.74	9.54	33.69
1.068	1.89	15.22	29.32	9.49	32.22
1.069	1.89	15.02	29.91	9.45	31.79
1.070	1.89	14.80	28.51	9.40	31.34
1.071	1.89	14.61	28.13	9.35	30.92
1.072	1.89	14.41	27.76	9.30	30.51
1.073	1.89	14.22	27.39	9.26	30.11
1.074	1.88	14.04	27.04	9.21	29.72
1.075	1.88	13.85	26.69	9.16	29.34
1.076	1.88	13.68	26.36	9.12	28.98
1.077	1.88	13.56	26.03	9.07	28.69
1.078	1.88	13.35	25.72	9.03	28.27
1.079	1.88	13.18	25.40	8.98	27.92
1.080	1.88	13.02	25.10	8.94	27.59
1.081	1.88	12.87	24.81	8.89	27.27
1.082	1.88	12.72	24.52	8.85	26.95
1.083	1.88	12.57	24.24	8.81	26.65
1.084	1.88	12.43	24.00	8.76	26.34
1.085	1.88	12.29	23.69	8.72	26.05
1.086	1.88	12.15	23.44	8.68	25.57
1.087	1.88	12.02	23.18	8.64	25.48
1.088	1.88	11.89	22.93	8.60	25.20
1.089	1.88	11.76	22.68	8.56	24.93
1.090	1.88	11.63	22.44	8.51	24.66
1.091	1.88	11.52	22.22	8.47	24.41
1.092	1.88	11.40	21.99	8.43	24.16
1.093	1.88	11.28	21.76	8.39	23.91
1.094	1.88	11.16	21.54	8.35	23.67
1.095	1.88	11.05	21.32	8.31	23.44
1.096	1.88	10.94	21.11	8.27	23.20
1.097	1.88	10.83	20.91	8.24	22.97
1.098	1.88	10.73	20.71	8.20	22.75
1.099	1.88	10.62	20.51	8.16	22.39
1.100	1.88	10.52	20.31	8.12	22.18
1.101	1.88	10.43	20.15	8.08	22.12
1.102	1.88	10.33	19.94	8.05	21.92
1.103	1.88	10.23	19.76	8.01	21.72
1.104	1.88	10.14	19.58	7.97	21.52
1.105	1.88	10.05	19.38	7.94	21.30
1.106	1.88	9.96	19.33	7.90	21.14
1.107	1.87	9.87	19.07	7.86	20.96
1.108	1.87	9.78	18.90	7.83	20.77
1.109	1.87	9.70	18.74	7.79	20.59
1.110	1.87	9.62	18.55	7.76	20.38
1.111	1.87	9.54	18.42	7.72	20.25
1.112	1.87	9.46	18.27	7.69	20.08
1.113	1.87	9.38	18.13	7.65	19.91
1.114	1.87	9.30	17.97	7.62	19.75
1.115	1.87	9.22	17.81	7.59	19.55
1.116	1.87	9.15	17.68	7.55	19.43
1.117	1.87	9.07	17.54	7.52	19.27
1.118	1.87	9.00	17.40	7.49	19.12
1.119	1.87	8.94	17.27	7.45	18.98
1.120	1.87	8.86	17.13	7.42	18.80
1.121	1.87	8.79	17.00	7.39	18.68
1.122	1.87	8.72	16.87	7.36	18.54
1.123	1.87	8.66	16.74	7.33	18.40
1.124	1.87	8.59	16.62	7.29	18.26
1.125	1.87	8.53	16.49	7.26	18.11
1.126	1.87	8.47	16.37	7.23	17.99
1.127	1.87	8.40	16.25	7.20	17.86
1.128	1.87	8.34	16.14	7.17	17.73
1.129	1.87	8.28	16.02	7.14	17.60
1.130	1.87	8.22	15.91	7.11	17.48
1.131	1.87	8.16	15.79	7.08	17.35
1.132	1.87	8.11	15.68	7.05	17.24
1.133	1.86	8.05	15.57	7.02	17.11
1.134	1.86	7.99	15.46	6.99	16.99
1.135	1.86	7.94	15.36	6.96	16.90
1.136	1.86	7.88	15.26	6.93	16.77
1.137	1.86	7.83	15.15	6.91	16.65
1.138	1.86	7.78	15.05	6.88	16.54
1.139	1.86	7.73	14.95	6.85	16.43
1.140	1.86	7.68	14.86	6.82	16.35

(*continued*)

TABLE 3.21.6.6(A) (*continued*)

K	*T*	*Z*	*Y*	*Y′*	*U*
1.141	1.86	7.62	14.76	6.79	16.22
1.142	1.86	7.57	14.66	6.77	16.11
1.143	1.86	7.53	14.57	6.74	16.01
1.144	1.86	7.48	14.48	6.71	15.91
1.145	1.86	7.43	14.39	6.68	15.83
1.146	1.86	7.38	14.29	6.66	15.71
1.147	1.86	7.34	14.20	6.63	15.61
1.148	1.86	7.29	14.12	6.60	15.51
1.149	1.86	7.25	14.03	6.58	15.42
1.150	1.86	7.20	13.95	6.55	15.34
1.151	1.86	7.16	13.86	6.53	15.23
1.152	1.86	7.11	13.77	6.50	15.14
1.153	1.86	7.07	13.69	6.48	15.05
1.154	1.86	7.03	13.61	6.45	14.96
1.155	1.86	6.99	13.54	6.43	14.87
1.156	1.86	6.95	13.45	6.40	14.78
1.157	1.86	6.91	13.37	6.38	14.70
1.158	1.86	6.87	13.30	6.35	14.61
1.159	1.86	6.83	13.22	6.33	14.53
1.160	1.86	6.79	13.15	6.30	14.45
1.161	1.85	6.75	13.07	6.28	14.36
1.162	1.85	6.71	13.00	6.25	14.28
1.163	1.85	6.67	12.92	6.23	14.20
1.164	1.85	6.64	12.85	6.21	14.12
1.165	1.85	6.60	12.78	6.18	14.04
1.166	1.85	6.56	12.71	6.16	13.97
1.167	1.85	6.53	12.64	6.14	13.89
1.168	1.85	6.49	12.58	6.12	13.82
1.169	1.85	6.46	12.51	6.09	13.74
1.170	1.85	6.42	12.43	6.07	13.66
1.171	1.85	6.39	12.38	6.05	13.60
1.172	1.85	6.35	12.31	6.03	15.53
1.173	1.85	6.32	12.25	6.00	13.46
1.174	1.85	6.29	12.18	5.98	13.39
1.175	1.85	6.25	12.10	5.96	13.30
1.176	1.85	6.22	12.06	5.94	13.25
1.177	1.85	6.19	12.00	5.92	13.18
1.178	1.85	6.16	11.93	5.90	13.11
1.179	1.85	6.13	11.87	5.88	13.05
1.180	1.85	6.10	11.79	5.86	12.96
1.181	1.85	6.07	11.76	5.83	12.92
1.182	1.85	6.04	11.70	5.81	12.86
1.183	1.85	6.01	11.64	5.79	12.79
1.184	1.85	5.98	11.58	5.77	12.73
1.185	1.85	5.95	11.50	5.75	12.64
1.186	1.85	5.92	11.47	5.73	12.61
1.187	1.85	5.89	11.42	5.71	12.54
1.188	1.85	5.86	11.36	5.69	12.49
1.189	1.85	5.83	11.31	5.67	12.43
1.190	1.84	5.81	11.26	5.65	12.37
1.191	1.84	5.78	11.20	5.64	12.31
1.192	1.84	5.75	11.15	5.62	12.25
1.193	1.84	5.73	11.10	5.60	12.20
1.194	1.84	5.70	11.05	5.58	12.14
1.195	1.84	5.67	11.00	5.56	12.08
1.196	1.84	5.65	10.95	5.54	12.03
1.197	1.84	5.62	10.90	5.52	11.97
1.198	1.84	5.60	10.85	5.50	11.92
1.199	1.84	5.57	10.80	5.49	11.87
1.200	1.84	5.55	10.75	5.47	11.81
1.201	1.84	5.52	10.70	5.45	11.76
1.202	1.84	5.50	10.65	5.43	11.71
1.203	1.84	5.47	10.61	5.41	11.66
1.204	1.84	5.45	10.56	5.40	11.61
1.205	1.84	5.42	10.52	5.38	11.56
1.206	1.84	5.40	10.47	5.36	11.51
1.207	1.84	5.38	10.43	5.35	11.46
1.208	1.84	5.35	10.38	5.33	11.41
1.209	1.84	5.33	10.34	5.31	11.36
1.210	1.84	5.31	10.30	5.29	11.32
1.211	1.83	5.29	10.25	5.28	11.27
1.212	1.83	5.27	10.21	5.26	11.22
1.213	1.83	5.24	10.16	5.24	11.17
1.214	1.83	5.22	10.12	5.23	11.12
1.215	1.83	5.20	10.09	5.21	11.09

K	*T*	*Z*	*Y*	*Y′*	*U*
1.216	1.83	5.18	10.04	5.20	11.03
1.217	1.83	5.16	10.00	5.18	10.99
1.218	1.83	5.14	9.96	5.16	10.94
1.219	1.83	5.12	9.92	5.15	10.90
1.220	1.83	5.10	9.89	5.13	10.87
1.221	1.83	5.07	9.84	5.12	10.81
1.222	1.83	5.05	9.80	5.10	10.77
1.223	1.83	5.03	9.76	5.09	10.73
1.224	1.83	5.01	9.72	5.07	10.68
1.225	1.83	5.00	9.69	5.06	10.65
1.226	1.83	4.98	9.65	5.04	10.60
1.227	1.83	4.96	9.61	5.03	10.56
1.228	1.83	4.94	9.57	5.01	10.52
1.229	1.83	4.92	9.53	5.00	10.48
1.230	1.83	4.90	9.50	4.98	10.44
1.231	1.83	4.88	9.46	4.97	10.40
1.232	1.83	4.86	9.43	4.95	10.36
1.233	1.83	4.84	9.39	4.94	10.32
1.234	1.83	4.83	9.36	4.92	10.28
1.235	1.83	4.81	9.32	4.91	10.24
1.236	1.82	4.79	9.29	4.89	10.20
1.237	1.82	4.77	9.25	4.88	10.17
1.238	1.82	4.76	9.22	4.87	10.13
1.239	1.82	4.74	9.18	4.85	10.09
1.240	1.82	4.72	9.15	4.84	10.05
1.241	1.82	4.70	9.12	4.83	10.02
1.242	1.82	4.69	9.08	4.81	9.98
1.243	1.82	4.67	9.05	4.80	9.95
1.244	1.82	4.65	9.02	4.79	9.91
1.245	1.82	4.64	8.99	4.77	9.87
1.246	1.82	4.62	8.95	4.76	9.84
1.247	1.82	4.60	8.92	4.75	9.81
1.248	1.82	4.59	8.89	4.73	9.77
1.249	1.82	4.57	8.86	4.72	9.74
1.250	1.82	4.56	8.83	4.71	9.70
1.251	1.82	4.54	8.80	4.70	9.67
1.252	1.82	4.52	8.77	4.68	9.64
1.253	1.82	4.51	8.74	4.67	9.60
1.254	1.82	4.49	8.71	4.66	9.57
1.255	1.82	4.48	8.68	4.65	9.54
1.256	1.82	4.46	8.65	4.63	9.51
1.257	1.82	4.45	8.62	4.62	9.47
1.258	1.81	4.43	8.59	4.61	9.44
1.259	1.81	4.42	8.56	4.60	9.41
1.260	1.181	4.40	8.53	4.58	9.38
1.261	1.81	4.39	8.51	4.57	9.35
1.262	1.81	4.37	8.49	4.56	9.32
1.263	1.81	4.36	8.45	4.55	9.28
1.264	1.81	4.35	8.42	4.54	9.25
1.265	1.81	4.33	8.39	4.53	9.23
1.266	1.81	4.32	8.37	4.51	9.19
1.267	1.81	4.30	8.34	4.50	9.16
1.268	1.81	4.29	8.31	4.49	9.14
1.269	1.81	4.28	8.29	4.48	9.11
1.270	1.81	4.26	8.26	4.47	9.08
1.271	1.81	4.25	8.23	4.46	9.05
1.272	1.81	4.24	8.21	4.45	9.02
1.273	1.81	4.22	8.18	4.44	8.99
1.274	1.81	4.21	8.15	4.43	8.96
1.275	1.81	4.20	8.13	4.41	8.93
1.276	1.81	4.18	8.11	4.40	8.91
1.277	1.81	4.17	8.08	4.39	8.88
1.278	1.81	4.16	8.05	4.38	8.85
1.279	1.81	4.15	8.03	4.37	8.82
1.280	1.81	4.13	8.01	4.36	8.79
1.281	1.81	4.12	7.98	4.35	8.77
1.282	1.81	4.11	7.96	4.34	8.74
1.283	1.80	4.10	7.93	4.33	8.71
1.284	1.80	4.08	7.91	4.32	8.69
1.285	1.80	4.07	7.89	4.31	8.66
1.286	1.80	4.06	7.86	4.30	8.64
1.287	1.80	4.05	7.84	4.29	8.61
1.288	1.80	4.04	7.81	4.28	8.59
1.289	1.80	4.02	7.79	4.27	8.56
1.290	1.80	4.01	7.77	4.26	8.53

(*continued*)

TABLE 3.21.6.6(A) (*continued*)

K	*T*	*Z*	*Y*	*Y′*	*U*
1.291	1.80	4.00	7.75	4.25	8.51
1.292	1.80	3.99	7.72	4.24	8.48
1.293	1.80	3.98	7.70	4.23	8.46
1.294	1.80	3.97	7.68	4.22	8.43
1.295	1.80	3.95	7.66	4.21	8.41
1.296	1.80	3.94	7.63	4.20	8.39
1.297	1.80	3.93	7.61	4.19	8.36
1.298	1.80	3.92	7.59	4.19	8.33
1.299	1.80	3.91	7.57	4.18	8.31
1.300	1.80	3.90	7.55	4.17	8.29
1.301	1.80	3.89	7.53	4.16	8.27
1.302	1.80	3.88	7.50	4.15	8.24
1.303	1.80	3.87	7.48	4.41	8.22
1.304	1.80	3.86	7.46	4.13	8.20
1.305	1.80	3.84	7.44	4.12	8.18
1.306	1.80	3.83	7.42	4.11	8.16
1.307	1.80	3.82	7.40	4.10	8.13
1.308	1.79	3.81	7.38	4.10	8.11
1.309	1.79	3.80	7.36	4.09	8.09
1.310	1.79	3.79	7.34	4.08	8.07
1.311	1.79	3.78	7.32	4.07	8.05
1.312	1.79	3.77	7.33	4.06	8.02
1.313	1.79	3.76	7.28	4.05	8.00
1.314	1.79	3.75	7.26	4.04	7.98
1.315	1.79	3.74	7.24	4.04	7.96
1.316	1.79	3.73	7.22	4.03	7.94
1.317	1.79	3.72	7.20	4.02	7.92
1.318	1.79	3.71	7.18	4.01	7.89
1.319	1.79	3.70	7.16	4.00	7.87
1.320	1.79	3.69	7.14	4.00	7.85
1.321	1.79	3.68	7.12	3.99	7.83
1.322	1.79	3.67	7.10	3.98	7.81
1.323	1.79	3.67	7.09	3.97	7.79
1.324	1.79	3.66	7.07	3.96	7.77
1.325	1.79	3.65	7.05	3.96	7.75
1.326	1.79	3.64	7.03	3.95	7.73
1.327	1.79	3.63	7.01	3.94	7.71
1.328	1.78	3.62	7.00	3.93	7.69
1.329	1.78	3.61	6.98	3.93	7.67
1.330	1.78	3.60	6.96	3.92	7.65
1.331	1.78	3.59	6.94	3.91	7.63
1.332	1.78	3.58	6.92	3.90	7.61
1.333	1.78	3.57	6.91	3.90	7.59
1.334	1.78	3.57	6.89	3.89	7.57
1.335	1.78	3.56	6.87	3.88	7.55
1.336	1.78	3.55	6.85	3.87	7.53
1.337	1.78	3.54	6.84	3.87	7.51
1.338	1.78	3.53	6.82	3.86	7.50
1.339	1.78	3.52	6.81	3.85	7.48
1.340	1.78	3.51	6.79	3.85	7.46
1.341	1.78	3.51	6.77	3.84	7.44
1.342	1.78	3.50	6.76	3.83	7.42
1.343	1.78	3.49	6.74	3.82	7.41
1.344	1.78	3.48	6.72	3.82	7.39
1.345	1.78	3.47	6.71	3.81	7.37
1.346	1.78	3.46	6.69	3.80	7.35
1.347	1.78	3.46	6.68	3.80	7.33
1.348	1.78	3.45	6.66	3.79	7.32
1.349	1.78	3.44	6.65	3.78	7.30
1.350	1.78	3.43	6.63	3.78	7.28
1.351	1.78	3.42	6.61	3.77	7.27
1.352	1.78	3.42	6.60	3.76	7.25
1.353	1.77	3.41	6.58	3.76	7.23
1.354	1.77	3.40	6.57	3.75	7.21
1.355	1.77	3.39	6.55	3.74	7.19
1.356	1.77	3.38	6.53	3.74	7.17
1.357	1.77	3.38	6.52	3.73	7.16
1.358	1.77	3.37	6.50	3.73	7.14
1.359	1.77	3.36	6.49	3.72	7.12
1.360	1.77	3.35	6.47	3.71	7.11
1.361	1.77	3.35	6.45	3.71	7.09
1.362	1.77	3.34	6.44	3.70	7.08
1.363	1.77	3.33	6.42	3.69	7.06
1.364	1.77	3.32	6.41	3.69	7.04
1.365	1.77	3.32	6.39	3.68	7.03

K	*T*	*Z*	*Y*	*Y′*	*U*
1.366	1.77	3.31	6.38	3.68	7.01
1.367	1.77	3.30	6.37	3.67	7.00
1.368	1.77	3.30	6.35	3.66	6.98
1.369	1.77	3.29	6.34	3.66	6.97
1.370	1.77	3.28	6.32	3.65	6.95
1.371	1.77	3.27	6.31	3.65	6.93
1.372	1.77	3.27	6.30	3.64	6.91
1.373	1.77	3.26	6.28	3.64	6.90
1.374	1.77	3.25	6.27	3.63	6.89
1.375	1.77	3.25	6.25	3.62	6.87
1.376	1.77	3.24	6.24	6.62	6.86
1.377	1.77	3.23	6.22	3.61	6.84
1.378	1.76	3.22	6.21	3.61	6.82
1.379	1.76	3.22	6.19	3.60	6.81
1.380	1.76	3.21	6.18	6.60	6.80
1.381	1.76	3.20	6.17	3.59	6.79
1.382	1.76	3.20	6.16	3.59	6.77
1.383	1.76	3.19	6.14	3.58	6.75
1.384	1.76	3.18	6.13	3.57	6.74
1.385	1.76	3.18	6.12	3.57	6.73
1.386	1.76	3.17	6.11	3.56	6.72
1.387	1.76	3.16	6.10	3.56	6.70
1.388	1.76	3.16	6.08	3.55	6.68
1.389	1.76	3.15	6.07	3.55	6.67
1.390	1.76	3.15	6.06	3.54	6.66
1.391	1.76	3.14	6.05	3.54	6.64
1.392	1.76	3.13	6.04	3.53	6.63
1.393	1.76	3.13	6.02	3.53	6.61
1.394	1.76	3.12	6.01	3.52	6.60
1.395	1.76	3.11	6.00	3.52	6.59
1.396	1.76	3.11	5.99	3.51	6.58
1.397	1.76	3.10	5.98	3.51	6.56
1.398	1.75	3.10	5.96	3.50	6.55
1.399	1.75	3.09	5.95	3.50	6.53
1.400	1.75	3.08	5.94	3.49	6.52
1.401	1.75	3.08	5.93	3.49	6.50
1.402	1.75	3.07	5.92	3.48	6.49
1.403	1.75	3.07	5.90	3.48	6.47
1.404	1.75	3.06	5.89	3.47	6.46
1.405	1.75	3.05	5.88	3.47	6.45
1.406	1.75	3.05	5.87	3.46	6.44
1.407	1.75	3.04	5.86	3.46	6.43
1.408	1.75	3.04	5.84	3.45	6.41
1.409	1.75	3.03	5.83	3.45	6.40
1.410	1.75	3.02	5.82	3.45	6.39
1.411	1.75	3.02	5.81	3.44	6.38
1.412	1.75	3.01	5.80	3.44	6.37
1.413	1.75	3.01	5.78	3.43	6.35
1.414	1.75	3.00	5.77	3.43	6.34
1.415	1.75	3.00	5.76	3.42	6.33
1.416	1.75	2.99	5.75	3.42	6.32
1.417	1.75	2.98	5.74	3.41	6.31
1.418	1.75	2.98	5.72	3.41	6.29
1.419	1.75	2.97	5.71	3.41	6.28
1.420	1.75	2.97	5.70	3.40	6.27
1.421	1.75	2.96	5.69	3.40	6.26
1.422	1.75	2.96	5.68	3.39	6.25
1.423	1.75	2.95	5.67	3.39	6.23
1.424	1.74	2.95	5.66	3.38	6.22
1.425	1.74	2.94	5.65	3.38	6.21
1.426	1.74	2.94	5.64	3.38	6.20
1.427	1.74	2.93	5.63	3.37	6.19
1.428	1.74	2.92	5.62	3.37	6.17
1.429	1.74	2.92	5.61	3.36	6.16
1.430	1.74	2.91	5.60	3.36	6.15
1.431	1.74	2.91	5.59	3.36	6.14
1.432	1.74	2.90	5.58	3.35	6.13
1.433	1.74	2.90	5.57	3.35	6.11
1.434	1.74	2.89	5.56	3.34	6.10
1.435	1.74	2.89	5.55	3.34	6.09
1.436	1.74	2.88	5.54	3.34	6.08
1.437	1.74	2.88	5.53	3.33	6.07
1.438	1.74	2.87	5.52	3.33	6.05
1.439	1.74	2.87	5.51	3.32	6.04
1.440	1.74	2.86	5.50	3.32	6.03

(*continued*)

TABLE 3.21.6.6(A) (*continued*)

K	*T*	*Z*	*Y*	*Y′*	*U*
1.441	1.74	2.86	5.49	3.32	6.02
1.442	1.74	2.85	5.48	3.31	6.01
1.443	1.74	2.85	5.47	3.31	6.00
1.444	1.74	2.84	5.46	3.30	5.99
1.445	1.74	2.84	5.45	3.30	5.98
1.446	1.74	2.83	5.44	3.30	5.97
1.447	1.73	2.83	5.43	3.29	5.96
1.448	1.73	2.82	5.42	3.29	5.95
1.449	1.73	2.82	5.41	3.29	5.94
1.450	1.73	2.81	5.40	3.28	5.93
1.451	1.73	2.81	5.39	3.28	5.92
1.452	1.73	2.80	5.38	3.28	5.91
1.453	1.73	2.80	5.37	3.27	5.90
1.454	1.73	2.80	5.36	3.27	5.89
1.455	1.73	2.79	5.35	3.26	5.88
1.456	1.73	2.79	5.34	3.26	5.87
1.457	1.73	2.78	5.33	3.26	5.86
1.458	1.73	2.78	5.32	3.25	5.85
1.459	1.73	2.77	5.31	3.25	5.84
1.460	1.73	2.77	5.30	3.25	5.83
1.461	1.73	2.76	5.29	3.24	5.82
1.462	1.73	2.76	5.28	3.24	5.80
1.463	1.73	2.75	5.27	3.24	5.79
4.464	1.73	2.75	5.26	3.23	5.78
1.465	1.73	2.74	5.25	3.23	5.77
1.466	1.73	2.74	5.24	3.23	5.76
1.467	1.73	2.74	5.23	3.22	5.74
1.468	1.72	2.73	5.22	3.22	5.73
1.469	1.72	2.73	5.21	3.22	5.72
1.470	1.72	2.72	5.20	3.21	5.71
1.471	1.72	2.72	5.19	3.21	5.70
1.472	1.72	2.71	5.18	3.21	5.69
1.473	1.72	2.71	5.18	3.21	5.68
1.474	1.72	2.71	5.17	3.20	5.67
1.475	1.72	2.70	5.16	3.20	5.66
1.476	1.72	2.70	5.15	3.20	5.65
1.477	1.72	2.69	5.14	3.19	5.64
1.478	1.72	2.69	5.14	3.19	5.63
1.479	1.72	2.68	5.13	3.19	5.62
1.480	1.72	2.68	5.12	3.18	5.61
1.481	1.72	2.68	5.11	3.18	5.60
1.482	1.72	2.67	5.10	3.18	5.59
1.483	1.72	2.67	5.10	2.17	5.59
1.484	1.72	2.66	5.09	2.17	5.58
1.485	1.72	2.66	5.08	3.17	5.57
1.486	1.72	2.66	5.07	3.17	5.56
1.487	1.72	2.65	5.06	3.16	5.55
1.488	1.72	2.65	5.06	3.16	5.55
1.489	1.72	2.64	5.05	3.16	5.54
1.490	1.72	2.64	5.04	3.15	5.53
1.491	1.72	2.64	5.03	3.15	5.52
1.492	1.72	2.63	5.02	3.15	5.51
1.493	1.71	2.63	5.02	3.15	5.51
1.494	1.71	2.62	5.01	3.14	5.50
1.495	1.71	2.62	5.00	3.14	5.49
1.496	1.71	2.62	4.99	3.14	5.48
1.497	1.71	2.61	4.98	3.13	5.47
1.498	1.71	2.61	4.98	3.13	5.47
1.499	1.71	2.60	4.97	3.13	5.46
1.500	1.71	2.60	4.96	3.13	5.45
1.501	1.71	2.60	4.95	3.12	5.44
1.502	1.71	2.59	4.94	3.12	5.43
1.503	1.71	2.59	4.94	3.12	5.43
1.504	1.71	2.58	4.93	3.12	5.42
1.505	1.71	2.58	4.92	3.11	5.41
1.506	1.71	2.58	4.91	3.11	5.40
1.507	1.71	2.57	4.90	3.11	5.39
1.508	1.71	2.57	4.90	3.11	5.39
1.509	1.71	2.57	4.87	3.10	5.38
1.510	1.71	2.56	4.88	3.10	5.37

K	*T*	*Z*	*Y*	*Y′*	*U*
1.511	1.71	2.56	4.87	3.10	5.36
1.512	1.71	2.56	4.86	3.09	5.35
1.513	1.71	2.55	4.86	3.09	5.35
1.514	1.71	2.55	4.85	3.09	5.34
1.515	1.71	2.54	4.84	3.09	5.33
1.516	1.71	2.54	4.83	3.08	5.32
1.517	1.71	2.54	4.82	3.08	5.31
1.518	1.71	2.53	4.82	3.08	5.31
1.519	1.70	2.53	4.81	3.08	5.30
1.520	1.70	2.53	4.80	3.08	5.29
1.521	1.70	2.52	4.79	3.07	5.28
1.522	1.70	2.52	4.79	3.07	5.27
1.523	1.70	2.52	4.78	3.07	5.27
1.524	1.70	2.51	4.78	3.07	5.26
1.525	1.70	2.51	4.77	3.06	5.25
1.526	1.70	2.51	4.77	3.06	5.24
1.527	1.70	2.50	4.76	3.06	5.23
1.528	1.70	2.50	4.76	3.06	5.23
1.529	1.70	2.49	4.75	3.05	5.22
1.530	1.70	2.49	4.74	3.05	5.21
1.531	1.70	2.49	4.73	3.05	5.20
1.532	1.70	2.48	4.72	3.05	5.19
1.533	1.70	2.48	4.72	3.04	5.19
1.534	1.70	2.48	4.71	3.04	5.17
1.535	1.70	2.47	7.40	3.04	5.17
1.536	1.70	2.47	4.69	3.04	5.16
1.537	1.70	2.47	4.68	3.04	5.15
1.538	1.69	2.46	4.68	3.03	5.15
1.539	1.69	2.46	4.67	3.03	5.14
1.540	1.69	2.46	4.66	3.03	5.13
1.541	1.69	2.45	4.66	3.03	5.12
1.542	1.69	2.45	4.65	3.03	5.11
1.543	1.69	2.45	4.64	3.02	5.11
1.544	1.69	2.45	4.64	3.02	5.10
1.545	1.69	2.44	4.63	3.02	5.09
1.546	1.69	2.44	4.63	3.02	5.08
1.547	1.69	2.44	4.62	3.01	5.07
1.548	1.69	2.43	4.62	3.01	5.07
1.549	1.69	2.43	4.61	3.01	5.06
1.550	1.69	2.43	4.60	3.01	5.05
1.551	1.69	2.42	4.60	3.01	5.05
1.552	1.69	2.42	4.59	3.00	5.04
1.553	1.69	2.42	4.58	3.00	5.03
1.554	1.69	2.41	4.58	3.00	5.03
1.555	1.69	2.41	4.57	3.00	5.02
1.556	1.69	2.41	4.57	3.00	5.02
1.557	1.69	2.40	4.56	2.99	5.01
1.558	1.69	2.40	4.56	2.99	5.00
1.559	1.69	2.40	4.55	2.99	4.99
1.560	1.69	2.40	4.54	2.99	4.99
1.561	1.69	2.39	4.54	2.99	4.98
1.562	1.69	2.39	4.53	2.98	4.97
1.563	1.68	2.39	4.52	2.98	4.97
1.564	1.68	2.38	4.51	2.98	4.96
1.565	1.68	2.38	4.51	2.98	4.95
1.566	1.68	2.38	4.50	2.98	4.95
1.567	1.68	2.37	4.50	2.98	4.94
1.568	1.68	2.37	4.49	2.97	4.93
1.569	1.68	2.37	4.48	2.97	4.92
1.570	1.68	2.37	4.48	2.97	4.92
1.571	1.68	2.36	4.47	2.97	4.91
1.572	1.68	2.36	4.47	2.97	4.91
1.573	1.68	2.36	4.46	2.96	4.90
1.574	1.68	2.35	4.46	2.96	4.89
1.575	1.68	2.35	4.45	2.96	4.89
1.576	1.68	2.35	4.44	2.96	4.88
1.577	1.68	2.35	4.44	2.96	4.88
1.578	1.68	2.34	4.43	2.96	4.87
1.579	1.68	2.34	4.42	2.95	4.86
1.580	1.68	2.34	4.42	2.95	4.86

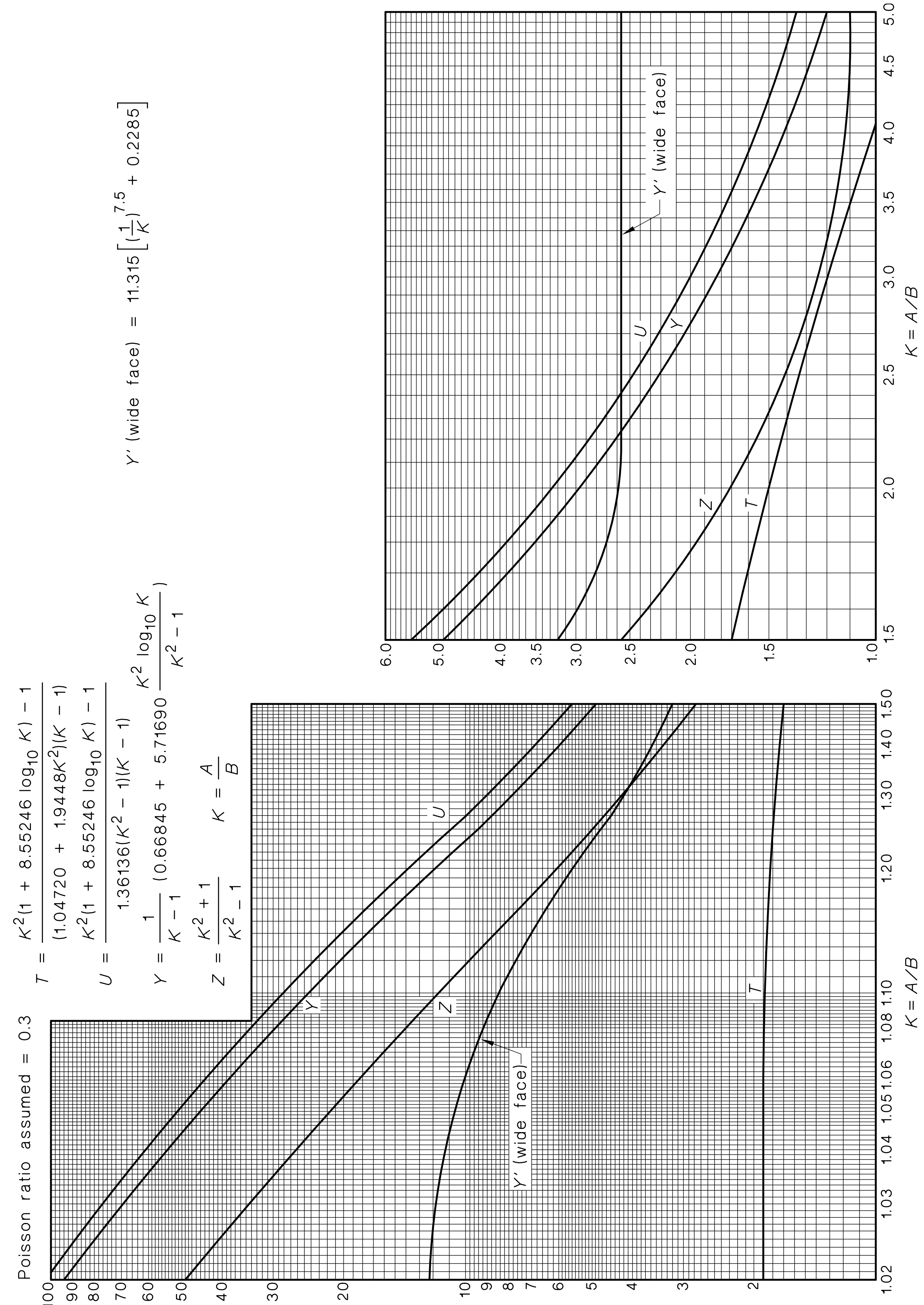


FIGURE 3.21.6.6(A) *T*, *U*, *Y*, *Y'* AND *Z* (TERMS INVOLVING *K*)

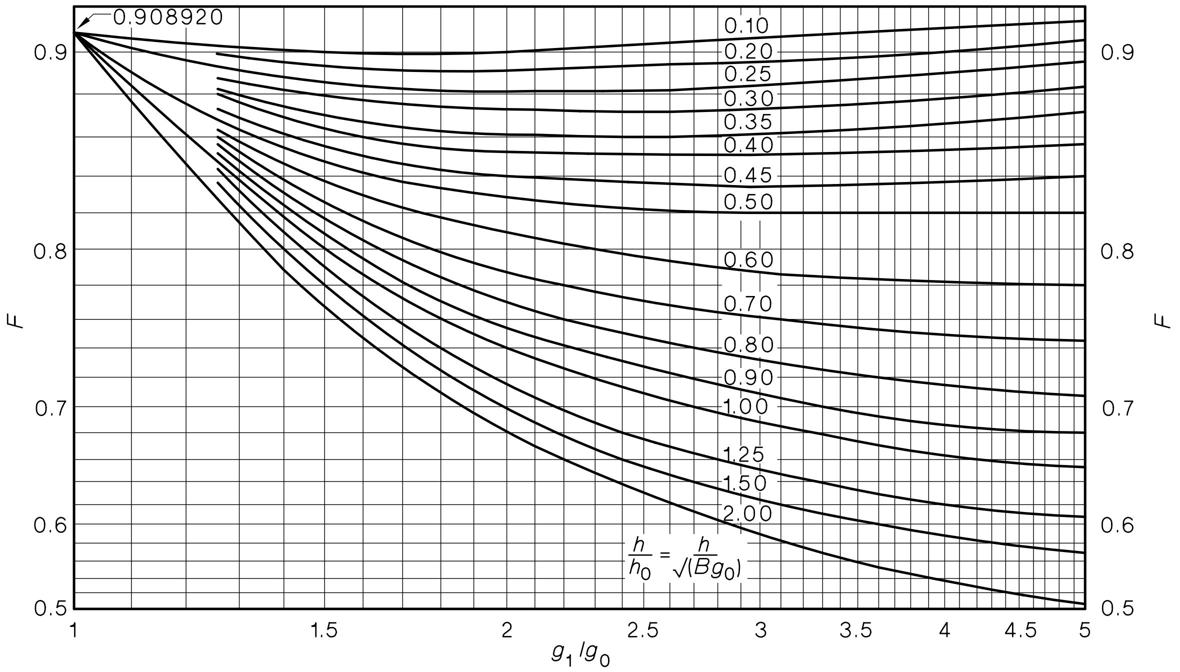


FIGURE 3.21.6.6(B) VALUES OF *F* (INTEGRAL FLANGE FACTORS)

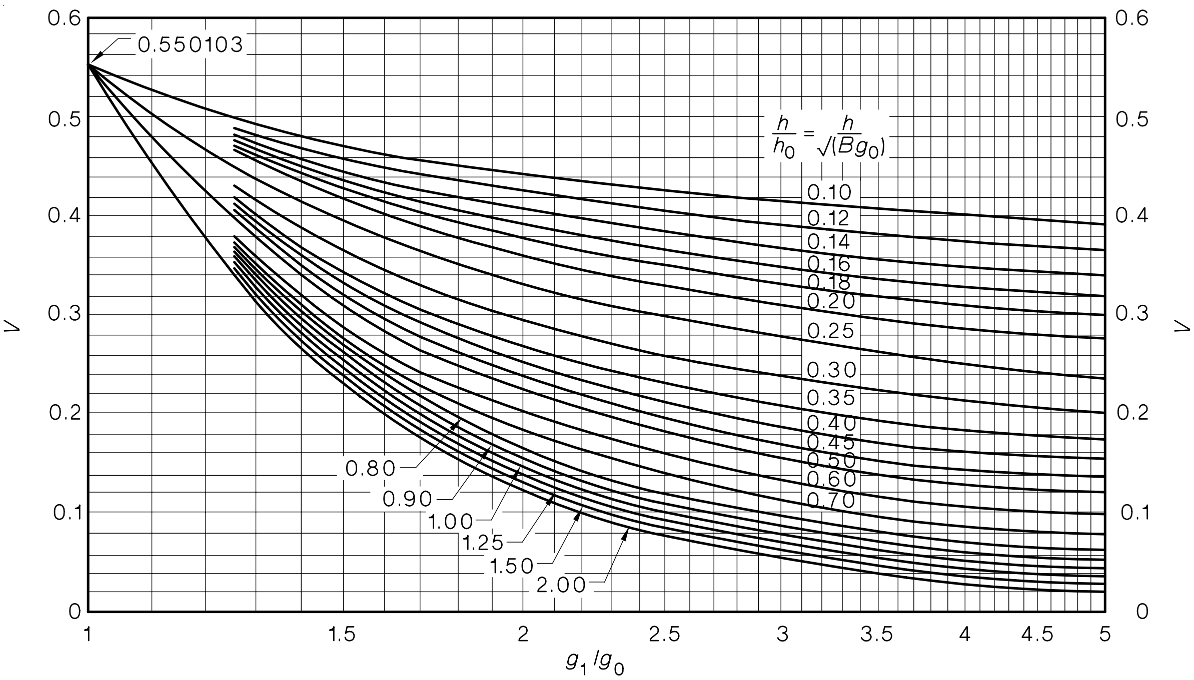


FIGURE 3.21.6.6(C) VALUES OF *V* (INTEGRAL FLANGE FACTORS)

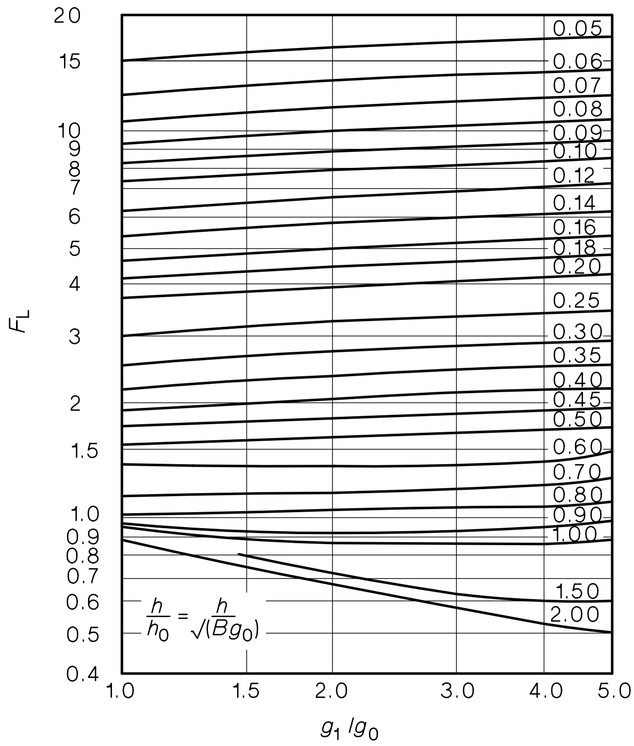


FIGURE 3.21.6.6(D) VALUES OF F_L (LOOSE HUB FLANGE FACTORS)

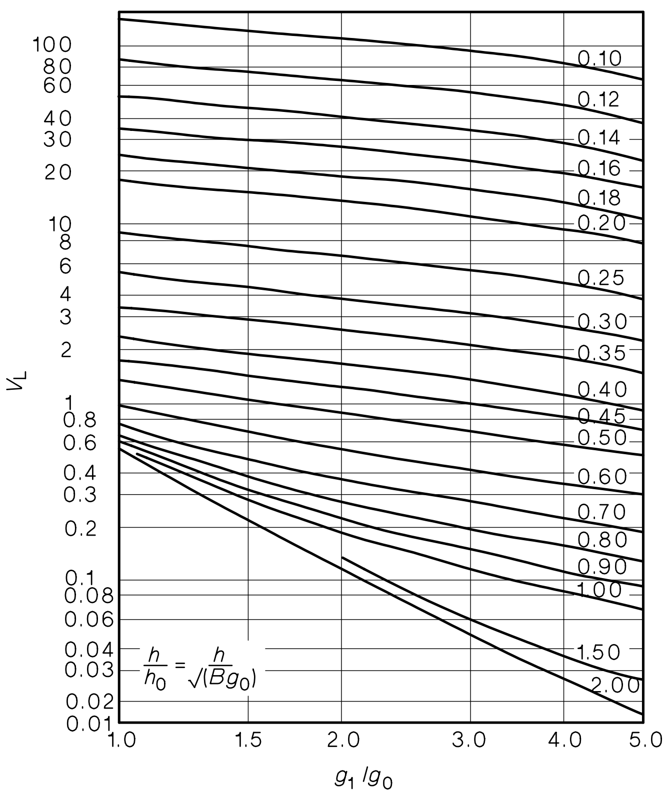
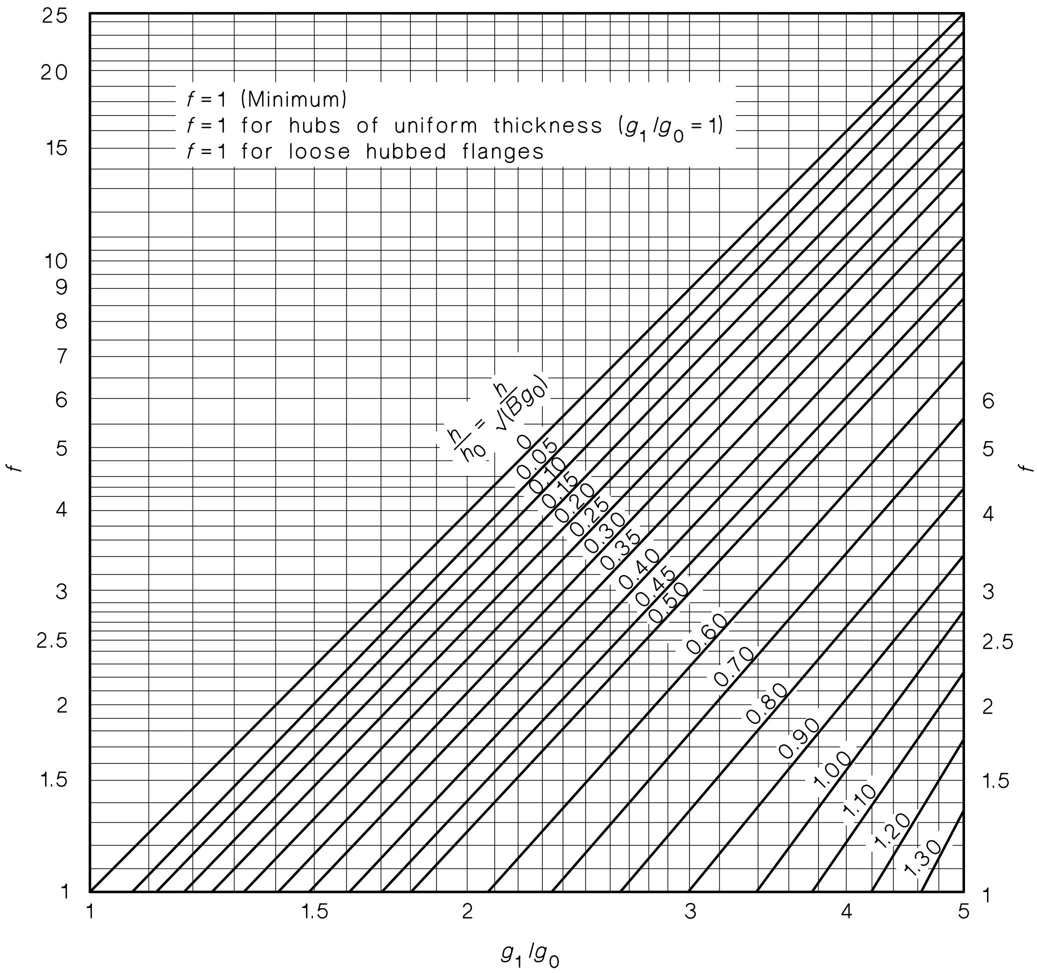


FIGURE 3.21.6.6(E) VALUES OF V_L (LOOSE HUB FLANGE FACTORS)



NOTE: See Table 3.21.6.6(B) for equations

FIGURE 3.21.6.6(F) VALUES OF f (HUB STRESS CORRECTION FACTOR)

TABLE 3.21.6.6(B)

FLANGE FACTORS IN EQUATION FORM

Integral flange

Factor F per Figure 3.21.6.6(B) is solved by $F = -\dfrac{E_6}{\left(\dfrac{C}{2.73}\right)^{1/4} \dfrac{(1 + A)^3}{C}}$

Factor V per Figure 3.21.6.6(C) is solved by $V = \dfrac{E_4}{\left(\dfrac{2.73}{C}\right)^{1/4} (1 + A)^3}$

Factor f per Figure 3.21.6.6(F) is solved by $f = C_{36}/(1 + A)$

A3 The values used in the above equations are solved using Equation (1) through (45), below, based on the values g_o, g_1, h, and h_o as defined by Clause 3.21.6.2.

Loose hub flange

Factor F_L per Figure 3.21.6.6(D) is solved by

A3 $$F_L = -\frac{C_{18}\left(\frac{1}{2} + \frac{A}{6}\right) + C_{21}\left(\frac{1}{4} + \frac{11A}{84}\right) + C_{24}\left(\frac{1}{70} + \frac{A}{106}\right) - \left(\frac{1}{40} + \frac{A}{72}\right)}{\left(\frac{C}{2.73}\right)^{1/4} \frac{(1 + A)^3}{C}}$$

Factor V_L per Figure 3.2.16.6(E) is solved by

$$V_L = \frac{\frac{1}{4} - \frac{C_{24}}{5} - \frac{3C_{21}}{2} - C_{18}}{\left(\frac{2.73}{C}\right)^{1/4} (1 + A)^3}$$

Factor f per Figure 3.21.6.6(F) is set equal to 1 $f = 1$

The values used in the above equations are solved using Equations (1) through (5), (7), (9), (10), (12), (14), (16), (18), (20), (23) and (26) below, based on the values of g_1, g_o, h, and h_o as defined by Clause 3.21.6.2.

Equations

	(1)	A	$= (g_1/g_o) - 1$
	(2)	C	$= 43.68(h/h_o)^4$
	(3)	C_1	$= 1/3 + A/12$
	(4)	C_2	$= 5/42 + 17A/336$
	(5)	C_3	$= 1/210 + A/360$
	(6)	C_4	$= 11/360 + 59A/5040 + (1 + 3A)/C$
A2	(7)	C_5	$= 1/90 + 5A/1008 - (1 + A)^3/C$
	(8)	C_6	$= 1/120 + 17A/5040 + 1/C$
	(9)	C_7	$= 215/2772 + 51A/1232 + (60/7 + 225A/14 + 75A^2/7 + 5A^3/2)/C$
	(10)	C_8	$= 31/6930 + 128A/45\,045 + (6/7 + 15A/7 + 12A^2/7 + 5A^3/11)/C$
	(11)	C_9	$= 533/30\,240 + 653A/73\,920 + (1/2 + 33A/14 + 39A^2/28 + 25A^3/84)/C$
A1	(12)	C_{10}	$= 29/3780 + 3A/704 - (1/2 + 33A/14 + 81A^2/28 + 13A^3/12)/C$
	(13)	C_{11}	$= 31/6048 + 1763A/665\,280 + (1/2 + 6A/7 + 15A^2/28 + 5A^3/42)/C$
A2	(14)	C_{12}	$= 1/2925 + 71A/300\,300 + (8/35 + 18A/35 + 156A^2/385 + 6A^3/55)/C$
	(15)	C_{13}	$= 761/831\,600 + 937A/1\,663\,200 + (1/35 + 6A/35 + 11A^2/70 + 3A^3/70)/C$
	(16)	C_{14}	$= 197/415\,800 + 103A/332\,640 - (1/35 + 6A/35 + 17A^2/70 + A^3/10)/C$
	(17)	C_{15}	$= 233/831\,600 + 97A/554\,400 + (1/35 + 3A/35 + A^2/14 + 2A^3/105)/C$
	(18)	C_{16}	$= C_1 C_7 C_{12} + C_2 C_8 C_3 + C_3 C_8 C_2 - (C_3^2 C_7 + C_8^2 C_1 + C_2^2 C_{12})$
	(19)	C_{17}	$= [C_4 C_7 C_{12} + C_2 C_8 C_{13} + C_3 C_8 C_9 - (C_{13} C_7 C_3 + C_8^2 C_4 + C_{12} C_2 C_9)]/C_{16}$

(*continued*)

TABLE 3.21.6.6(B) (*continued*)

		Equations
A1	(20)	$C_{18} = [C_5\,C_7\,C_{12} + C_2\,C_8\,C_{14} + C_3\,C_8\,C_{10} - (C_{14}\,C_7\,C_3 + C_8^2\,C_5 + C_{12}\,C_2\,C_{10})]/C_{16}$
	(21)	$C_{19} = [C_6\,C_7\,C_{12} + C_2\,C_8\,C_{15} + C_3\,C_8\,C_{11} - (C_{15}\,C_7\,C_3 + C_8^2\,C_6 + C_{12}\,C_2\,C_{11})]/C_{16}$
	(22)	$C_{20} = [C_1\,C_9\,C_{12} + C_4\,C_8\,C_3 + C_3\,C_{13}\,C_2 - (C_3^2\,C_9 + C_{13}\,C_8\,C_1 + C_{12}\,C_4\,C_2)]/C_{16}$
A2	(23)	$C_{21} = [C_1\,C_{10}\,C_{12} + C_5\,C_8\,C_3 + C_3\,C_{14}\,C_2 - (C_3^2\,C_{10} + C_{14}\,C_8\,C_1 + C_{12}\,C_5\,C_2)]/C_{16}$
	(24)	$C_{22} = [C_1\,C_{11}\,C_{12} + C_6\,C_8\,C_3 + C_3\,C_{15}\,C_2 - (C_3^2\,C_{11} + C_{15}\,C_8\,C_1 + C_{12}\,C_6\,C_2)]/C_{16}$
	(25)	$C_{23} = [C_1\,C_7\,C_{13} + C_2\,C_9\,C_3 + C_4\,C_8\,C_2 - (C_3\,C_7\,C_4 + C_8\,C_9\,C_1 + C_2^2\,C_{13})]/C_{16}$
	(26)	$C_{24} = [C_1\,C_7\,C_{14} + C_2\,C_{10}\,C_3 + C_5\,C_8\,C_2 - (C_3\,C_7\,C_5 + C_8\,C_{10}\,C_1 + C_2^2\,C_{14})]/C_{16}$
	(27)	$C_{25} = [C_1\,C_7\,C_{15} + C_2\,C_{11}\,C_3 + C_6\,C_8\,C_2 - (C_3\,C_7\,C_6 + C_8\,C_{11}\,C_1 + C_2^2\,C_{15})]/C_{16}$
	(28)	$C_{26} = -(C/4)^{1/4}$
A1	(29)	$C_{27} = C_{20} - C_{17} - 5/12 - [C_{17}\,(C/4)^{1/4}]$
	(30)	$C_{28} = C_{22} - C_{19} - 1/12 - [C_{19}\,(C/4)^{1/4}]$
	(31)	$C_{29} = -(C/4)^{1/2}$
A1	(32)	$C_{30} = -(C/4)^{3/4}$
	(33)	$C_{31} = 3A/2 + C_{17}(C/4)^{3/4}$
	(34)	$C_{32} = 1/2 + C_{19}\,(C/4)^{3/4}$
	(35)	$C_{33} = 0.5C_{26}\,C_{32} + C_{28}\,C_{31}\,C_{29} - (0.5\,C_{30}\,C_{28} + C_{32}\,C_{27}\,C_{29})$
	(36)	$C_{34} = 1/12 + C_{18} - C_{21} + C_{18}(C/4)^{1/4}$
A1, A2	(37)	$C_{35} = -C_{18}\,(C/4)^{3/4}$
	(38)	$C_{36} = (C_{28}\,C_{35}\,C_{29} - C_{32}\,C_{34}\,C_{29})/C_{33}$
	(39)	$C_{37} = [0.5\,C_{26}\,C_{35} + C_{34}\,C_{31}\,C_{29} - (0.5\,C_{30}\,C_{34} + C_{35}\,C_{27}\,C_{29})]/C_{33}$
	(40)	$E_1 = C_{17}\,C_{36} + C_{18} + C_{19}\,C_{37}$
	(41)	$E_2 = C_{20}\,C_{36} + C_{21} + C_{22}\,C_{37}$
	(42)	$E_3 = C_{23}\,C_{36} + C_{24} + C_{25}\,C_{37}$
	(43)	$E_4 = 1/4 + C_{37}/12 + C_{36}/4 - E_3/5 - 3E_2/2 - E_1$
	(44)	$E_5 = E_1(1/2 + A/6) + E_2\,(1/4 + 11A/84) + E_3(1/70 + A/105)$
A1	(45)	$E_6 = E_5 - C_{36}\,(7/120 + A/36 + 3A/C) - 1/40 - A/72 - C_{37}(1/60 + A/120 + 1/C)$

3.21.7 Narrow-face split loose flanges Loose flanges of the type shown in Figure 3.21.3(k) may be of a split design to permit installation after heat treatment of the vessel or, in other cases, where it is desired to have the flanges completely removable from the vessel or branch.

Loose flanges split across a diameter and designed in accordance with Clause 3.21.6 may be used under the following provisions:

(a) Where the flange consists of a single split flange or flange ring, it shall be designed as if it were a solid flange, i.e. without splits, using 200 percent of the total moment M_o as defined in Clause 3.21.6.5.

(b) Where the flange consists of two split rings, each ring shall be designed as if it were a solid flange, i.e. without splits, using 75 percent of the total moment M_o as defined in Clause 3.21.6.5. The pair of rings shall be assembled so that the splits in one ring shall be 90 degrees from the splits in the other ring.

(c) The splits should preferably be midway between bolt holes.

3.21.8 Narrow-face non-circular shaped flanges with circular bore These flanges shall be designed in accordance with Clauses 3.21.6 and 3.21.12, except that the outside diameter A for a non-circular flange with a circular bore shall be taken as the diameter of the largest circle, concentric with the bore, inscribed entirely within the outside edges of the flange. Bolt forces and moments, as well as stresses, are then calculated as for circular flanges, using a bolt circle drawn through the centres of the outermost bolt holes.

3.21.9 Flanges subject to external pressure

NOTE: When internal pressure occurs only during the required pressure test, the design may be based on external pressure and auxiliary devices such as clamps may be used during the application of the required test pressure.

3.21.9.1 *Design for external pressure* The design of flanges for external pressure only shall be based on the equations given in Clause 3.21.6.6 for internal pressure except for the following:

For operating conditions—

$$M_o = H_D(h_D - h_G) + H_T(h_T - h_G) \quad \ldots 3.21.9(1)$$

For gasket seating—

$$M_o = Wh_G \quad \ldots 3.21.9(2)$$

where

$$W = \frac{A_{m2} + A_b}{2} S_a$$

$$H_D = 0.785B^2P_e$$

$$H_T = H - H_D$$

$$H = 0.785G^2 P_e$$

P_e = external design pressure, in megapascals

See Clause 3.21.6.7 for definitions of other symbols.

3.21.9.2 *Design for external and internal pressure* When flanges are subject at different times during operation to external or internal pressure, the design shall satisfy the external pressure design requirements given in Clause 3.21.9.1 and the internal pressure design requirements given in Clause 3.21.6.

NOTE: The combined force of external pressure and bolt loading may plastically deform certain gaskets and result in loss of gasket contact pressure when the connection is depressurized. To maintain a tight joint when the unit is repressurized consideration should be given to gasket and facing details, so that excessive deformation of the gasket will not occur. Joints subject to pressure reversals, such as in heat exchanger floating heads, are in this type of service.

3.21.10 Flat-face flanges with metal-to-metal contact outside the bolt circle The design of flat-face flanges with metal-to-metal contact outside the bolt circle shall comply with ANSI/ASME BPV VIII-1 or other approved methods.

3.21.11 Flanges with full-face gaskets

3.21.11.1 *General* The flange design methods outlined in this Clause (3.21.11) are applicable to all circular flanges including loose type, integral type and hub type with full-face gaskets subject to internal pressure. Flanges for use with full-face gaskets are not recommended for use at pressures exceeding 2.1 MPa (see Clause 3.21.2(b)).

3.21.11.2 *Notation* The notation is the same as that of Clause 3.21.6.2, except that the following symbols are modified:

b = effective gasket or joint-contact-seating width, in millimetres

$$= \frac{C - B}{4}$$

G = diameter at the location of that portion of the gasket reaction between the bolt circle and the internal diameter of the flange, in millimetres

= $C - 2h_G$

H = total hydrostatic end-force, in newtons

= $0.785G^2P$

H_p = total joint-contact-surface compression force, in newtons

= addition of gasket-force between the bolt circle and the inside of the flange, plus the gasket-force between the bolt circle and the outside of the flange

= $(2b\pi GmP)(1 + \frac{h_G}{h'_G})$

H_G = total gasket-force (difference between flange design bolt-force and total hydrostatic end-force), in newtons

= $W - H$

h_G = radial distance from the bolt circle to the reaction of that portion of the gasket-force between the bolt circle and the inside of the flange, in millimetres

= $\frac{(C - B)(2B + C)}{6(B + C)}$

h'_G = radial distance from the bolt circle to the reaction of that portion of the gasket force between the bolt circle and the outside of the flange, in millimetres

= $\frac{(A - C)(2A + C)}{6(C + A)}$

M_G = component of the internal moment at the bolt circle, due to gasket-force, in newton millimetres

= $\frac{(W - H)}{\frac{1}{h_G} + \frac{1}{h'_G}}$

W = flange design bolt-force for the operating conditions or gasket seating, as may apply (see Clause 3.21.11.4.3), in newtons

W_{m1} = minimum required bolt-force for operating conditions (see Clause 3.21.11.4.1(a)), in newtons

W_{m2} = minimum required bolt-force for gasket seating (see Clause 3.21.11.4.1(b)), in newtons

m = gasket factor, obtained from Table 3.21.11.4

y = gasket or joint-contact-surface seating stress, obtained from Table 3.21.11.4

Y' = factor involving K, obtained from Figure 3.21.6.6(A)

3.21.11.3 *Circular flange types* For circular flange types, the classifications given in Clause 3.21.6.3 apply.

3.21.11.4 *Bolt-forces*

3.21.11.4.1 *Required bolt-forces* The flange bolt-force used in calculating the required cross-sectional area of bolts shall be determined in accordance with Items (a) and (b). In addition, the requirements of Clause 3.21.6.4.2 shall be met.

(a) *Force for operating conditions.* The required bolt-force for the operating conditions W_{m1} shall be sufficient to resist the hydrostatic end-force H, exerted by the maximum allowable working pressure on the area bounded by the diameter of that portion of the gasket reaction between the bolt circle and the inside of the flange, and in addition, to maintain on the gasket or joint-contact surface, a compression force H_p, which experience has shown to be sufficient to ensure a tight joint. (This compression force is expressed as a multiple m of the internal pressure. Its value is a function of the gasket material and facing. See Note to Table 3.21.11.4.) The required bolt-force for the operating conditions, W_{m1}, is determined in accordance with the following equation:

$$W_{m1} = H + H_p = 0.785G^2P + 2b\pi GmP(1 + \frac{h_G}{h'_G}) \quad \ldots 3.21.11.4(1)$$

TABLE 3.21.11.4

GASKET MATERIALS AND CONTACT FACTORS

Gasket material	Gasket factor, m	Min. design seating strength y, MPa
Soft rubber or neoprene	0.25	2.0
Rubber with fabric insertion	0.80	2.9
Compressed asbestos fibre	0.90	3.5

NOTE: Gasket factors for use with wide face flanges are not well known and are the subject of considerations for temperature, gasket characteristics, type of fluid, etc. Some suggested values for use with fluids below 260°C are given in Table 3.21.11.4. Values which are too low may result in leakage at the joint without affecting the safety of the joint.

The effect of increasing these values will result in higher bolt stresses.

Asbestos type gaskets may not be permitted in some applications.

(b) *Gasket seating-force* Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial force (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt force required for this purpose (W_{m2}), shall be determined in accordance with the following equation:

$$W_{m2} = \pi bGy(1 + \frac{h_G}{h'_G}) \quad \ldots 3.21.11.4(2)$$

The need for providing sufficient bolt-force to seat the gasket or joint-contact-surface in accordance with Equation 3.21.11.4(2) will prevail in many low-pressure designs and with facings and materials that require a high seating-force, and where the bolt-force calculated by Equation 3.21.11.4(1) for the operating conditions is insufficient to seat the joint. Accordingly, it is necessary to furnish bolting and to pre-tighten the bolts to provide a bolt-force sufficient to satisfy both of these requirements, each one being individually investigated. When

Equation 3.21.11.4(2) governs, flange proportions will be a function of the bolting instead of internal pressure.

3.21.11.4.2 *Total required and actual bolt areas A_m and A_b* The requirements of Clause 3.21.6.4.3 apply.

3.21.11.4.3 *Flange design bolt-force W* The requirements of Clause 3.21.6.4.4 apply.

3.21.11.5 *Flange moments* In the calculation of flange stresses, the moment of force acting on the flange is the product of the force and its moment arm. The moment arm is determined by the relative position of the bolt circle with respect to that of the force producing the moment. No credit shall be taken for reduction in moment arm due to cupping of the flanges or due to inward shifting of the line of action of the bolts as a result thereof.

A2 | For the operating conditions, the total flange moment M_o, is the sum of only two individual moments M_D and M_T, as defined in Clause 3.21.6.2, and based on the flange A2 | design bolt-force of Equation 3.21.6.4.4(1) with moment arms as given in Table 3.21.11.5. In this calculation, it is assumed that when full fixation at the bolt circle is produced during bolting up, the gasket moments due to the reaction each side of the bolt circle are equal and opposite.

For the gasket seating conditions, the total flange moment, is based on the flange design bolt-force of Clause 3.21.11.4.3 which is opposed only by the gasket-force, in which case—

$$M_o = M_G = \frac{(W - H)}{\frac{1}{h_G} + \frac{1}{h'_G}} \quad \text{. . . 3.21.11.5}$$

TABLE 3.21.11.5

MOMENT ARMS FOR FLANGE FORCES UNDER OPERATING CONDITIONS

Values			
h_D	h_T	h_G	h'_G
$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{(C - B)(2B + C)}{6(B + C)}$	$\frac{(A - C)(2A + C)}{6(A + C)}$

3.21.11.6 *Calculation of flange stresses* The stresses in the flange shall be determined for both the operating conditions and gasket seating, whichever controls, in accordance with the following equations:

Tangential flange stress—

$$S_T = \frac{Y' M_o}{t^2 B} \quad \text{. . . 3.21.11.6(1)}$$

Radial flange stress—

$$S_R = \frac{6M_o}{t^2 (\pi C - nD)} \quad \text{. . . 3.21.11.6(2)}$$

3.21.11.7 *Flange design strength* The flange stress calculated by either equation in Clause 3.21.11.6 shall be no greater than S_f.

3.21.12 Reverse flange

3.21.12.1 *General* The flange design methods outlined in this Clause (3.21.12) are applicable to reverse flanges of types shown in Figure 3.21.12.2.

The method is applicable where values of K is less than and equal to 2. For values of K greater than 2, the design method becomes increasingly conservative as values of K increase and the results shall be treated with caution.

3.21.12.2 *Notation* The notation given in Clause 3.21.6.2 is used in the design methods in this Clause (3.21.12) with the following modifications and additions:

B = for reverse flanges, inside diameter of shell, in millimetres

B'' = inside diameter of reverse flange, in millimetres

d_r = factor which applies to reverse flanges, in millimetres to the third power

$$= \frac{U_r}{V} h_{or} g_o^2$$

e_r = factor which applies to reverse flanges, in millimetres to the power of minus one

$$= \frac{F}{h_{or}}$$

F = factor for integral type flanges (from Figure 3.21.6.6(B) substituting h_{or} for h_o)

f = hub stress correction factor for integral flanges (from Figure 3.21.6.6(F)) substituting h_{or} for h_o for reverse flanges) (when greater than one, this is the ratio of the stress in the small end of the hub to the stress in the large end) (for values below the limit of the Figure, use $f = 1$)

h_{or} = factor which applies to reverse flanges, in millimetres

$$= \sqrt{(Ag_o)}$$

K = ratio of outside diameter of flange to inside diameter of flange

= A/B'' for a reverse flange

L_r = factor which applies to reverse flanges

$$= \frac{te_r + 1}{T_r} + \frac{t^3}{d_r}$$

M_o = total moment acting upon the flange, for operating conditions or gasket seating as may apply, in newton millimetres (see Clause 3.21.6.5 and Clause 3.21.12.3); this notation applies to flanges covered by Clauses 3.21.6 to 3.21.9 inclusive, and Clause 3.21.12

S_{T1} = calculated tangential stress at outside diameter of a reverse flange, in megapascals

S_{T2} = calculated tangential stress at inside diameter of a reverse flange, in megapascals

T_r = factor which applies to reverse flanges

$$= \left(\frac{Z + 0.3}{Z - 0.3}\right) \alpha_r T$$

U_r = factor which applies to reverse flanges

$= \alpha_r U$

V = factor for integral type flanges (from Figure 3.21.6.6(C) substituting h_{or} for h_o for reverse flanges)

Y_r = factor which applies to reverse flanges

= $\alpha_r Y$ for flanges with ring type gaskets

= $\alpha_r Y'$ for flanges with full face gaskets

$$\alpha_r = \left(1 + \frac{0.668(K + 1)}{Y}\right)\frac{1}{K^2} \text{ for flanges with ring type gaskets}$$

$$= \left(1 + \frac{0.668(K + 1)}{Y'}\right)\frac{1}{K^2} \text{ for flanges with full face gaskets}$$

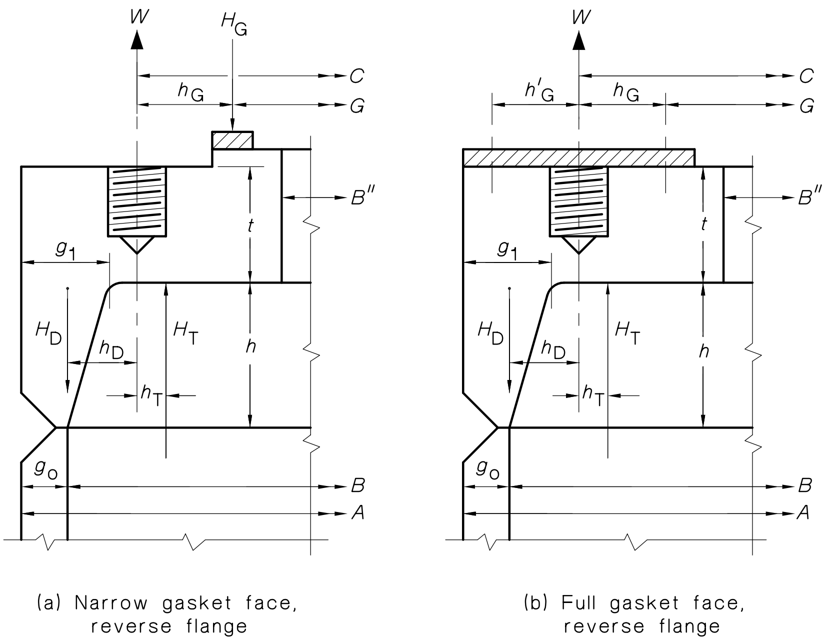


FIGURE 3.21.12.2 REVERSE FLANGE NOTATION

3.21.12.3 *Flange moments for reverse flanges with ring-type gaskets* The total flange moment (M_o), shall be calculated for both the gasket seating and operating conditions in accordance with Clause 3.21.6.5, substituting Figure 3.21.12.2(a) where reference is made to Figure 3.21.6.2, and the following:

(a) For gasket seating condition— . . . 3.21.12.3(1)

$M_o = Wh_G$

(b) For operating conditions—

$M_o = M_D + M_T + M_G$ . . . 3.21.12.3(2)

NOTE: For reverse flanges, h_D and H_T are negative (see Figure 3.21.12.2(a)).

If (M_o) is negative, its absolute value shall be used in calculating stresses for comparison with allowable stresses.

3.21.12.4 *Flange moments for reverse flanges with full-face gaskets* The total flange moment (M_o) shall be calculated for both the gasket seating and operating conditions in accordance with Clause 3.21.11.5 and Figure 3.21.12.2(b), and the following:

(a) For gasket seating conditions—

$$M_o = M_G \qquad \text{. . . 3.21.12.4(1)}$$

(b) For operating conditions—

$$M_o = M_D + M_T \qquad \text{. . . 3.21.12(2)}$$

NOTE: For reverse flanges, h_D and H_T are negative (see Figure 3.21.12.2(b)).

h_T maybe positive as in Figure 3.21.12.2(a) but can be negative if the line of action of H_T is on the other side of the bolt circle.

If M_o is negative, its absolute value shall be used in calculating stresses for comparison with allowable stresses.

3.21.12.5 *Calculation of flange stresses* The stresses in the flange shall be determined for both the gasket seating and operating conditions in accordance with the following:

(a) Stresses at flange outside diameter—

$$S_H = \frac{f\,M_o}{L_r\, g_1^2\, B''} \qquad \text{. . . 3.21.12.5(1)}$$

$$S_R = \frac{(1.33te_r + 1)\, M_o}{L_r\, t^2\, B''} \qquad \text{. . . 3.21.12.5(2)}$$

$$S_{T1} = \frac{Y_r\, M_o}{t^2\, B''} - ZS_R\left(\frac{0.67\; te_r + 1}{1.33\; te_r + 1}\right) \qquad \text{. . . 3.21.12.5(3)}$$

(b) Stresses at flange inside diameter—

$$S_{T2} = \left(\frac{M_o}{t^2\, B''}\right)\left[Y - \frac{2K^2\left(1 + \frac{2te_r}{3}\right)}{(K^2 - 1)L_r}\right]$$

for flanges with ring type gaskets . . . 3.21.12.5(4)

$$S_{T2} = \left(\frac{M_o}{t^2\, B''}\right)\left[Y' - \frac{2K^2\,(1 + \frac{2te_r}{3})}{(K^2 - 1)L_r}\right]$$

for flanges with full face gaskets . . . 3.21.12.5(5)

NOTE: For simplicity, the designer may calculate the construction as a loose-type flange provided that none of the following values are exceeded:

A2 P = 2.1 MPa, Design temperature = 370°C.

In this case, the stress at the flange outside diameter is $S_{T1} = Y_r\, M_o/(t^2B'')$ and at the inside diameter is $S_{T2} = Y'\, M_o/(t^2B'')$. S_H and S_R = 0.

3.21.12.6 *Flange design strength* The flange stresses calculated by the equations in Clause 3.21.12.5 shall not exceed the permissible stresses specified in Clause 3.21.6.7.

3.22 PIPES AND TUBES

3.22.1 General The design of pipe and tube components shall be accordance with AS 4041 modified by Clauses 3.22.2 and 3.22.3 for those which are integral components of a vessel.

3.22.2 Thickness The calculated wall thickness for tube and pipe shall be determined in accordance with—

(a) Clause 3.7, when subject to internal pressure; and

(b) Clause 3.9, when subject to external pressure.

Additional thickness shall be provided in accordance with Clause 3.4.2. Where the tube end is threaded, the tube thickness shall be based on the bottom of the thread.

Where the tube is bent, the resulting thickness at the thinnest part shall be no less than that required for straight tube unless it can be demonstrated that the method of forming the bend results in no decrease in strength at the bend compared with straight tube.

For staytubes, see Clause 3.16.5, and for tubes in heat exchangers, see Clause 3.17.

3.22.3 Attachment Attachment of tubes and pipes to shell and ends shall be in accordance with Clause 3.19, and staytubes shall be attached to stayed surfaces in accordance with Clause 3.16.5.

Attachment of tubes to flat tubeplates or other surfaces shall be in accordance with Clause 3.17.

3.23 JACKETED VESSELS

3.23.1 General Jacketed vessels, including jacketed troughs, shall be designed in accordance with the requirements given for each element given elsewhere in this Standard except where modified in this Clause (3.23). The jacketed portion of the vessel is defined as the inner and outer walls, the closure devices, and all other penetrations or parts within the jacket which are subjected to pressure stresses. Parts such as branches, closure members and stiffening or stay rings are included.

The inner vessel shall be designed to resist the full differential pressure that may exist under any operating condition, including accidental vacuum in the inner vessel due to condensation of vapour contents where this circumstance can arise.

Where the inner vessel is to operate under vacuum and the hydrostatic test pressure for the jacket is correspondingly increased to test the inner vessel externally, care shall be taken that the jacket shell is designed to withstand this extra pressure.

The effect of localized internal and external forces and thermal expansion shall be considered. If the number of full thermal stress cycles is expected to exceed 5000, the design shall cater for thermal stresses caused by varying expansion rates between the jacket and inner vessel. Impingement plates or baffles shall be provided at the jacket inlet where erosion of the vessel or jacket wall is a possibility due to condensation of steam or other condensable vapour.

3.23.2 Types of jacketed vessels This Clause (3.23) applies to jacketed vessels having jackets which cover the shell or ends as illustrated in Figure 3.23.2 and partial jackets as illustrated in Figure 3.23.7. Jackets, as shown in Figure 3.23.2, shall be continuous circumferentially for Types 1, 2, 4 and 5 shown, and shall be circular in cross-section for Type 3. The use of a combination of the types shown is permitted on a single vessel provided that the individual requirements for each are met. Dimpled jackets are not covered by this Clause (see Clause 3.16.6). (For jacketed troughs see Clause 3.23.8.)

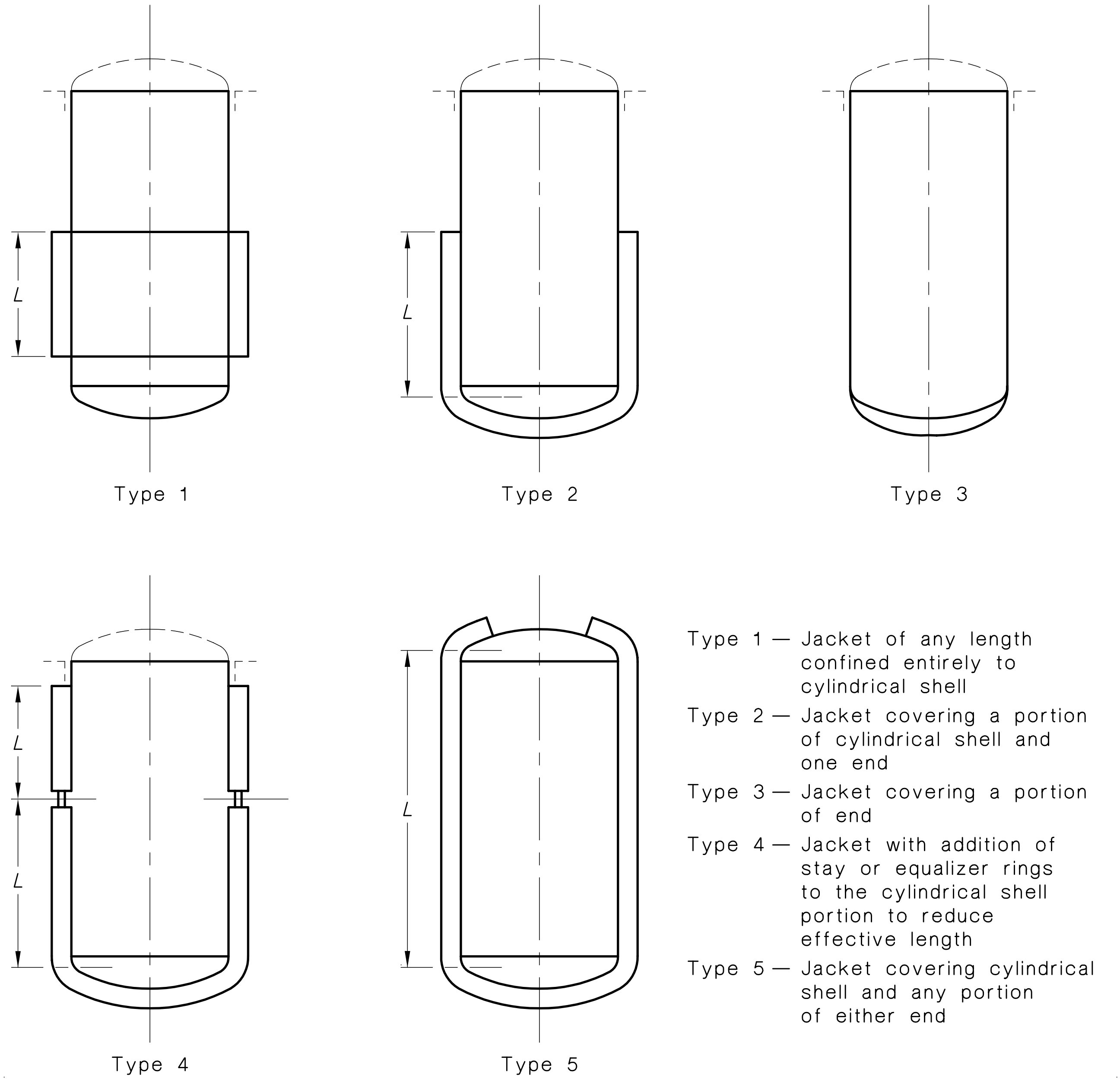


FIGURE 3.23.2 SOME ACCEPTABLE TYPES OF JACKETED VESSEL

3.23.3 Design of jacket shells and jacket ends The design of jacket shells and jacket ends shall comply with the requirements of Section 3 of this Standard, and with the general requirements of Clause 3.23.1.

3.23.4 Notation For the purpose of this Clause (3.23), the following notation applies:

t_s = actual thickness of inner vessel wall, in millimetres

t_{rj} = minimum required thickness of outer jacket wall exclusive of corrosion allowance, in millimetres

t_{rc} = minimum required thickness exclusive of corrosion allowance of closure member as determined herein, in millimetres

t_c = actual thickness of closure member, in millimetres

t_j = actual thickness of outer jacket wall, in millimetres

t_n = nominal thickness of branch, in millimetres

r = corner radius of torus closures, in millimetres

R_s = outside radius of inner vessel, in millimetres

R_j = inside radius of jacket, in millimetres

R_p = radius of opening in the jacket at the jacket penetration, in millimetres

P = design pressure in the jacket chamber, in megapascals

P_v = design vacuum in inner vessel, in megapascals

f = design strength, in megapascals

j = jacket space, in millimetres

= inside radius of jacket, minus outside radius of inner vessel, in millimetres

a, b, = minimum weld dimensions for attachment of closure minimum weld dimensions

c, Y, = for attachment of closure member to inner vessel measured as shown in

Z shown in Figures 3.23.5 and 3.23.6, in millimetres

L = design length of a jacket section as shown in Figure 3.23.2, in millimetres.

This length is determined as—

(a) the distance between inner vessel end bend lines plus one-third of the depth of each inner vessel end where there are no stiffening rings or jacket closure between the end bend lines;

(b) the centre-to-centre distance between two adjacent stiffening rings or jacket closures; or

(c) the distance from the centre of the first stiffening ring or the jacket closure to the jacketed inner end bend line plus one-third of the inner vessel end, all measured parallel to the axis of the vessel.

For the design of a closure member or stiffening ring, the greater adjacent L shall be used.

3.23.5 Design of jacket closures Jacket closures shall conform to those shown in Figure 3.23.5, and shall comply with the following requirements unless otherwise agreed between the parties concerned.

(a) Closures of the type shown in Figure 3.23.5(a) that are used on Type 1, Type 2, or Type 4 jacketed vessels as shown in Figure 3.23.2 shall have t_{rc} at least equal to t_{rj} and corner radius r shall not be less than $3t_c$. This closure design is limited to a maximum thickness t_{rc}, of 15 mm. Where this construction is used on Type 1 jacketed vessels, the weld dimension Y shall be not less than $0.7t_c$; and where used on Types 2 and 4 jacketed vessels, the dimension Y shall be not less than $0.85t_c$.

(b) Closures of the type shown in Figure 3.23.5 (b-1) and (b-2) shall have t_{rc} at least equal to t_{rj}. A butt weld attaching the closure to the inner vessel and fully penetrating the closure thickness t_c, may be used with any of the types of jacketed vessels shown in Figure 3.23.2. However, a fillet weld having a minimum throat dimension of $0.7t_c$ may also be used to join the closure of the inner vessel of Type 1 jacketed vessels of Figure 3.23.2.

(c) Closures of the type shown in Figure 3.23.5(c) shall be used only on Type 1 jacketed vessels shown in Figure 3.23.2. The closure thickness t_{rc}, shall be determined by Clause 3.10 but shall be not less than t_{rj}. The angle α shall be limited to 30 degrees maximum.

(d) Closure of the types shown in Figure 3.23.5(d-1), (d-2), (e-1), and (e-2), shall be used only on Type 1 jacketed vessels as shown in Figure 3.23.2 and with the further limitation that t_{rj} does not exceed 15 mm. The required minimum thickness for the closure bar shall be the greater value of that determined by the following Equation:

$$t_{rc} = 2(t_{rj}) \qquad \ldots 3.23.5(1)$$

A2

$$t_{rc} = 0.707 j \left(\frac{P}{f}\right)^{0.5} \qquad \ldots 3.23.5(2)$$

Fillet weld sizes shall be as follows:

(i) *Y* shall be not less than the smaller of $0.75t_c$ and $0.75t_s$.

(ii) *Z* shall be not less than t_j.

(e) Closure bar and closure bar to inner vessel welds of the types shown in Figure 3.23.5(f-1), (f-2) and (f-3) may be used on any of the types of jacketed A2 vessels shown in Figure 3.23.2. For all other types of jacketed vessels the required minimum closure bar thickness shall be determined by the following equation:

A2

$$t_{rc} = 1.414 \left(\frac{P R_s j}{f}\right)^{0.5} \qquad \ldots 3.23.5(3)$$

The width of the jacket space shall not exceed the value determined by the following equation:

$$j = \frac{2 f t_s^{2}}{P R_j} - 0.5(t_s + t_j) \qquad \ldots 3.23.5(4)$$

Weld sizes connecting the closure bar to the inner vessel shall be as follows:

(i) *Y* shall be not less than the smaller of $1.5t_c$ and $1.5t_s$ and shall be measured as the sum of dimensions *a* and *b* as shown in the appropriate sketch of Figure 3.23.5.

(ii) *Z* minimum fillet leg length necessary when used in conjunction with a groove weld or another fillet weld to maintain the minimum required *Y* dimension.

(f) Jacket to closure bar attachment welds shown in Figure 3.23.5(g-1), (g-2) and (g-3) may be used on any of the types of jacketed vessels shown in Figure 3.23.2. Attachment welds shown in Figure 3.23.5(g-4) may be used on any of the types of jacketed vessels shown in Figure 3.23.2 where t_{rj} does not exceed 15 mm. Attachment welds shown in Figure 3.23.5(g-5) and (g-6), may be used in Type 1 jacketed vessels shown in Figure 3.23.2 where t_j does not exceed 15 mm.

(g) Closures shown in Figure 3.23.5(h) and (j) shall be limited to jackets where t_{rj} does not exceed 15 mm.

(h) Closures for conical or toriconical jackets shown in Figure 3.23.5(k) and (l) shall comply with the requirements of Type 2 jacketed vessels shown in Figure 3.23.2.

(i) Each radial weld in a closure member shall be a butt-welded joint penetrating through the full thickness of the member and shall be ground flush where attachment welds are to be made.

(j) Closures for any type of staybolted jacket may be designed in accordance with the requirements of Type 1 jackets shown in Figure 3.23.2 provided that the entire jacket is staybolted to compensate for pressure end-forces.

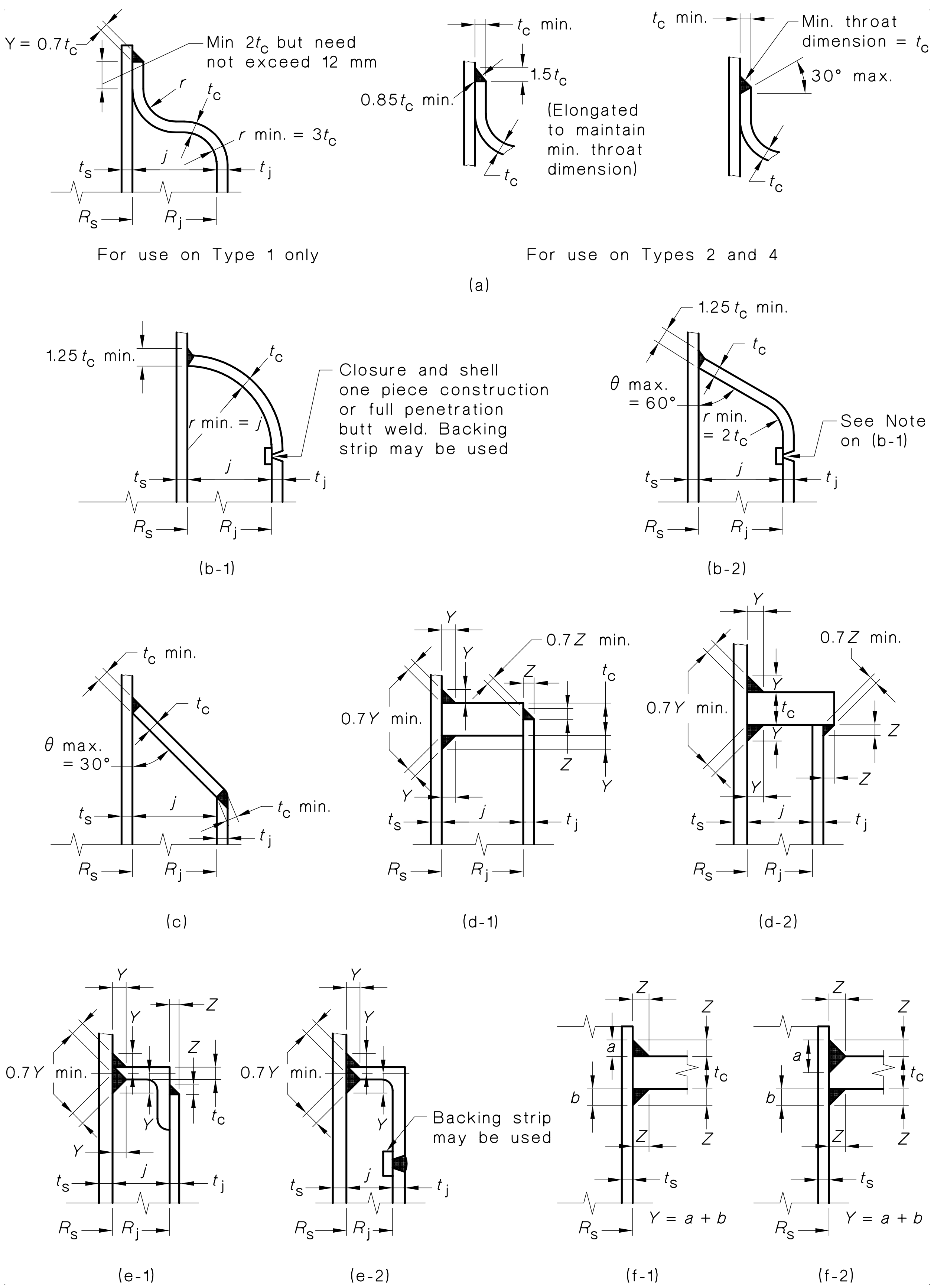


FIGURE 3.23.5 (in part) SOME ACCEPTABLE TYPES OF JACKET CLOSURE
(See Clause 3.23.5 for limitations on use)

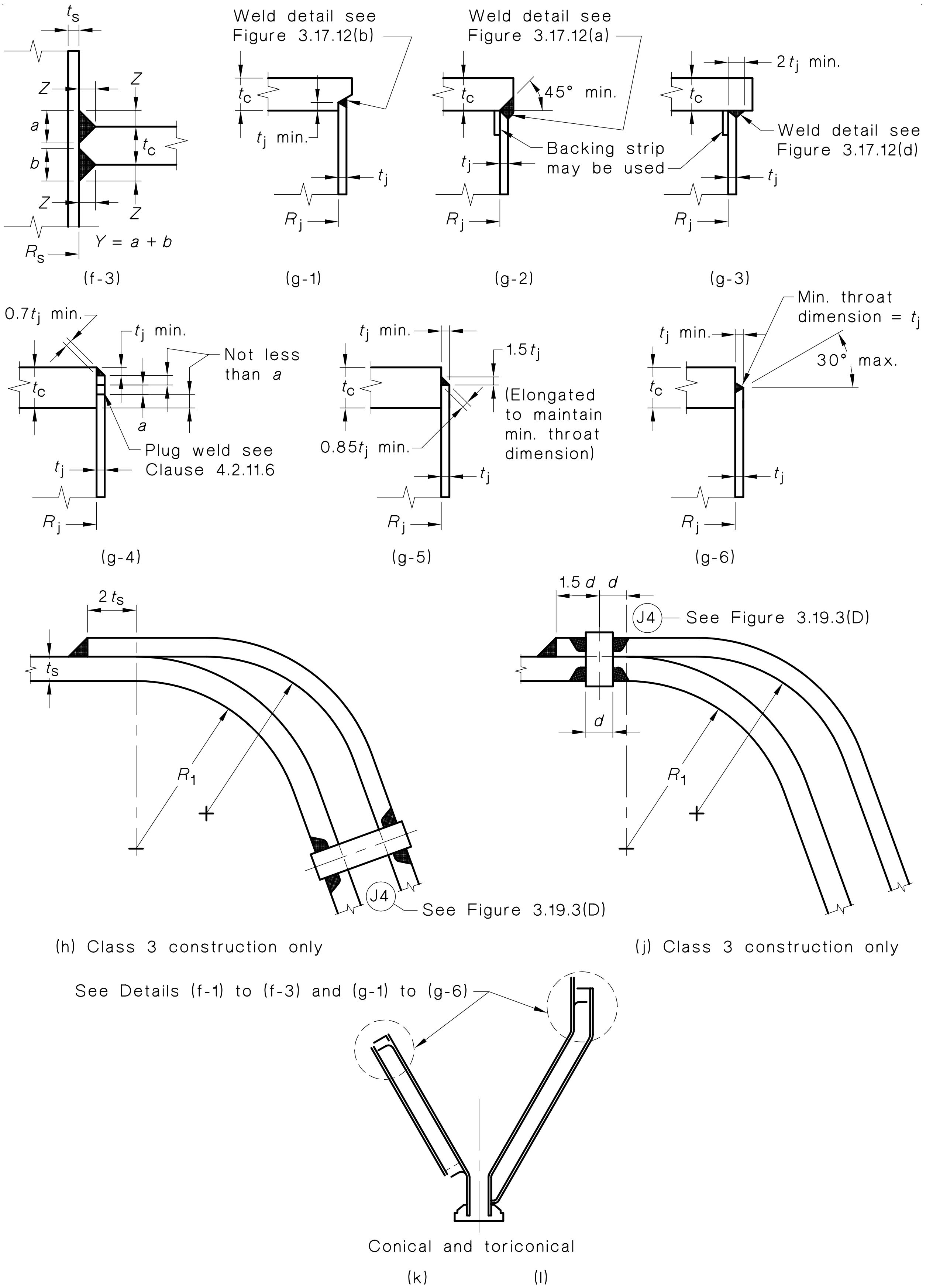


FIGURE 3.23.5 (in part) SOME ACCEPTABLE TYPES OF JACKET CLOSURES
(See Clause 3.23.5 for limitations on use)

3.23.6 Design of penetrations through jackets The following requirements apply to openings through jackets:

(a) The design of openings through the jacket space shall be in accordance with the requirements of this Standard.

(b) Reinforcement of the opening in the jacket shall not be required for penetrations shown in Figure 3.23.6 since the opening is stayed by virtue of the branch or neck of the closure member.

(c) The jacket penetration closure member minimum thickness considers only pressure membrane loading. Axial pressure loadings and secondary loadings given in Clause 3.2.3 shall be considered in the design (see Clause 3.23.6(d)(vi)).

(d) Jacket penetration closure member designs shown in Figure 3.23.6 shall conform to the following requirements:

(i) The branch may be used as the closure member as shown in Figure 3.23.6(a), where jacket is welded to branch.

(ii) The minimum required thickness t_{rc}, for designs Figure 3.23.6(b) and (d) shall be calculated as a shell under external pressure in accordance with Clause 3.9.

(iii) The minimum required thickness t_{rc}, for design Figure 3.23.6(c) shall be equal to t_{rj}.

(iv) For designs Figure 3.23.6(e-1) and (e-2), the thickness required of the closure member attached to the inner vessel t_{rc1}, shall be calculated as a shell under external pressure in accordance with Clause 3.9. The required thickness of the flexible member t_{rc2}, shall be determined by one of the following equations:

When no tubular section exists between jacket and torus—

$$t_{rc2} = \frac{Pr}{(f\eta - 0.5P)} \quad \text{. . . 3.23.6(1)}$$

When tubular sections exists between jacket and torus–

$$t_{rc2} = \frac{PR_p}{(f\eta - 0.5p)} \quad \text{. . . 3.23.6(2)}$$

where

η = welded joint efficiency from Table 3.5.1.7 for circumferential weld in the torus for equation using r, or for any weld in opening closure member for equation using R_p, radius of penetration.

(v) The minimum thickness t_{rc}, for design Figure 3.23.6(f) shall be calculated as a shell of radius R_p, under external pressure in accordance with Clause 3.9.

(vi) Designs in Figure 3.23.6(b), (c), (d) and (e) provide for some flexibility and are designed on a similar basis to that of expansion joints under the conditions of Clause 3.1.3 in combination with Clauses 3.2.3 and 3.3.1. Only pressure membrane loading is considered in establishing the minimum thickness of the penetration closure member, and it is not the intent that the combination of direct localization and secondary bending stress need be held to the design strength values in Clause 3.3.1. It is recognized that high localized and secondary bending stresses may exist.

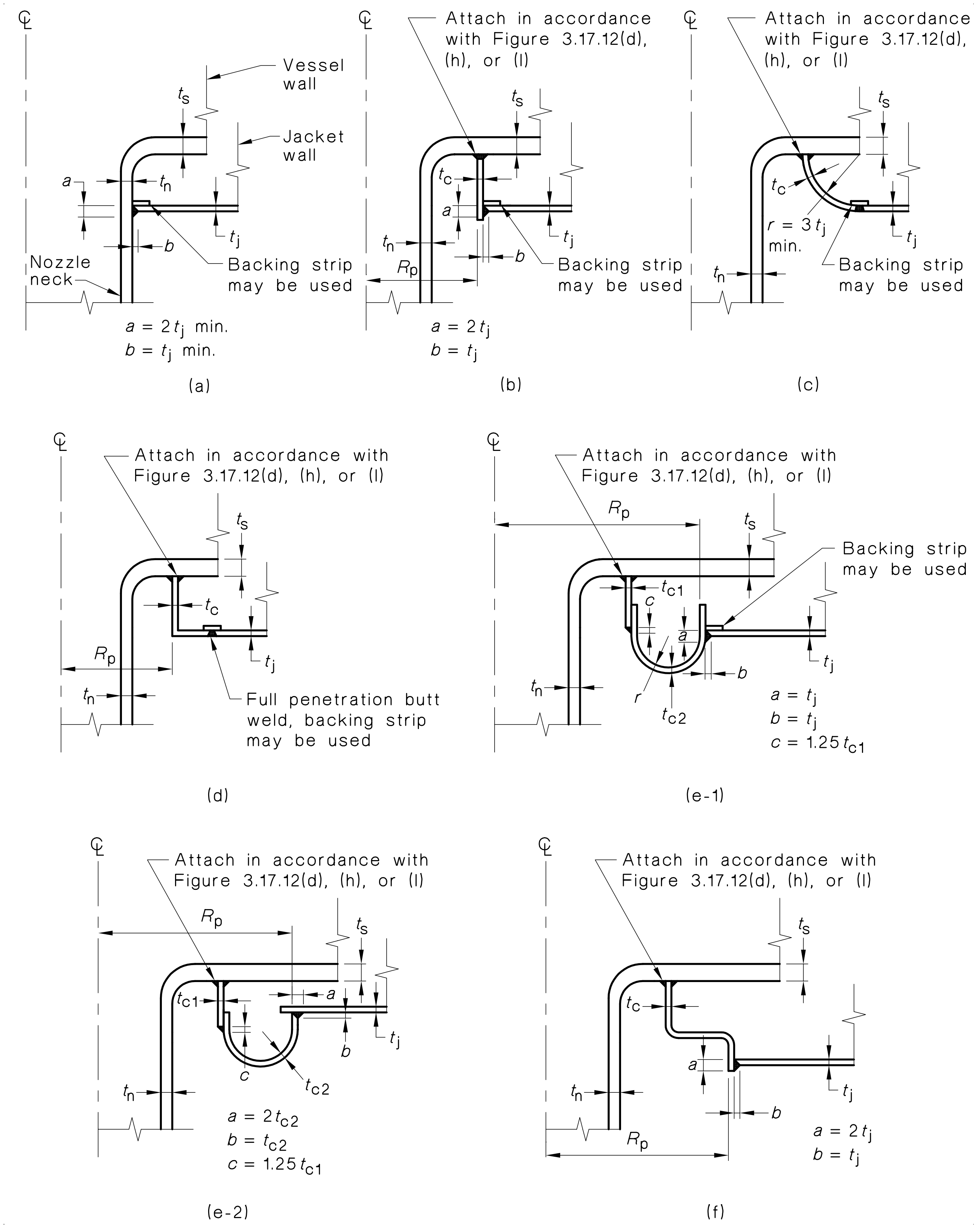


FIGURE 3.23.6 SOME ACCEPTABLE TYPES OF PENETRATION DETAILS

(vii) All radial welds in opening sealer membranes shall be butt-welded joints penetrating through the full thickness of the member.

(viii) Closure member wells shall be circular, elliptical, or obround in shape where possible. Rectangular member wells are permissible provided that corners are rounded to a suitable radius.

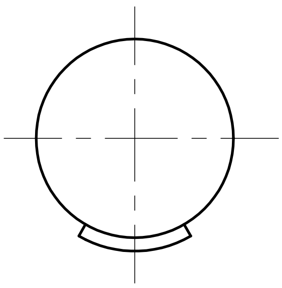
3.23.7 Design of partial jackets (excluding troughs)

3.23.7.1 *General* Partial jackets are jackets which encompass less than the full circumference of the vessel. Some variations are shown in Figure 3.23.7.

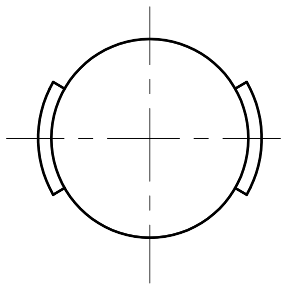
3.23.7.2 *Application* The requirements for construction of jacketed vessels given in Clauses 3.23.1 to 3.23.6 shall apply to partial jackets with the following exceptions:

(a) Stayed partial jackets shall be designed and constructed in accordance with Clause 3.16. Closure members shall comply with Clause 3.23.5.

(b) Partial jackets which by virtue of their service or configuration do not lend themselves to staybolt construction, may be fabricated by other means provided that they are designed using appropriate stress values and are proof hydrostatic tested in accordance with Clause 5.12.



a) Continuous partial jacket



b) Multiple or pod type jacket

FIGURE 3.23.7 SOME TYPES OF PARTIAL JACKET

3.23.8 Jacketed troughs The design of open-top trough-shaped vessels with jacket spaces for steam heating, unless otherwise agreed by the parties concerned shall comply with one of the following:

(a) *As shown in Figure 3.23.8(a)* The thickness of the flat portion of the side-plates subject to stream pressure shall be calculated as for a flat surface, and the side-plates shall be provided with stay-bolts in accordance with Clause 3.16. The inner bottom half cylindrical plate shall be stiffened or stayed as for a cylinder in compression, the outer half cylindrical plate being calculated as for a cylinder in tension. The top edges of the jacket side-plates shall be butt-welded to a longitudinal bar taking the pressure load. The troughs shall be suitably stiffened to resist distortion due to out of balance loads, e.g. by tie bars.

(b) *As shown in Figure 3.23.8(b)* The design shall comply with the requirements of Clause 3.23.8(a), except that the jacket side-plates shall be flanged over at the top and welded to the jacket and inner plates to take the pressure load.

(c) *As shown in Figure 3.23.8(c)* The whole area of the plate subject to pressure shall be stayed as flat surfaces in accordance with Clause 3.16. The troughs shall be suitably stiffened to resist distortion due to out of balance loads, e.g. by tie bars.

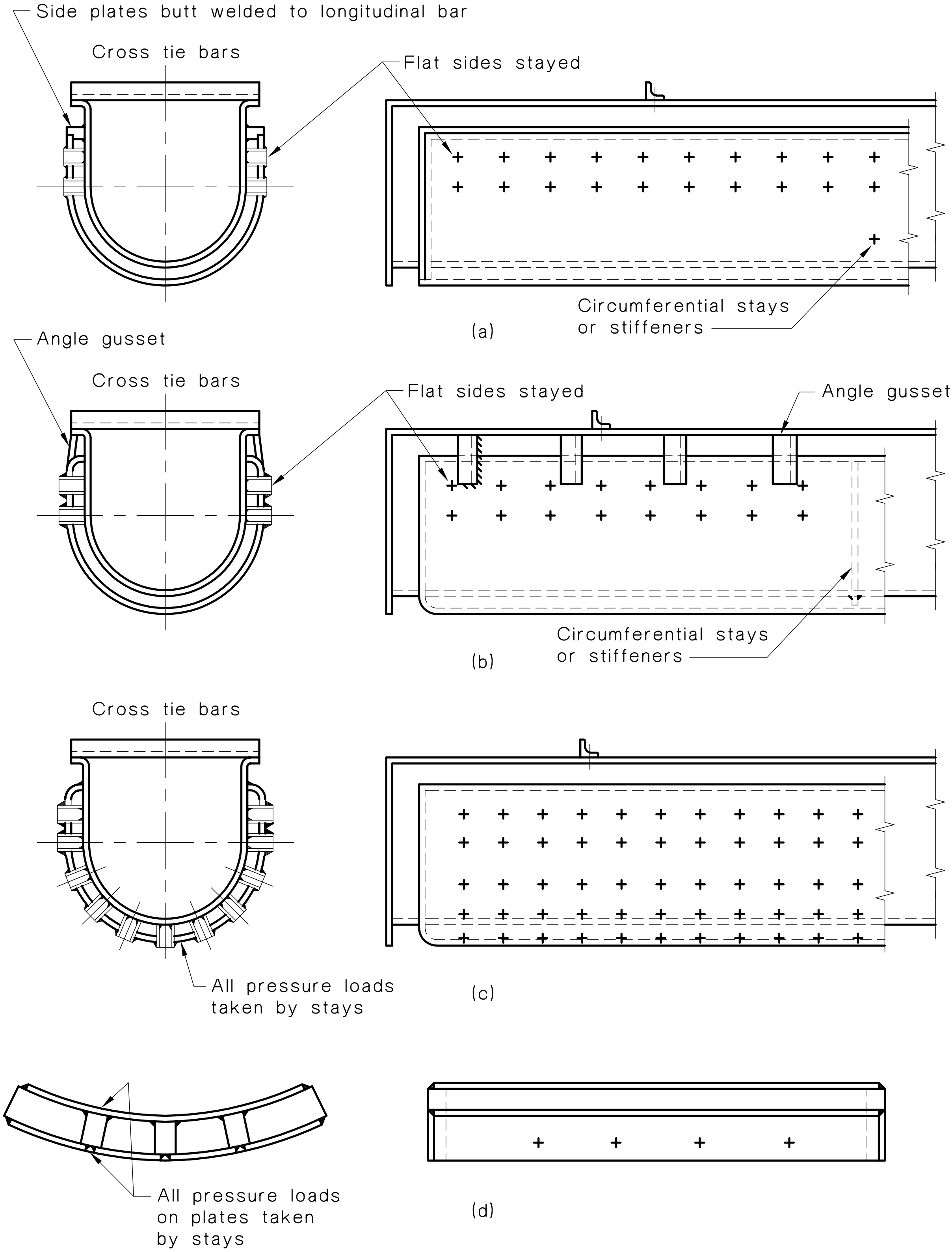


FIGURE 3.23.8 STEAM PRESSURE JACKETED TROUGHS

(d) *As shown in Figure 3.23.8(d)* Shallow curved trough plates shall be calculated as flat surfaces throughout, and shall be provided with stay-bolts in accordance with Clause 3.16.

3.24 VESSEL SUPPORTS

3.24.1 General Vessels shall be so supported and the supporting members arranged, or attached to the vessel wall, or both, in such a way as will withstand the maximum imposed loadings (see Clause 3.2.3), without causing excessive localized stresses and deformations in the vessel wall and instability of the vessel.

Supports shall be designed to allow for movement of the vessel wall due to thermal and pressure changes, and also for the possibility that highest stress may occur in some vessels under hydrostatic tests before pressure is applied. Care shall be taken that the temperature gradients in external structures immediately adjacent to the shell do not produce stresses in excess of those laid down as permissible. If necessary, lagging should be applied to limit the temperature gradient to a value producing acceptable stresses.

Full details for the design of supports and attachments are not given because they involve many variables, such as the size, weight, service temperature and pressure, the arrangement of the supporting structure, and any piping, or the like, attached to the vessel. Where the proposed supports depart from normal or proven practice or reasonable doubts exist as to their suitability, the design shall be assessed by detailed analysis, e.g. in accordance with Clause 3.1.3 or with BS 5500. The stresses so determined shall comply with Clause 3.3.1.1.

NOTE: U.S. Welding Research Council Bulletin No 107, *Local Stresses in Spherical and Cylindrical Shells due to External Loading*, provides a method for assessment by detailed analysis.

Typical vessel supports are shown in Figure 3.24. See Clause 3.26.10 for supports for transportable vessels.

3.24.2 Supporting members The design of supporting members (including brackets, columns, etc,) and anchors shall conform to good structural practice.

Steel supports which do not form part of the vessel shall comply with AS 3990 or AS 4100. Reinforced concrete supports shall comply with AS 3600.

Suitable means shall be provided to prevent corrosion between the vessel wall and the supporting members. Fire-resistant supports shall be used in environments where fire hazards may occur and also for a vessel with flammable content.

Substantial foundations shall be provided so as to withstand the maximum imposed loading (see Clause 3.2.3) and to prevent subsidence or settling which may result in excessive loading of the vessel.

3.24.3 Supports for vertical vessels

3.24.3.1 *Bracket support* (See Figure 3.24(a)). Where vertical vessels are supported by brackets or lugs attached to the shell, the supports under the bearing surfaces shall be as close to the shell as clearance for any insulation will permit. The choice between a number of brackets and a ring girder will depend upon the conditions for each individual vessel.

3.24.3.2 *Column support* (See Figure 3.24(b)). Vertical vessels supported on a number of posts or columns may require bracing or stiffening by means of a ring girder, internal partition or similar device, to resist the forces tending to buckle the vessel wall.

3.24.3.3 *Skirt support* (See Figure 3.24(c) and (d)). Vertical vessels may be supported on cylindrical or conical skirts which attach to the cylindrical portion of the vessel and this method is recommended for large vessels. Openings in the skirt (see Clause 3.24.8) shall be reinforced if necessary.

A3 Where the product of a skirt diameter (millimetres), thickness (millimetres), and temperature at the top of the skirt above ambient (°C) exceeds 16×10^6, account shall be taken of the discontinuity stresses in both skirt and vessel induced by the temperature gradient in the upper section of the skirt. Skirts shall be designed to avoid buckling, and otherwise comply with the requirements of Clause 3.7.5.

Skirts shall have a half apex angle (α) not greater than 30 degrees.

NOTE: Where the actual thickness is less than twice the minimum thickness, openings should be properly reinforced. Further, where the opening exceeds the size specified in Clause 3.18.4.1, the skirt should be subject to special analysis.

3.24.3.4 *Stool support* (See Figure 3.24(e)). Vertical vessels may be supported on stools. Stools shall be designed in accordance to Clause 3.24.3.3 with particular attention given to the stresses in the end at the attachment where a decrease in the stool diameter will increase the unit reaction load normal to the end surface. The design of the vessel and stool shall consider the worst combination of design and super imposed loads expected in service (see Clause 3.2.3) and during the initial hydrostatic testing, consideration should also be given to future hydrostatic testing on location.

3.24.4 Support for horizontal vessels (See Figures 3.24(f) and (g)) Horizontal vessels may be supported by means of saddles, equivalent leg support, ring supports or suspension members. Vessels exceeding 1 m diameter shall be provided with saddle supports subtending at least 120° shell circumference continuously or shall be supported by other means proven to be suitable by analysis (see Clause 3.24.1).

Supports should be as few as possible, preferably two in the length of the vessel. Where this is not practicable, provision shall be made to ensure suitable distribution of load. The vessel may be stiffened where necessary by stiffening rings at intermediate sections.

With thin-walled vessels, vacuum vessels, or with large horizontal storage vessels which may distort excessively due to the vessel weight when internal pressure nears atmospheric, consideration shall be given to the placing of supports near the ends of the vessel or using ring supports, stiffeners or other reinforcements to prevent stresses in the shell in excess of those permitted and to avoid excessive distortion.

Ring supports shall be calculated by the following equation:

$$f = \frac{K_1 W' R}{Z} + \frac{K_2\, W'}{A_s} \qquad \text{. . . 3.24.4}$$

where

A_s = cross-sectional area of the section

f = design strength at calculation temperature, in megapascals (Table 3.3.1)

W' = load acting on one ring, in newtons

R = radius of the ring measured to the neutral axis, in millimetres

Z = section modulus of the cross-section of the ring support, in millimetres to the third power; in the calculation of Z and R a part of the shell may be included having an effective length, L_s, as defined in Clause 3.9

K_1, K_2 = factors dependent on half of the included angle of the supports θ (see Figure 3.24(g) and Table 3.24.4).

Welds attaching ring supports to the vessel shall have a minimum leg length no less than the thickness of the thinner of the shell and the web of the ring.

TABLE 3.24.4

ANGLE FACTORS FOR RING SUPPORT

Angle θ°	K_1	K_2
30	0.075	0.41
35	0.065	0.40
40	0.057	0.39
45	0.049	0.38
50	0.043	0.37
55	0.039	0.36
60	0.035	0.35
65	0.030	0.34
70	0.025	0.32
75	0.020	0.31
80	0.017	0.29
85	0.015	0.27
90	0.015	0.25

3.24.5 Supports for vessels subject to external pressure Vessels subject to external pressure shall be supported through the medium of a substantially continuous ring or equivalent means to limit distortion.

NOTE: Concentrated loading on shell or ends of such vessels may cause deformations which seriously reduce the buckling resistance of the vessel.

3.24.6 Supports for jacketed vessels Where vessel supports are attached to the jacket, consideration shall be given to the transfer of the supported load of inner vessel and contents.

3.24.7 Attachment of supports Where supports are attached to vessels, the attachment shall be in accordance with Clause 3.25 and shall be located to leave all circumferential welds clear for inspection unless otherwise approved.

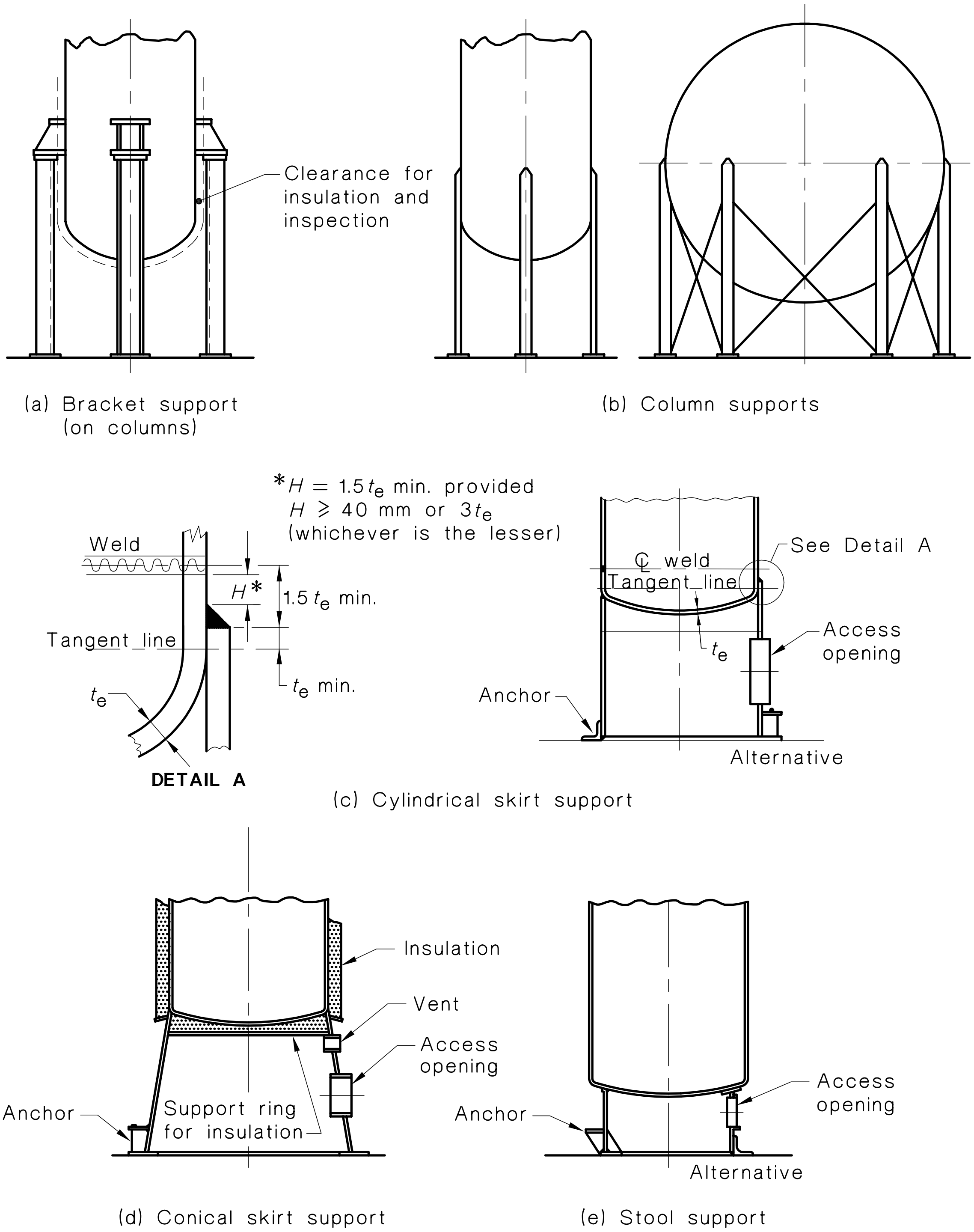
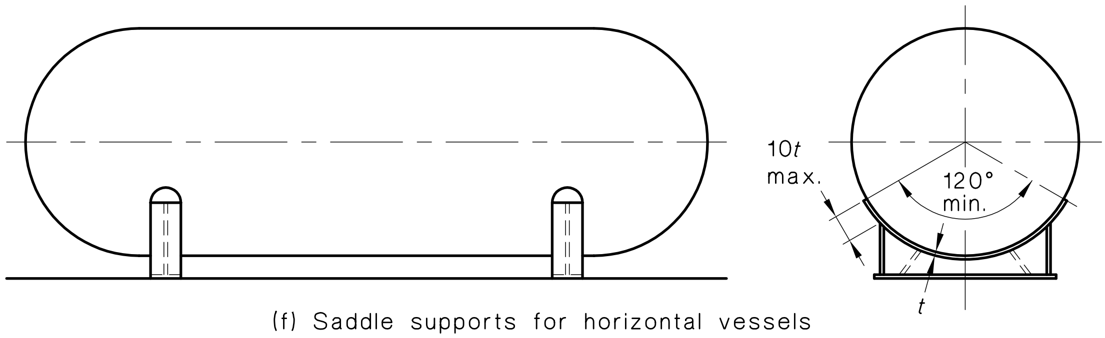
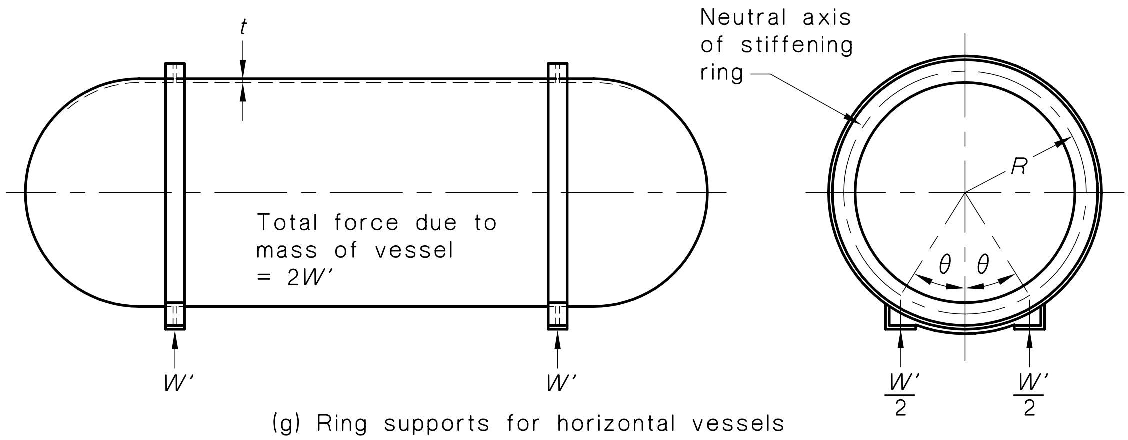


FIGURE 3.24 (in part) SOME TYPICAL VESSEL SUPPORTS



(f) Saddle supports for horizontal vessels



(g) Ring supports for horizontal vessels

FIGURE 3.24 (in part) SOME TYPICAL VESSEL SUPPORTS

Attachments to pressure vessels with directly mounted reciprocating machines shall be designed and installed in such a manner as to avoid fatigue cracking at such attachments. Where vibration from any source may induce fatigue failure in the pressure parts of a vessel at the attachment of the vessel supports or equipment (e.g. air compressors) mounted on the vessel, provision shall be made to adequately distribute the load of the attachment. Where doubling plates are used they shall comply with Clause 3.26.10.2.

3.24.8 Access for inspection Supports shall be designed to facilitate inspection of the vessel. Openings shall be made in the sides of skirts or stools if the bottoms are not readily visible through the supporting structure. Saddle supports not seal welded shall be designed to permit inspection of the shell wall on the saddle.

3.25 ATTACHED STRUCTURES AND EQUIPMENT

3.25.1 Structures–general Internal and external non-pressure structures and fittings attached to the vessel shall be designed in accordance with good engineering practice and shall be arranged as far as practicable without imposing local concentrated loads on the vessel wall. Loads from attached structures, equipment and fittings, should be carried by means of suitable stiffeners and/or spacers, directly to the vessel supports and thus to the foundations without stressing the vessel walls or ends, and where this is not practicable, shall be supported in accordance with Clause 3.24. For attachments to transportable vessels see Clause 3.26.14.

Lugs, rings, brackets, and the like, should be designed so as to drain water away from, rather than towards, any insulation attached to the vessel. Pockets or crevices which could trap liquid and cause corrosion should be avoided.

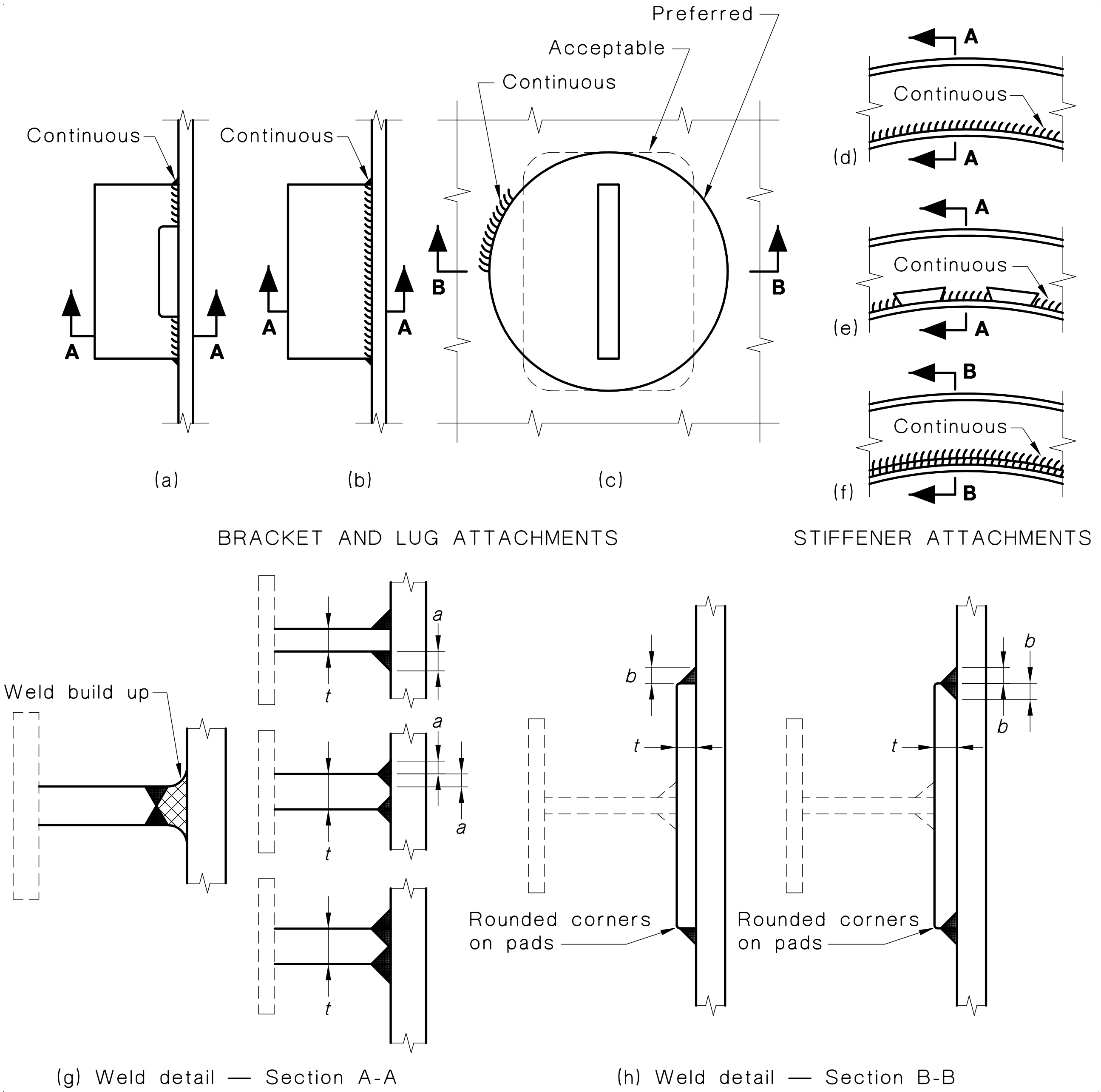
3.25.2 Internal structures Internal structures shall be designed to prevent failing in service, and should rest on top of their supports in preference to being suspended from them. Such structures and supports shall be constructed of material corrosion-resistant to their environment, or provided with additional metal where corrosion is expected. For structures which can be readily replaced the corrosion allowance need not be the same as for the vessel.

3.25.3 General method of attachment Lugs, clips or supports for structures, lining, insulation, operating equipment and piping may be attached to the inside or outside of the vessel provided that allowance has been made to prevent excessive stresses or distortion in the vessel wall under all service conditions. Lugs, clips and supports welded to the vessel wall shall be of sufficient size to prevent over-stressing and should be not more than twice the wall thickness.

Resistance welded studs may only be used for non-pressure attachments to pressure parts and by agreement with the parties concerned.

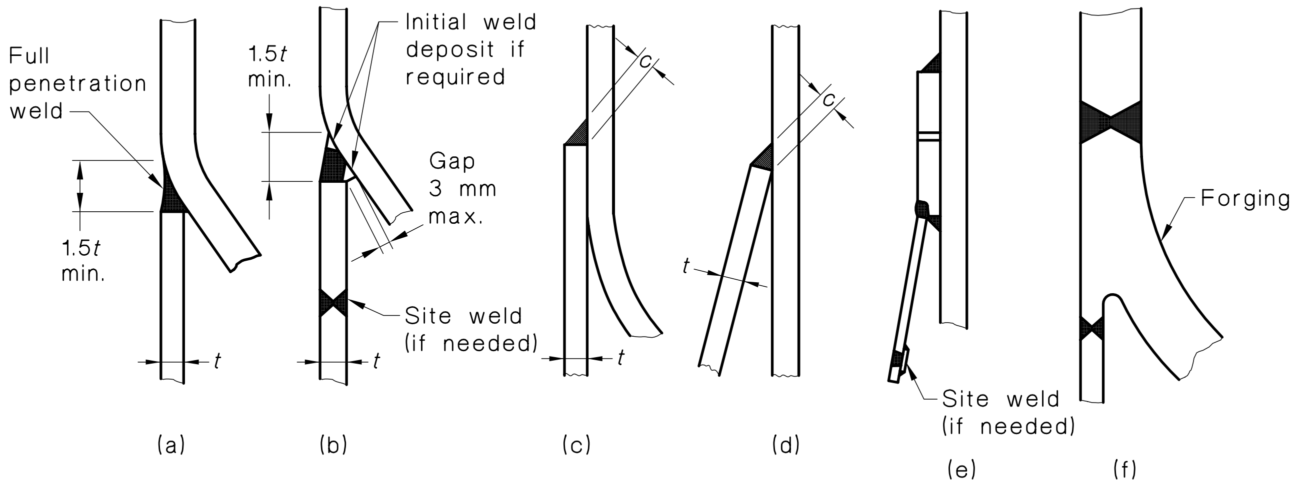
Welded attachments shall be designed in accordance with Clause 3.5 and Figure 3.25(A) and (B), with attachment weld strength determined in accordance with Clause 3.19.3.5. Where practicable, all welds, particularly to pressure parts, shall be continuous. See AS 4458 for welding of attachments.

For clad construction when attachments are made to cladding and not directly to the base metal, it shall be demonstrated that the bond between the cladding and the base metal is adequate for the loads and complies with other relevant requirements of this Standard.



NOTES: a≥ t/4; b≥ t/2 where t = thickness of attached member.

FIGURE 3.25(A) BRACKET, LUG AND STIFFENER ATTACHMENT



NOTE: c≥ t where t = thickness of attached member.

FIGURE 3.25(B) SKIRT SUPPORT ATTACHMENT

3.26 TRANSPORTABLE VESSELS

3.26.1 General The design of transportable vessels shall within the limits of Clause 1.3 comply with the requirements of this Standard and the additional requirements given in this Clause (3.26). The design shall also satisfy such additional requirements as are imposed by the relevant equipment or application Standards and the purchaser. (See Appendix E.)

NOTE: This Clause is concerned only with those basic requirements of a transportable vessel which pertain to its performance as a pressure vessel and includes its immediate attachments. This Standard is not concerned with those particular requirements relating to its performance as a vehicle for which the specific requirements are covered in relevant application Standards (e.g. AS 2809.1, AS 2809.3, AS 2809.4 and AS 2809.6).

3.26.2 Types and application Transportable vessels are pressure vessels designed for the transport of fluids under pressure and for the purpose of this Standard include the following types:

(a) *Road tanker vessels* These are vessels designed to be permanently mounted on or form an integral part of a road vehicle.

(b) *Rail tanker vessels* These are vessels which form part of a rail tank wagon, and are designed to be permanently mounted on an underframe on bogies or alternatively the vessel itself may form a structural part of the wagon.

(c) *Portable vessels* These are vessels which are designed in such a manner as to permit them to be moved (normally by road or rail) to various locations. Such vessels also include those which are fitted with suitable steel ‘runners’ or ‘skids’ and are generally known as ‘skid or demountable tanks’.

(d) *Tank shipping containers* These are vessels also designed, manufactured, tested and inspected in accordance with AS/NZS 3711.6 and contained in a Standard frame for multi-modal transport (sea, rail and road).

NOTE: Compliance with the IMDG Code may result in vessels thinner than this Standard.

Vessels which are used for the transport of material under no pressure but which are subject to pressure on discharge of contents may be regarded as static vessels, except that the design and manufacture of supports and attachments to the pressure parts shall comply with the requirements for transportable vessels.

3.26.3 General design

3.26.3.1 *Class of construction* Transportable vessels shall be constructed to Class 1 requirements except as follows:

(a) Class 2A construction may be used for—

(i) portable, LPG vessels not exceeding 8000 L capacity; or

(ii) transportable vessels with non-lethal fluid and with pressure times volume not exceeding 10 times that permitted for transportable vessels of hazard level C to AS 3920.1.

(b) Class 2 construction may be used for transportable vessels not exceeding 5000 L capacity with non-harmful fluid (see AS 3920.1).

(c) Relief valves shall be sized in accordance with Section 8 with particular reference to the integrity of insulation in accidents and under fire conditions (see Clause 8.2.2.2).

Arrangements shall be made to protect the relief valves from damage caused by the tanker overturning.

3.26.3.2 Design pressure Single-wall uninsulated transportable vessels and associated pressure parts shall have a design pressure not less than that specified in the application Standard and where this is not specified the greater value of—

(a) 700 kPa; and

(b) the vapour pressure of the fluid at the maximum fluid service temperature determined from AS 2872 (or if desired, the vapour pressure at 50°C for vessels with a capacity greater than 500 L and at 46°C for vessels with capacity greater than 2000 L).

For fully insulated transportable vessels with substantial external protection the design pressure shall be not less than the greater of—

(i) 170 kPa; and

(ii) the vapour pressure at the maximum service temperature of the fluid normally determined by the set pressure of the pressure relief device.

3.26.3.3 *Openings* No openings shall be provided on the outside circumference of the cylindrical shell within an area of 30° above the horizontal centre-line, unless provided with a recess. The recess shall ensure that all pressure relief valves and other fittings lie within the outline of the cylindrical shell as protection from damage in a roll over.

Vessels for chlorine or more toxic substances shall have only one manway. The manway opening and closures to openings shall lie within the outside vessel envelope.

3.26.3.4 *Loadings* Transportable vessels, supports and attachments shall be designed to withstand the loadings in accordance with Clause 3.2.3 and the following:

(a) *Road tanker vessels*—loadings in any direction equal to twice the force due to the mass of the vessel together with its attachments and contents, when filled to the maximum permissible loading and also the loadings in Clause 3.26.3.7.

(b) *Rail tanker vessels*—loadings due to shunting, and rail service as specified by the rail authority (Railways of Australia Committee).

(c) *Portable vessels (excluding skid tanks)*—loadings in any direction equal to twice the force due to the mass of the vessel together with its attachments and contents, when filled to the maximum permissible loadings and also loadings in Clause 3.26.3.7.

(d) *Skid tanks*—loadings in any direction equal to four times the force due to the mass of the vessel together with its attachments and contents, when filled to the maximum permissible loading.

(e) *Shipping containers*—loadings specified in AS/NZS 3711.6.

3.26.3.5 *Structural integrity* This Clause covers stresses which act over the entire cross section of the vessel and thus specifically excludes local stresses which are covered in Clause 3.24.

The maximum membrane stress calculated at any point in the vessel under this Clause shall not exceed that listed for the material in Clause 3.3.1.1. Alternatively test or analytical methods or a combination thereof, may be used if the methods are accurate and verifiable.

Corrosion allowance shall be added to the design minimum thickness.

3.26.3.6 *Calculation* Calculation shall allow for the combined effect of pressure loadings (both circumferential and longitudinal stresses), torsion, shear, bending and acceleration of the vessel as a whole (both forward and rearward). Consideration shall be given to the effects of thermal gradients and fatigue.

The vessel design shall include calculation of membrane stresses generated by design pressure, the weight of contents, the weight of structure supported by the vessel wall and the loadings specified in Clause 3.26.3.4 and the effect of temperature gradients resulting from vessel contents and ambient temperature extremes. When dissimilar materials are used, their thermal coefficients shall be used in calculation of thermal stresses. See Clause 3.26.10.1 for stresses which occur at pads, cradles or other supports.

A3 **3.26.3.7** *Combined stresses* The equivalent stress from static or dynamic loads listed below, or a combination thereof that can occur at the same time, is given by the following equations:

$$S_E = \frac{(S_c + S_l)}{2} \pm \sqrt{\left(\frac{S_c - S_l}{2}\right)^2 + S_s^2} \quad \ldots 3.26.3.7(1)$$

where $S_l = S_c/2 \pm S_b$ (longitudinal stress) . . . 3.26.3.7(2)

$S_s = 2Q/\pi D_m^2 t$ (shear stress) . . . 3.26.3.7(3)

and the value of—

S_E, S_c and $S_l \leq \eta f$ . . . 3.26.3.7(4)

When S_c and/or S_l are compressive (negative), these shall be limited as per Clause 3.7.5.

For the purpose of this Clause, refer to Clauses 3.7.2 and 3.7.5 for notation and equations, except that the force due to the mass shall be incorporated in the bending moment, *M*.

The equivalent stress shall be evaluated at any point for the following loading conditions:

(a) The circumferential stress generated by internal or external pressure (or both).

(b) The longitudinal tensile stress generated by internal pressure.

(c) The tensile or compressive stress generated by the axial load resulting from a decelerative force equal to twice the static weight of the fully loaded vessel applied independently to suspension assembly at the road surface.

(d) The tensile or compressive stress generated by the bending moment resulting from a decelerative force equal to twice the static weight of the fully loaded vessel applied independently to each suspension assembly at the road surface.

For vessels with internal baffles, the decelerative force may be reduced by ‘0.25g’ for each baffle assembly, but in no case may the total reduction in decelerative force exceed ‘1g’.

(e) The tensile or compressive stress generated by the axial load resulting from an accelerative force equal to the static weight of the fully loaded vessel applied to the horizontal pivot of the fifth wheel supporting the vessel, if used.

(f) The tensile or compressive stress generated by the bending moment resulting from an accelerative force equal to the static weight of the fully loaded vessel applied to the horizontal pivot of the fifth wheel supporting the vessel, if used.

(g) The tensile or compressive stress generated by the bending moment produced by a vertical force equal to three times the static weight of the fully loaded vessel.

(h) The shear stress generated by a vertical force equal to three times the static weight of the vessel and contents.

(i) The lateral shear stress generated by a lateral accelerative force which will produce an overturn but not less than 0.75 times the static weight of the fully loaded vessel, applied at the road surface.

(j) The torsional shear stress generated by a lateral accelerative force which will produce an overturn but not less than 0.75 times the static weight of the fully loaded vessel, applied at the road surface.

3.26.4 Materials

3.26.4.1 *General* For materials see Clause 2.5.3 for suitability with contents and Clause 2.6 for provision against brittle fracture.

Material for pads shall be the same material group, as for the vessel to which they are attached.

Where low melting point materials are used for flammable products the following conditions shall be met:

(a) The vessel, including manholes and branches, shall be insulated with a material agreed between the parties concerned.

(b) The applied insulation shall have a thermal conductance at 900°C temperature difference of not more than 0.43 W/m^2K.

(c) The entire insulation shall be covered with a weather-tight steel jacket at least 3mm thickness.

(d) The interior surface of the jacket shall be corrosion resistant or protected against corrosion.

3.26.4.2 *Material for vessels with lethal (see Clause 1.7.1) and very toxic (e.g. chlorine, sulfur dioxide and ammonia) contents* Chlorine vessels shall be constructed of carbon-manganese fine grain steel plate with impact test requirements in both the longitudinal and transverse direction at a temperature of minus 40°C and energy values to be met shall be in accordance with Table 2.6.2.

Sulfur dioxide vessels shall be constructed of carbon-manganese fine grain steel.

A vessel in anhydrous ammonia service shall be constructed of steel. The use of copper, silver, zinc or their alloys is prohibited. Baffles made from aluminium may be used only if joined to the tank by a process not requiring postweld heat treatment of the tank. Compliance with AS 2022 is required.

3.26.4.3 Minimum thickness The minimum thickness of single wall vessels not covered by other standards shall be 5mm for goods classified as dangerous in the Commonwealth of Australia—Navigation Act—Classified List of Dangerous Goods and in accordance with Clause 3.4.3 for goods not so classified. For vessels with the wall thickness less than 10 mm, circumferential reinforcement shall be assessed in accordance with Clause 3.9 for full vacuum design. For vacuum-insulated (double wall) vessels the minimum thickness of each wall shall be in accordance with Clause 3.4.3.

In chlorine and sulfur dioxide vessels the minimum wall thickness including corrosion allowance shall be at least 15 mm.

3.26.5 Corrosion allowance A vessel subject to thinning by corrosion, erosion or mechanical abrasion due to the contents, shall be protected by providing the vessel with a suitable increase in material thickness (see Clause 3.2.4).

For chlorine and sulfur dioxide vessels a corrosion allowance of 20% of minimum calculated thickness or 2.5 mm, whichever is less, shall be provided.

3.26.6 Welds Welded longitudinal joints in the shell shall be located in the upper half of the vessel. No welding, other than that of attachments to pads provided for that purpose, shall be performed on the vessel after final heat treatment.

3.26.7 Heat treatment All transportable vessels except those constructed from high alloy steels or non-ferrous materials or of Class 2 construction shall be postweld heat treated in accordance with AS 4458.

3.26.8 Protection against damage The design, manufacture or installation (or both) of transportable vessels shall minimize the possibility of damage.

The strength of the attachment of appurtenances to shells, ends or mounting pads, shall be such that when force is applied to the appurtenance (as mounted and normally equipped) in any direction except normal to the vessel shell or within 45 degrees thereof, the attachment shall fail completely without such damage occurring to the shell or end as would affect the product-retention integrity of the vessel.

All structural and non-pressure attachments to the shell, ends, or mounting pads, such as stiffening rings, lifting lugs, baffles, rear bumper and overturn protection, shall comply with the requirements of this Clause (3.26).

All closures for filling, emptying, inspection or other openings shall be protected by enclosing these fittings within the outline equal to the diameter of the vessel or dome attached to the vessel or by guards (see Clause 3.26.12), or by suitable emergency internal valves and a shear section outboard of the valve. Manholes in the ends of a vessel need not meet these requirements.

3.26.9 Stability and clearances The stability and clearances of a road or rail tanker shall be adequate to ensure safe transport and shall comply with the requirements of the appropriate authorities concerned (e.g. motor transport authorities and railway departments). The minimum road clearance of the vessel or a protective guard located between any two adjacent axles on a vehicle, shall comply with AS 2809.1 and the Australian Design Rules for Vehicles.

Ground clearance for portable vessels shall be at least 50 mm.

3.26.10 Vessel supports

3.26.10.1 *General* In addition to meeting the applicable requirements of Clauses 3.24 and 3.25 supports for transportable vessels shall be designed to resist the appropriate forces (see Clauses 3.2.3 and 3.26.3.4) and meet the following requirements:

(a) Vessels which constitute in whole or in part the stress-members used in lieu of a frame shall be supported by external saddles subtending at least 120 degrees of the shell circumference continuously or by other means demonstrated to have equivalent impact and fatigue performances. Alternatively the design shall satisfy Clause 3.1.3.

(b) Local stresses developed in the shell or ends at saddles due to shear, bending and torsion shall be calculated in accordance with the recommended methods of calculation of stresses for local loads in BS 5500, or alternatively the design shall satisfy Clause 3.1.3. Stresses shall be limited to those given in Clause 3.3.1.

(c) Vessels which are not constructed integrally with or not welded directly to the frame of the vehicle, shall be provided with turn-buckles or similar positive devices for the drawing the vessel tightly to the frame. In addition, suitable anchors or stops shall be attached to the frame or the vessel (or both) to prevent relative motion between them due to stopping, starting or change of direction. Devices for drawing-down the vessel shall secure the vessel to the vehicle in a safe manner that will not introduce excessive stress in the vessel.

(d) Stresses developed at components of supports, anchors, stops and the like, shall be calculated and limited to those given in Clause 3.3.1.

(e) The 'g' loadings shall be applied through the vessel centre line and shall be assumed to be uniformly distributed.

3.26.10.2 *Pads* Vessel supports and anchor points permanently attached to the vessel wall (see Clause 3.26.3.5) should be attached by means of pads which should be of the same material as the vessel wall.

Pads shall—

(a) have thickness not exceeding 1.5 times the thickness of the shell or head and not less than 5mm (the throat thickness of the fillet weld joining pad to vessel shell shall be not more than the shell thickness);

A2 (b) extend at least 4 times its thickness in each direction beyond the toe of the weld attaching the support;

(c) have its corner rounded to a radius equal to at least four times the thickness of the pad;

(d) have weep or tell-tale holes, drilled or punched before attachment to the vessel and subsequently filled to prevent ingress of moisture, in accordance with Clause 3.19.3.4;

(e) be attached to the vessel by continuous fillet welding;

(f) be designed so that firstly the attachment of the appurtenance to the pad, and secondly the pad, will fail completely without damage to the shell or end; and

(g) be located clear of the main joints of the vessel (see Clause 3.5.1.3).

3.26.10.3 *Lugs* Support, holding down or lifting lugs may be integral with the doubling or mounting pads on portable vessels.

3.26.11 Rear impact protection Each tanker shall be provided with a system of bumpers or barriers (or both) to protect the vessel from rear impact and underrun in accordance with AS 2809.1.

3.26.12 Guards for vessel fittings When guards are required to protect vessel fittings from damage which would result in leakage of the contents in the event of over-turning of the vehicle, they shall be designed and installed to withstand a vertical force equal to twice the force due to the mass of the loaded vessel without allowing application of force to the fitting, and a horizontal force in any direction of half the force due to the mass of the loaded vessel. These design forces may be considered individually. The maximum calculated stress shall not exceed 75% of the tensile strength of the material basis.

3.26.13 Lifting lugs Lifting lugs or eyes for a portable vessel shall be designed to permit safe lifting of the vessel. Each lug of a portable vessel shall be designed to withstand a static force in any direction equal to twice the force due to the mass of the vessel and its contents.

3.26.14 Attachment of structures The attachment of structures to the walls of transportable vessels shall meet the requirements of Clause 3.25 and other requirements of this Clause 3.26. They shall be designed to avoid fatigue.

Lightweight attachments such as a conduit clip, brakeline clip or placard holder shall—

(a) be constructed of a material of lesser strength than the vessel wall material;

(b) not be more than 70% of the thickness of the material to which it is attached.

The attachment may be secured directly to the vessel wall if the device is designed and installed in such a manner that, if damaged, it will not affect the lading retention integrity of the tank.

Major load-carrying structures such as supports, lifting lugs, bumpers, baffles and surgeplates and those structures which may induce fatigue forces into the shell, shall be attached by pads and shall meet the other requirements of Clause 3.25 and this Clause 3.26.

3.26.15 Pressure relief valves Pressure relief valves shall be sized in accordance with Section 8 with particular reference to the integrity of insulation in accidents and under fire conditions (see Clause 8.2.2.2) and shall comply with the relevant application Standard. Arrangements shall be made to protect the relief valves from damage caused by the vessel overturning.

3.27 QUICK-ACTUATING CLOSURES

A3 **3.27.1 Types of closures** Quick-actuating closures, also designated as quick-opening closures, are closures designed for more rapid opening and closing than closures of the multi-bolted type. Most quick-actuating closures are within the following classifications:

(a) Interlocking lug-type closures, with load-bearing lugs on the door engaging/disengaging with lugs on the shell or a ring on the shell by part rotation of one set of lugs.

(b) Expanding or contracting ring-type closures, where the holding is by a ring connecting the door to the vessel.

(c) Clamp-latch-type closures, using multiple clamps to connect the door to a flange on the vessel. May incorporate type (b) rings.

(d) Bar-locking-type closures, where multiple bars are actuated simultaneously to connect the door to the vessel.

(e) Single swing bolt-type, beam and yoke closures, where the closure is retained by a bridge or equivalent across the closure with a retaining device such as a latch or swing bolt. The closure door may function as the beam.

(f) Sliding-type closures, where the door is retained by guides and opens in the same plane as the vessel opening face.

NOTE: Internally fitted doors of the type covered by Clause 3.15.5 are not covered by this Clause (3.27).

3.27.2 Design requirements Many types of quick-actuating closures are available and it is not practicable to write detailed requirements for each or to prevent the circumvention of safety devices. Where such closures and their appurtenances are used, the following requirements and recommendations apply to their design and installation, with the exception of swing bolt closures of Clause 3.27.3:

(a) The holding elements (see Note) shall be designed so that failure of any one holding element cannot result in the release or failure of all the other holding elements. A single bridge or yoke-type holding element with external closure may be used for openings having an internal cross-sectional area not exceeding 0.25 m^2.

A3 NOTE: Holding elements are those elements which hold the closure to the vessel and resist the end pressure and closure force, e.g. lugs, levers and bridges.

(b) Locking elements shall be provided where applicable (see Note).

NOTE: Locking elements are those elements which lock the holding elements firmly in position while the vessel is under pressure.

(c) The locking arrangement shall be designed so that failure of any one of the locking elements does not result in the release of the closure under pressure.

(d) The closure shall be arranged so that it can be determined by visual external inspection that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

(e) The closure, its holding elements, and locking elements shall be of a type that requires all parts to be fully engaged before pressure can be built up in the vessel.

(f) Pressure tending to force the closure clear of the vessel shall be reduced to a low value (see Note) before the holding elements can be operated, and shall be reduced to atmospheric pressure before the closure can be fully opened.

The closure shall not open suddenly in one stroke. The initial opening action shall be such as to ensure that there is sufficient time to allow all pressure to be released before the holding elements are fully disengaged, e.g. by initially developing a gap of approximately 3 mm between the closure and the vessel, or by other equivalent means as appropriate for the type of closure.

NOTE: The following Equation may be used to estimate the value to which the pressure should be reduced before disengagement of the holding elements can be started:

$$P = \frac{1.30 \times 10^6}{D^2} + 7$$

where

P = maximum pressure in vessel before holding elements can be operated, in kilopascals

D = inside diameter of opening, in millimetres

(g) Where compliance with Items (e) and (f) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed. Pressure gauges and pressure switches shall not suffice for this requirement.

(h) A closure with several holding elements shall have locking elements dimensioned and fitted so that during operation individual holding elements are uniformly engaged.

(i) Holding and locking elements shall be able to withstand all forces and moments encountered during closure and subsequent operations.

(j) The design strength for elements shall be the same as permitted for the design of flanged joints (see Clause 3.21).

(k) Holding and locking elements and other parts shall have adequate allowance for corrosion and wear.

(l) Seals and gaskets shall provide leak-tightness acceptable to the parties concerned when the cover is in the closed and locked position. For vessels containing lethal or flammable fluids, leak-tightness shall be ensured by the adoption of appropriate special measures.

A3 Seals and gaskets shall be positively separated from the closure faces before the holding elements can be fully released. Where adherence of contents or other matter retards free disengagement of the seal, positive mechanical means shall break the seal prior to full release of holding element(s).

(m) Surfaces which are to be handled during the opening operation should have a temperature not exceeding 55°C for metal or 60°C for heat-insulating material.

(n) When installed, vessels having quick-actuating closures shall be provided with a pressure-indicating device visible to the operator from the closure-operating area. Additional warning devices, whether audible or visible, are not prohibited, but shall not be considered as satisfying any of the foregoing requirements.

(o) Manually operated closures shall be provided with an audible or a visible warning device which shall set off an alarm to the operator if an attempt is made to pressurize the vessel when the holding elements are not fully engaged, or if any attempt is made to disengage the locking elements while the vessel is pressurized.

(p) For Lethal Gases, or Very Harmful Gases, provision should be made for the gas to be purged prior to release of the seal.

3.27.3 Swing bolt closures Where covers with slots (or equivalent) are engaged by bolts which are released by pivoting clear of the cover the following requirements apply:

(a) The design shall prevent inadvertent or immediate release of the cover after loosening of any bolt.

(b) Single, two-bolt, and three-bolt closures shall—

(i) have pressurized areas not exceeding 0.125 square meters; and

(ii) be used only for vessels of hazard levels D or E (reference AS 4343).

(c) A minimum of four swing bolts shall be used on vessels for—

(i) lethal contents; and

(ii) very harmful contents, with hazard levels B or C (reference AS 4343).

(d) Pins on which the bolt swings shall be supported at each end, and be securely retained in the carrying lugs.

(e) Bending, shear and bearing stresses in the pins shall comply with Section 3.3.

(f) Washers, if provided, shall have minimum thickness of 0.25 × nominal bolt diameter.

(g) Each nut (or washer if fitted), shall seat into a recess or behind a barrier on the cover. The recess or barrier shall prevent swinging of the bolt until the nut has been loosened by the greater of 3 mm or 0.2 × nominal bolt diameter.

3.28 METALLIC EXPANSION JOINTS Metallic expansion joints shall comply with the requirements specified in the Standards of the Expansion Joint Manufacturers Association in ANSI/ASME BPV-VIII or equivalent Standard agreed by the parties concerned.

3.29 PRESSURE VESSELS FOR HUMAN OCCUPANCY The design, fabrication, inspection, and testing of pressure vessels for human occupancy shall comply with ANSI/ASME PVHO-1.

3.30 BURIED AND MOUNDED STORAGE VESSELS

3.30.1 Design conditions Buried and mounded storage vessels shall be designed and manufactured to Class 1 or 1H construction. The design pressure shall be at least the maximum pressure expected under all operating conditions and not less than that specified in the pressure equipment application Standard, e.g. AS 1596 The maximum design temperature shall be no less than 50°C. The minimum design temperature shall be the lower of 0°C, the minimum operating temperature or the temperature at which the contents are received. The fatigue life shall be based on a minimum of 1000 cycles.

3.30.2 Vessel support Buried or mounded storage vessels may be supported on saddles, or on a continuous sand bed supporting the vessel over it’s full length on a subsoil with little uneven settlement which may cause problems with connected piping and exert considerable stresses in the vessel wall.

3.30.3 Design loads Buried or mounded storage vessels will have additional loads caused by the mound and the method of support.

The earth mound and supports will cause bending moments, normal forces and shear forces in the vessel wall which may not be carried by the relatively thin vessel wall, especially in large diameter vessels. Then continuous internal stiffening rings should be considered.

The design of the vessel shall consider the effect of the following loads, and combinations thereof as applicable.

(a) The dead weight of vessel, contents and the effective earth mound assumed to be supported on top of the vessel.

(b) Live loads by machinery and equipment during installation, maintenance or during operation.

(c) Soil pressures and friction loads during expansion and contraction of the vessel and attachments caused by temperature and pressure variations. Special attention should be given to the non-uniform nature of the external soil pressures which will result in circumferential bending moments in the vessels wall.

(d) Local loads in vessel wall at nozzles and attachments.

(e) Buoyance forces. Special care shall be given to hold down bracket attachment to vessel with loads due to buoyancy of the empty vessel in fully flooded site condition.

(f) Earthquake loads for the vessel and contents in horizontal and vertical accelerations at the centre of the vessel with no support assumed from the mound to the vessel.

The design of the vessel shall consider the effect of the loads described above for the fully corroded vessel under full design conditions including vacuum if required by design, during shutdown and maintenance with the vessel empty and at atmospheric pressure, and during site hydrostatic testing if required.

3.30.4 Material The specified minimum tensile strength of the vessel shell shall not be greater than 500 MPa.

3.30.5 Pipe connections Buried vessels shall have pipe connections grouped together at the top of the vessel, preferably through a tower manway cover.

Mounded vessel may use grouped pipe connections located at one end of the vessel provided that connected pipelines are clear of restraints and infill material, e.g. by passing through ducting; and the vessel support nearest to the pipe connection end is fixed. The second support may need to be designed to accommodate axial movement due to expansion and contraction.

3.30.6 Nozzles No screwed connections or flanged joints shall be used buried. Nozzles shall be of integral construction with full penetration weld (see Figures 3.19.9 and 3.19.3B(f) to (k) for examples).

3.30.7 Corrosion allowance An internal and external corrosion allowance shall be assessed in accordance to Clause 3.2.4, but in no case less than 1.5 mm for the external surfaces of the vessel and its integral attachments.

3.30.8 Coating and cathodic protection systems Notwithstanding provision of corrosion allowance, an adequate coating system and a cathodic protection system shall be provided and satisfactorily tested prior to the vessel installation.

3.31 VESSELS OF NON-CIRCULAR CROSS-SECTION Vessels of rectangular cross-section shall be designed by—

(a) the method described in AS 1228, but with design strength from this Standard,

(b) by the design method in Appendix 13 of ASME BPV-VIII-1; or

(c) by an agreed similar area moment method. These methods may be used for vessels having an obround cross-section and vessels of circular cross-section with a single diametral stay plate.

Clause 3.1.3 may be used for other design methods.

3.32 FIRED PRESSURE VESSELS

3.32.1 Scope and application This Clause 3.32 specifies additional requirements for fired pressure vessels, i.e. vessels heated directly by fire, the products of combustion, electrical power or similar high temperature means such as focussed solar radiation or molten or high temperature metal e.g. cooling rolls.

It applies to fired heaters as defined in AS/NZS 1200, and includes fired process heaters, fired water heaters (i.e. water heated below 100°C), fired oil heaters, fired vaporisers, and similar fired vessels.

It does not apply to boilers as defined in AS/NZS 1200 (i.e. heating water or steam at above 100°C), nor to sterilizers, domestic hot water heaters and other equipment excluded by AS/NZS 1200, fired vats or other containers with a large vent area direct to atmosphere.

NOTE: Water heaters and other vessels with small vent pipes have exploded when vents are blocked.

3.32.2 Construction Standards

A3 **3.32.2.1** *General* Fired vessels shall be designed and manufactured in accordance with—

(a) the relevant requirements of this Standard;

(b) AS 1228, or equivalent, with suitable agreed provisions to cater for the particular heated fluid, when properties significantly different from water; or

(c) Clauses 3.32.2.2 to 3.32.2.6.

Marking with 'AS 1210' applies only where the design, manufacture and testing complies with AS 1210.

3.32.2.2 *Water heaters* Water heaters (including heaters for beverages and liquids predominantly of water) may alternatively comply with AS 1056.1, AGA/ALPG Code AG 102 for gas types, AS 3500.4, AS 3142, or equivalent Standard and capacity. Water

A3 heaters of hazard level E to AS 4343 or lower, may be made to good engineering practice but not necessarily to the full requirements of this Standard, i.e. where any one of the following apply:

(a) Of any pressure or volume but design temperature is less than 65°C.

(b) Of any volume but design pressure is less than 0.05 MPa and design temperature is less than 100°C.

(c) Of any pressure but volume less than 10 L and design temperature less than 100°C.

(d) Of any pressure and volume if product of design pressure and volume is less than 300 000 MPa L, and design temperature less than 90°C.

3.32.2.3 *Electrically heated calorifiers* Electrically heated calorifiers may alternatively comply with BS 853.

3.32.2.4 *Fired process heaters* Fired process heaters may alternatively comply with industry Standards.

3.32.2.5 *Fired LPG vaporizers* Fired LPG vaporizers may alternatively comply with AS 1596.

3.32.2.6 *Fired organic fluid and vaporizers* Fired organic fluid and vaporizers may alternatively comply with AS 1228.

3.32.3 Design features The design shall be in accordance with the relevant construction Standard and the following:

(a) For design temperature, see Clause 3.2.2.1.

(b) The class of construction shall be determined as for unfired vessels except for welded joints which are specified in Clause 3.32.5.

(c) For ferritic steel, the minimum corrosion allowance shall be 0.75 mm.

(d) Suitable provision shall be made for each of the following:

  (i) To limit thermal stresses and distortion arising from local or general differential heating or thermal expansion of parts.

  (ii) To avoid thermal cracking due to high local stress.

  (iii) To avoid thermal fatigue cracking due to cyclic temperature changes due to operational needs or unstable fluid flow.

  (iv) To limit thickness of parts exposed to high radiant heat e.g. 25 mm maximum for carbon steel.

3.32.4 Welded joints subjected to heating All longitudinal and circumferential joints subject to radiant heat shall be full penetration double welded. When these joints are not subject to radiant heat they may be single-welded with backing strip. Other joints e.g. at branches, stiffeners, attachments and supports shall be full penetration when subject to radiant heat and preferably full penetration when not subject to radiant heat.

Tube attachments shall provide good thermal contact preferably with a weld throat thickness at least equal to the tube thickness. Incomplete penetration welds, slip-on, socket-welding and threaded joints shall be limited to metal temperatures not exceeding 250°C.

Postweld heat treatment is required where the thickness at welded joints exceeds one half that thickness requiring postweld heat treatment in AS 4458.

3.32.5 Safety controls and devices Fired vessels shall be provided with pressure and temperature controls, energy input controls, level controls, flow controls, safety devices, valves and other fittings to—

(a) permit safe operation;

(b) effectively limit pressure to not more than 1.1 times the design pressure;

(c) limit the design temperature and fluid temperature to not more than the design value, except for short-term variation permitted by this Standard;

(d) control the risk of pressure explosion and electrical and fire hazards; and

(e) comply with the applicable requirements of Section 8.

3.32.6 Valves, gauges and other fittings Suitable fittings shall be provided to permit safe operation of the vessel and to comply with the relevant requirements of Section 8. See also AS 3653 for general guidance on valves, gauges and other fittings.

Vent pipes (or equivalent arrangements) for vessels with a design pressure exceeding 0.05 MPa due solely to static head, shall comply with each of the following:

(a) For water heaters have a vent size complying with Table 3.32.5.

(b) Be designed and sized to minimize fouling and prevent blockage or restriction which could cause excessive pressure.

(c) Be arranged to facilitate in-service checking for adequate venting.

(d) Have no valves in the vent between the vessel and the atmosphere.

NOTE: Inadequate venting has been a main cause of some serious explosions.

To avoid high thermal stress and fatigue for cyclically operated vessels, on/off (100% to 0%) energy control is not permitted for heat inputs greater than 1 MW.

TABLE 3.32.5

MINIMUM VENT SIZE FOR WATER HEATERS

Heat input **kW**	**Internal diameter of vent (see Note)** **mm**
<60	25
≥60 <150	32
≥150 <300	38
≥300 <600	50
≥600	Vent area (mm^2) equal to 3.5 times heat input (kW)

NOTE: Vents with equivalent cross sectional area may be used.

A2 **3.33 VESSELS WITH INCREASED DESIGN STRENGTH AT LOW TEMPERATURE** The use of design tensile strength greater than that in Table 3.3.1, for vessels operating at temperatures below 0°C, may be used provided the vessels meet the requirements given in the alternative rules of Part ULT ANSI/ASME VIII-1 for such vessels. (See also Clauses 3.2.2 and 3.3.3 for further requirements for design strength at low-temperature service.)

A2 **3.34 PLATE HEAT EXCHANGERS** Unless otherwise agreed by the parties concerned, plate heat exchangers shall be designed as follows:

(a) End plates in accordance with Clause 3.15.

(b) Bolting in accordance with Clause 3.21.5.

SECTION 4 MANUFACTURE

4.1 GENERAL

4.1.1 Requirements All pressure vessels and vessel parts of welded construction shall be constructed in accordance with this Section.

4.1.2 Manufacture and workmanship The manufacturer shall—

(a) fabricate the vessels in compliance with AS 4458;

(b) be responsible for the work carried out by his organization;

(c) conduct or have conducted all tests and inspections of materials, processes, welding personnel and procedures during the various stages of manufacture of a vessel; and

(d) ensure that tests and inspection are witnessed and are acceptable as required by this Standard.

For purchaser's requirements see Appendix E.

4.1.3 Competence of manufacturer The purchaser may require the manufacturer to demonstrate the adequacy of plant and personnel prior to acceptance of the manufacturer for work on vessels within the scope of this Standard.

4.1.4 Material identification and marking Material identification and marking shall be in accordance with Clause 2.4 and AS 4458.

4.2 WELDED CONSTRUCTION

4.2.1 General welding requirements Vessels and associated pressure parts fabricated by welding shall comply with the following requirements:

(a) All details of design and fabrication shall conform to the requirements of this Standard and AS 4458.

(b) All materials shall meet the requirements of Section 2.

(c) Welding shall be carried out by qualified personnel (Clause 4.2.2).

(d) Welding shall be carried out in conformity with the qualified welding procedure
A3 | (see AS/NZS 3992).

(e) Fabrication shall be in conformity with Clause 4.1.

4.2.2 Welding personnel

4.2.2.1 *Competence of welding supervisors* All welding shall be carried out under the supervision of a person who has had suitable training or experience in the form of fabrication and the process of welding used on the vessel, except where otherwise agreed. Such supervisor shall hold a welding supervisor's certificate in accordance with AS 1796, or have other acceptable qualifications or experience.

4.2.2.2 *Competence of welders* Each welder engaged in the welding of vessels or vessel parts shall meet the requirements specified.

(a) hold an appropriate welder's certificate in accordance with AS 1796; or

(b) have had training or experience in the particular welding process to be used.

In addition, each welder shall meet the specific welder qualification requirements in
A3 | AS/NZS 3992.

4.3 CLAD AND LINED CONSTRUCTION Vessels or parts of vessels constructed of integrally clad plate (i.e. plate having a corrosion-resistant material integrally bonded to a base of less resistant material) and those having applied linings (i.e. a corrosion-resistant lining intermittently attached to a base of less resistant material) shall comply with the appropriate requirements of this Standard and AS 4458.

4.4 NOT ALLOCATED

4.5 BRAZED CONSTRUCTION

4.5.1 General brazing requirement Vessels and associated pressure parts fabricated by brazing shall comply with the following requirements:

(a) All details of design and fabrication shall conform to the requirements of this Standard and AS 4458.

(b) All materials shall meet the requirements of Section 2.

(c) Brazing shall be carried out by qualified personnel (see Clause 4.5.2).

(d) Brazing shall be carried out in conformity with the qualified brazing procedure (see A3 AS/NZS 3992).

(e) Fabrication shall be in conformity with Clause 4.1.

4.5.2 Brazing personnel

4.5.2.1 *Supervisors, brazens and brazing operators* Brazing shall be carried out under adequate supervision and by brazens and brazing operators qualified in accordance with A3 AS/NZS 3992. Supervisors, brazens and brazing operators shall satisfy the requirements of AS/NZS 3992.

NOTE: Brazing operators are assigned to carry out brazing by automatic means or by furnace,, induction, resistance, or dip brazing.

4.5.2.2 *Identification* Each brazer and brazing operator shall be assigned an identifying number, letter or symbol by the manufacturer which shall be used to identify the work of that brazer or brazing operator.

4.5.2.3 *Record* The manufacturer shall maintain a sufficient record of the brazens and brazing operators employed by him showing the date and results of tests and the identifying mark assigned to each. These records shall be certified by the manufacturer and shall be accessible to the Inspectors.

4.6 FORGED CONSTRUCTION Each vessel or other pressure part constructed by forging shall comply with the relevant requirements of the forging material specification, this Standard and the requirements of AS 4458.

4.7 CAST CONSTRUCTION Each vessel or other pressure part constructed by casting shall comply with the relevant requirement of the casting material specification, this Standard and the requirements of AS 4458.

SECTION 5 TESTING AND QUALIFICATION

5.1 GENERAL

5.1.1 Scope of section This Section 5 specifies requirements for the qualification of welding and brazing procedures and personnel, for production testing, and for non-destructive examination and pressure tests.

5.1.2 Responsibilities and facilities for testing and inspection The manufacturer shall be responsible for—

(a) conducting or having conducted all qualifications and tests specified in this Section;

(b) providing the labour and appliances necessary for such tests and inspection as required;

(c) such additional checks as may be agreed between the parties concerned; and

(d) giving reasonable notice to the inspection body and purchaser, as agreed between them, or when the pressure vessel will reach a stage at which inspection is required.

5.2 WELDING AND BRAZING QUALIFICATION AND PRODUCTION TEST PLATES

A3 **5.2.1 Welding and brazing procedure** Each welding and brazing procedure and each welder and brazer shall be qualified in accordance with AS/NZS 3992.

5.2.2 Welded production test plates

A2 A3 **5.2.2.1** *General* Welded production test plates representative of the completed vessels shall be prepared and tested to check the quality of welds in Class 1 and Class 2A vessels except for welds listed below:

A3 (a) Welds which comply with a prequalified welding procedure of AS/NZS 3992 where the maximum product thickness is 20 mm and the MDMT is warmer than 0°C.

(b) Welds in group K materials with a maximum product thickness of 10 mm.

The relaxations in Items (a) and (b) do not apply to Class 2B vessels.

All conditions for the welding of production test plates shall be similar to the production welding of the vessel.

A2 **5.2.2.2** *Number of plates for single vessels* For each vessel as required by Clause 5.2.2.1, one production test plate welded as a continuation of a longitudinal joint shall be provided to represent each type of longitudinal weld within the limits of the essential variables of the welding procedure. This plate shall also represent circumferential joints in the same shell or ends, provided that the welding procedure is within the limits of the essential variables of the qualified welding procedures. Where one test plate represents more than one welded joint, the welding of such joints shall be carried out in a reasonably continuous operation.

An additional test plate shall be provided to represent welding where—

(a) another welding procedure outside the limits of essential variables of the first production test plate weld is used for longitudinal or circumferential type joints (Clause 3.5.1) in the main shell or ends;

A2 (b) the length of weld represented, is evaluated for longitudinal joints only (unless a different weld procedure is used for the circumferential joint) and exceeds 200 m for automatic welding or 100 m for manual or semi-automatic welding for ferrous metals, and 30 m and 22 m respecticely for non-ferrous metals; or

(c) the welding is not done in a reasonably continuous operation using the same welding procedure.

5.2.2.3 *Number of test plates for multiple vessels* Where a number of vessels are welded in succession, one test plate may present each 200 m or fraction of automatically welded joints or each 100 m or fraction of manually or semi-automatically welded joints in ferrous metals, provided that—

(a) such test plate represents the welds within the limits of the essential variables of the
A3 welding procedure (see AS/NZS 3992); and

(b) all the welding represented by the test plate is done in a reasonably continuous operation using the same welding procedure.

5.2.2.4 *Test plate material* Test plates shall be made from material of the same Standard, grade and manufacturing process as, and shall closely approximate the mechanical properties of, the material used in the construction of the vessel.

NOTE: It is recommended that test plates be taken from a plate used in the vessel or another plate from the same batch. Extension of the shell plates or cut-outs from the shell may be used.

5.2.2.5 *Test plate size* The size of the test plate shall be sufficient to provide all the
A3 test specimens required by AS/NZS 3992.

NOTE: It is recommended that an additional allowance in the size of the test plate be made for retesting.

The width of a test plate shall be such that the temperatures during welding will be comparable with those during welding of the vessel. Typical sizes of each half of the test plate are—

(a) 150 mm wide for steel equal to or less than 6 mm thickness;

(b) 225 mm wide for steel greater than 6 mm thickness; and for non-ferrous metal equal to or less than 6 mm thickness;

(c) 300 mm wide for non-ferrous metal greater than 6 mm thickness.

5.2.2.6 *Location and attachment of test plates* Where the length of weld represented does not exceed 15 m, a test plate may be located so that it is welded at the beginning or end of welding of the length of joints represented.

Where the length of weld represented exceeds 15 m, the test plate shall, where possible, be divided and located so that it is welded at the beginning and end of welding of the length of joints represented; one part being used for the tests and the other part for possible retests.

Test plates shall be attached to the plates being welded to permit welding as a continuation of the longitudinal joint, except for test plates representing circumferential joints only.

Where there are circumferential joints only, or where the welding procedure for the circumferential joint differs from that used for the longitudinal joint, the test plate shall be welded separately in accordance with the procedure for the circumferential weld.

The test plate shall be reinforced or supported during welding so that any relative displacement due to distortion does not exceed 5 degrees.

5.2.2.7 *Welding of test plates* Each condition including the welding procedure, for welding a test plate shall be the same as that for the joint it represents. Except for test plates representing circumferential joints only, the test plate shall be welded continuously with the longitudinal joint. Weld defects in the test plate shall not be repaired and shall be clearly marked on the plate.

5.2.2.8 *Testing of test plates* The test plates shall be tested in accordance with
A3 AS/NZS 3992 and shall meet the requirements of that Standard.

5.2.2.9 *Requirement* If the results of any of the retests do not meet the specified requirements, the welds in the vessel represented by the test plate shall be removed or otherwise treated as required by the inspection body or purchaser.

5.3 NON-DESTRUCTIVE EXAMINATION All components and welds shall be subject to non-destructive examination as specified in AS 4037 to ensure compliance of material and manufacture with the appropriate requirements specified in that Standard. Non-destructive examination includes—

(a) visual examination;

(b) radiographic examination;

(c) ultrasonic examination;

(d) magnetic particle examination; and

(e) penetrant examination.

Clauses 5.4, 5.5, 5.6, 5.7, 5.8 and 5.9 Not allocated.

5.10 HYDROSTATIC TESTS

5.10.1 General Each vessel after final welding and heat treatment shall pass satisfactorily the standard hydrostatic test as prescribed in this Clause (5.10) except where the vessel is tested in accordance with Clause 5.11 (pneumatic test) or Clause 5.12 (proof hydrostatic test).

5.10.2 Test pressure

5.10.2.1 *Single-wall vessels designed for internal pressure* For each single-wall vessel designed for internal pressure, except vessels provided for in Clauses 5.10.2.2, 5.10.2.4 and 5.10.2.5, the hydrostatic test pressure P_h shall be at least that determined by the following equation:

$$P_h = 1.5P \times \frac{f_h}{f} \quad \text{. . . 5.10.2}$$

where

P_h = hydrostatic test pressure, in megapascals

P = design pressure of the vessel, in megapascals

f_h/f = lowest ratio (for the materials of which the vessel is constructed) of—

$$\frac{\text{design strength at test temperature, MPa}}{\text{design strength at design temperature, MPa}}$$

(Values to be taken from Table 3.3.1)

This test pressure shall include any static head acting during the test on the part under consideration. The test pressure should not be exceeded; therefore attention should be given to the pressure caused by static head, thermal expansion of the test liquid or the like, which may exist during the test and which differs from those specified for the design conditions.

The test pressure should be as close as practicable to the pressure determined in accordance with Equation 5.10.2. If a higher pressure is applied, either intentionally or accidentally, the vessel may become visibly and permanently distorted beyond the dimensional limits specified in this Standard or may leak at mechanical joints, or may crack. In such cases the vessel is liable to rejection.

5.10.2.2 *Single-wall vessels designed for external pressure* Single-wall vessels designed for full or partial vacuum shall be subjected to an internal hydrostatic test of at least 1.5 times the difference between atmospheric pressure (absolute) and the minimum design internal pressure (absolute). An internal vacuum test may be substituted for the hydrostatic test when so agreed between the parties concerned.

5.10.2.3 *Multiple-chamber vessels (including jacketed types)* Vessels consisting of more than one pressure chamber shall have each chamber hydrostatically tested as follows:

(a) For chambers designed to operate independently, each chamber shall be tested at the test pressure for internal pressure or vacuum as appropriate (see Clauses 5.10.2.1 and 5.10.2.2), without pressure in the adjacent chamber.

(b) For jacketed vessels where the inner vessel is designed to operate at atmospheric pressure or vacuum condition only, the test pressure shall be determined by Equation 5.10.2 except that the design pressure P, shall be the maximum differential pressure between inner and outer vessels, and shall be applied only to the jacket space.

(c) For jacketed vessels where the outer vessel is designed to operate at atmospheric pressure or under vacuum conditions only, the test pressure shall be determined by Equation 5.10.2 except that the design pressure P, shall be the maximum differential pressure between the inner and outer vessels, and shall be applied only to the inner vessel. Where the outer vessel is designed to operate under vacuum conditions, it shall be tested in accordance with Clause 5.10.2.2.

(d) For chambers having common elements designed for the maximum differential pressure that can possibly occur during start-up, operation, and shut down, and the differential pressure is less than the higher pressure in the adjacent chamber, the common element shall be tested at the test pressure determined by Equation 5.10.2 except that the design pressure P, shall be the maximum differential pressure acting internally, where applicable. Following this test (and inspection) adjacent compartments shall be tested simultaneously at the test pressure required for internal pressure taking care to limit the differential pressure across the common elements.

5.10.2.4 *Cast iron and SG iron vessels* The test pressure for vessels constructed of cast iron or spheroidal graphite iron shall be—

(a) 2.0 times the design pressure for design pressures exceeding 210 kPa; or

(b) 2.5 times the design pressure, but not exceeding 420 kPa, for design pressures not exceeding 210 kPa.

For vacuum and multi-chamber vessels the test pressure shall be in accordance with Clauses 5.10.2.2 and 5.10.2.3.

5.10.2.5 *Coated vessels* Galvanized, tinned, painted, enamelled, rubber-lined or similar coated vessels shall be subjected, before coating, to a hydrostatic test to the requirements of Clause 5.10.2.1, 5.10.2.2 or 5.10.2.3, as appropriate. After coating, by agreement between the parties concerned the vessel may be hydrostatically tested to a pressure adequate to prove the integrity of the coating but not exceeding the original test pressure.

5.10.2.6 *Tubular heat exchangers* Tubular heat exchangers shall be hydrostatically tested at pressures in accordance with Clauses 5.10.2.1 and 5.10.2.2, as appropriate. The shell side and the tube side shall be tested separately in a manner that leaks at the tube joints can be detected from at least one side. Where construction permits, and the tube-side design pressure is the higher pressure, the tube bundle shall be tested outside of the shell.

5.10.2.7 *Clad vessels* Vessels or parts of vessels constructed of integrally clad plate as specified in Clause 4.3 shall be tested in accordance with the relevant requirements of this Clause (5.10).

5.10.2.8 *Lined vessels* Vessels or parts of vessels having applied linings as specified in Clause 4.3 shall be tested in accordance with the relevant requirements of this Clause (5.10) and the following:

(a) Prior to the hydrostatic test, an appropriate test shall be carried out to demonstrate the integrity of the liner. This test may be—

  (i) a test which requires pressurizing of the space between the liner and the base metal to a pressure which will not cause buckling of the applied liner;

  (ii) a halide test;

  (iii) a penetrant test; or

  (iv) other methods agreed between the parties concerned.

  Care shall be taken to ensure that the test fluid used in the space between the liner and the base material shall not cause deterioration of the vessels in service through either corrosion or the generation of excessive pressure.

  NOTE: The above test is required to minimize the potential for leakage into the space behind the liner and the need for liner repairs after the hydrostatic test.

(b) Following the hydrostatic test, the interior of the vessel shall be visually examined to determine if any seepage of the test fluid through the liner has occurred, and all welds shall be penetrant tested or otherwise tested by methods agreed between the parties concerned.

  NOTE: Where seepage of the test fluid into the space behind the liner occurs, the fluid may remain there until the vessel is put into service. Where the operating temperature of the vessel exceeds the boiling point of the test fluid, the vessel should be heated for a period sufficient to expel all test fluid from behind the liner without damaging the liner. Welding or brazing repairs should be carried out after this drying treatment.

(c) Where the integrity of the liner has been found to be defective, a suitable repair shall be made, followed by testing in accordance with methods and requirements agreed between the parties concerned.

5.10.3 Site retests Where required by the Inspector, the completed vessel shall be hydrostatically retested on the site after erection and completion of all field welds at a test pressure agreed by the parties concerned but not less than 1.25 times the design pressure. The main component parts shall have been tested in accordance with the requirements of this Standard.

5.10.4 Tests after weld repairs After repairs or modifications involving welding on hydrostatically tested vessels, the vessels shall be re-submitted to the standard hydrostatic test pressure, provided that in special cases or after repairs which do not affect the safety of the vessel, the hydrostatic test may be waived by agreement between the parties concerned.

NOTE: A hydrostatic test is normally necessary after repairs or modifications which—

(a) involve complete welding of portion of the main joints of the shell or ends;

(b) involve the re-welding of branch attachments;

(c) require re-heat treatment of the weld; or

(d) involve welding of pressure parts of carbon, carbon-manganese and alloy steel vessels where the minimum operating temperature is 30°C or more colder than the appropriate Material Design Minimum Temperature given in Figure 2.6.2.

Where a hydrostatic test is not carried out, the weld shall be subject to non-destructive testing and leak testing as agreed between the parties concerned.

5.10.5 Hydrostatic test procedure and requirements The hydrostatic test procedure and requirement shall be in accordance with AS 4037.

5.10.6 Reporting of results Test results shall be reported as specified in AS 4037.

5.11 PNEUMATIC TESTS

5.11.1 General Pneumatic testing shall be avoided, but may be used in place of the standard hydrostatic test in special circumstances. Pneumatic tests and combined pneumatic/hydrostatic tests shall be in accordance with AS 4037.

5.11.2 Vessel quality All butt-welded joints shall be tested in accordance with requirements for Class 1 construction (Clause 1.7.2) prior to pneumatic testing or as agreed between the parties concerned.

5.11.3 Test pressure Unless otherwise agreed between the parties concerned the test
A1 pressure shall be 1.25 times the equivalent design pressure or pressure difference, as required by Clause 5.10.

A2 **5.11.4 Departures** Where pneumatic testing is carried out under such protection and conditions that vessel failure could not cause injury to persons or property, the requirements of Clauses 5.11.2 and 5.11.3 do not apply.

5.12 PROOF HYDROSTATIC TESTS

5.12.1 Application The design pressure of vessels or calculation pressure of vessel parts for which the strength cannot be calculated with a satisfactory assurance of accuracy, shall be established in accordance with the other requirements of this Clause (5.12).

The tests described in this Clause (5.12) may be used only for the purpose of establishing the calculation pressure of those parts of the vessel for which the thickness cannot be determined by means of the design requirements of this Standard.

5.12.2 Types of test Proof tests may be of various types but provision is made here for only the following:

(a) *Tests based on yielding* These are applicable only to materials having a ratio of specified minimum yield strength to specified minimum tensile strength of 0.625 or less. They include:

   (i) *Strain gauge tests* (see Clause 5.12.4) *and brittle coating tests* (see Clause 5.12.5). These tests are used in all cases where it is necessary to measure local strains in selected positions in order to establish the acceptability of the design.

   (ii) *Displacement tests* (see Clause 5.12.6). These tests are used where it can be demonstrated that a number of displacement readings are sufficient to establish the acceptability of the design. Typical cases include measurement of the change in diameter of large nozzle to shell junctions, and circumferential measurement of cylindrical sections.

   Brittle coating and displacement tests are suitable only for vessels or parts under internal pressure, and with materials with a definite yield stress.

(b) *Tests based on bursting* These are applicable to all materials in vessels under internal pressure. Test requirements are given in Clause 5.12.7.

Combinations of these tests may also be used.

5.12.3 General requirements

5.12.3.1 *Hydrostatic testing* The general requirements for the standard hydrostatic tests in Clause 5.10 which are relevant, shall apply.

5.12.3.2 *Prior pressure* The vessel or vessel part for which the design or calculation pressure is to be established shall not previously have been subjected to a pressure greater than the anticipated equivalent design pressure (see Clause 5.10.2.1).

5.12.3.3 *Safety* Serious consideration shall be given to the safety of testing personnel when conducting proof tests, particularly during any burst tests. Particular attention should be paid to the elimination of any air pocket.

5.12.3.4 *Witnessing of tests* Testing shall be witnessed by a competent person. Test results shall be reported.

5.12.3.5 *Duplicate vessels* When the design or calculation pressure of a vessel or vessel part has been established by a proof test, duplicate parts of the same materials, design and manufacture need not be proof tested but shall be given a hydrostatic test in accordance with Clause 5.10 or a pneumatic test in accordance with Clause 5.11. The dimensions and minimum thickness of the structure to be tested shall not vary materially from those actually used.

5.12.3.6 *Retests* A retest shall be allowed on a duplicate vessel or vessel part if errors or irregularities are obvious in the test results.

5.12.4 Strain gauge tests

NOTE: See Clause 5.12.2(a) for application.

5.12.4.1 *Strain gauges* Strains shall be measured by any device capable of measuring principal strains with a sensitivity of 1/20 and an accuracy of 1/15; and a range of three times the yield strain of the material being tested.

5.12.4.2 *Location of gauges* Gauges shall be positioned in a manner that will enable strains to be measured in areas where the highest primary membrane and bending stresses are anticipated. Positioning of gauges internally and externally, selection of gauge types, rosettes, mirror pairs or the like, shall be a matter for agreement between the parties concerned and the organization conducting the test. As a check that the measurements are being made at the most highly stressed areas, a brittle coating may be required to be suitably applied on all areas of probable high stress concentration.

NOTE: Strains should be measured such that they represent primary membrane stress and bending stresses. It is not intended that the design pressure obtained from this Clause be based on the measurement of high localized or secondary bending stresses. In this Standard, design requirements for details have been written to hold such stresses at a safe level consistent with experience.

The vessel may be cycled to 50% of the anticipated design pressure several times as a means of relieving most of the initial residual stress distribution.

Gauges shall be applied to the vessel before the test proper is begun and while the vessel is not pressurized.

The gauges shall be attached in a manner which will ensure accurate measurement.

5.12.4.3 *Application of pressure* The hydrostatic pressure in the vessel or vessel part shall be increased gradually and steadily until approximately 50% of the anticipated design pressure is reached. Thereafter, the test pressure shall be increased gradually and steadily, pausing at increments of approximately 10% or less of the anticipated design pressure, until the pressure required by Clause 5.12.4.6 is reached.

The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by Clause 5.12.4.4 to be made.

5.12.4.4 *Strain and pressure readings* During each pause in accordance with Clause 5.12.4.3, readings of pressure and strain at each strain gauge shall be taken and recorded. Where any such reading indicate a departure from the line of proportionality between pressure and strain, the vessel shall be completely depressurized and measurement taken of any permanent deformation at the location of each strain gauge. After such readings have been taken, the pressure shall be re-applied, as often as necessary, as specified in Clause 5.12.4.3.

5.12.4.5 *Plotting of strain* Two curves of strain against test pressure shall be plotted for each gauge as the test progresses, one showing total strain under pressure, and the other showing permanent strain when the pressure is removed.

5.12.4.6 *Maximum test pressure* The test may be discontinued when either—

(a) the test pressure reaches the value which will, by Equation 5.12.4.7(1) or (2) justify the desired design (or calculation) pressure; or

(b) the plotted points in Clause 5.12.4.5 for the most highly strained gauge reaches 0.2% permanent strain (or 0.5% total strain for copper-base alloys).

5.12.4.7 *Design pressure* The design (or calculation) pressure to be assigned to the vessel (or part) shall not exceed the value determined by the following equation:

$$P = 0.5P_h \left(\frac{T - C}{T}\right)\left(\frac{f}{f_h}\right)\left(\frac{Y_s}{Y_a}\right) \qquad \ldots 5.12.4.7(1)$$

where

P = design pressure of vessel (or calculation pressure of part), in megapascals

P_h = hydrostatic test pressure at which test was stopped in accordance with Clause 5.12.4.6, in megapascals

T = nominal thickness of material over the area represented by the strain measurement of the most highly strained gauge, in millimetres

C = allowance for corrosion, erosion and abrasion, in millimetres

f = design strength at design temperature (see Table 3.3.1), in megapascals

f_h = design strength at test temperature (see Table 3.3.1), in megapascals

Y_s = specified minimum yield strength, in megapascals

Y_a = actual average yield strength obtained in accordance with Clause 5.12.4.8, in megapascals.

As an alternative to the above and to eliminate the necessity of determining the actual yield strength of the material under test, the following equation may be used:

$$P = 0.4P_h \left(\frac{T - C}{T}\right)\left(\frac{f}{f_h}\right) \qquad \ldots 5.12.4.7(2)$$

5.12.4.8 *Determination of actual yield strength* The yield strength shall be determined in accordance with AS 1391. Materials sensitive to the rate of straining during testing shall be tested at a straining rate range (A, B or C) appropriate to the rate of straining during hydrostatic testing. The strength shall be the average of four specimens cut from the part tested after the test is completed.

The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength, and shall be representative of the material where maximum stress occurs.

Where excess stock from the same piece of wrought material is available and has been given the same heat treatment as the pressure part, the test specimens may be cut from this excess stock.

Test specimens shall not be removed by thermal cutting or other method involving heat sufficient to affect the mechanical properties of the specimen.

5.12.5 Brittle-coating tests

NOTE: See Clause 5.12.2(a) for application.

5.12.5.1 *Coating* Suitable brittle coating shall be applied on all external areas of probable highest stress (see Note in Clause 5.12.4.2). The surfaces shall be suitably cleaned before the coating is applied so as to obtain satisfactory adhesion. The technique used shall be suited to the coating material.

5.12.5.2 *Application of pressure* Pressure shall be applied as in Clause 5.12.4.3. The parts being proof-tested shall be examined between pressure increments for signs of yielding as evidenced by flaking or cracking of the coating.

5.12.5.3 *Maximum test pressure* The test shall be discontinued at the first sign of yielding, or may be discontinued at some lower pressure.

5.12.5.4 *Design pressure* The design or calculation pressure to be assigned to the vessel or part, shall not exceed the value determined by Equation 5.12.4.7(1) but with P_h equal to the hydrostatic test pressure at which test was stopped in accordance with Clause 5.12.5.3, in megapascals

As an alternative to the above and to eliminate the necessity of determining the actual yield strength of the material under test the following equations may be used.

For carbon and carbon-manganese steels (with specified minimum tensile strength not exceeding 490 MPa) the following equation applies:

$$P = 0.5P_h\left(\frac{T - C}{T}\right)\left(\frac{f}{f_h}\right)\left(\frac{S}{S + 34.5}\right) \quad \ldots 5.12.5.4(1)$$

where

S = specified minimum tensile strength, in megapascals

For all other materials acceptable in this Standard, equation 5.12.4.7(1) applies.

When either Equation 5.12.5.4(1) or 5.12.4.7(2) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal.

5.12.6 Displacement tests

5.12.6.1 *Displacement measurement* Displacement measurement shall be made of those movements of the vessel which would arise from yielding at the location under investigation as defined in Clause 5.12.4.2. The measuring device shall be demonstrated by the manufacturer to be reliable, and accurate under all anticipated conditions of pressure, temperature variations, and vessel movement. It shall also be sufficiently sensitive and accurate to detect permanent deformation of 0.02% in the area under consideration.

5.12.6.2 *Application of pressure* The pressure shall be applied as in Clause 5.12.4.3. However, before commencing the test proper, the vessel may be cycled to 50% of the anticipated design pressure several times as a means of relieving most of the initial residual stress distribution.

5.12.6.3 *Displacement and pressure readings* During each pause in accordance with Clause 5.12.4.3, readings of the displacement and hydrostatic test pressure shall be taken and recorded. Where any such reading indicates a departure from the line of proportionality between pressure and displacement, the vessel shall be completely depressurized and measurement taken of any permanent deformation at the location of each displacement. Care shall be taken to ensure that the readings represent only displacement of the parts on which measurements are being made and that such readings do not include slip of the measuring devices or movement of the fixed base points or of the pressure part as a whole.

5.12.6.4 *Plotting of strain* Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed.

5.12.6.5 *Maximum test pressure* The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line. The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

5.12.6.6 *Design pressure* The design (or calculation) pressure to be assigned to the vessel or part shall not exceed the value determined by Equation 5.12.5.4(1) using P_h as the hydrostatic test pressure at which the test was stopped in accordance with Clause 5.12.6.5. Using this same designation for P_h, the alternatives provided in Equations 5.12.5.4(2) and 5.12.5.4(3) may be used.

5.12.7 Bursting tests

NOTE: See Clause 5.12.2(b) for application.

5.12.7.1 *General* Where the design pressure or calculation pressure is to be determined by a hydrostatic burst test, a full size sample of the vessel or part under consideration shall be used. The hydrostatic pressure shall be applied gradually and steadily, and the pressure at which rupture occurs shall be determined.

5.12.7.2 *Design pressure* The design (or calculation) pressure to be assigned to the vessel (or part) shall not exceed the value determined by one of the following equations:

(a) *Parts constructed of material other than cast materials*—

$$P = \frac{P_B}{5}\left(\frac{S\eta}{S_a}\right)\left(\frac{f}{f_h}\right)$$

or

$$P = \frac{P_B}{5}\left(\frac{S\eta}{S_m}\right)\left(\frac{f}{f_h}\right) \quad \ldots 5.12.7.2(1)$$

(b) *Parts constructed of cast iron and low ductility SG iron*—

$$P = \frac{P_B}{6.67}\left(\frac{S}{S_a}\right) \quad \ldots 5.12.7.2(2)$$

(c) *Parts constructed of ductile SG iron*—

$$P = \frac{P_B}{5}\left(\frac{S}{S_a}\right) \quad \ldots 5.12.7.2(3)$$

(d) *Parts constructed of cast materials other than those indicated in (b) and (c) ductile SG iron*—

$$P = \frac{P_B}{5}\left(\frac{SF}{S_a}\right)\left(\frac{f}{f_h}\right)$$

or

$$P = \frac{P_B}{5}\left(\frac{SF}{S_m}\right)\left(\frac{f}{f_h}\right) \quad \ldots 5.12.7.2(4)$$

where

P = design (or calculation) pressure, in megapascals

P_B = bursting test pressure, in megapascals

S = specified minimum tensile strength, in megapascals

η = efficiency of welded joint (see Table 3.5.1.7)

S_a = average actual tensile strength of test specimens (determined in a like manner to the yield test Y_a in Clause 5.12.4.8) or in the case of cast material the minimum tensile strength of an associated arbitration bar, in megapascals

S_m = maximum tensile strength of range of specification, in megapascals

f = design strength at design temperature (see Table 3.3.1), in megapascals

f_h = design strength at test temperature (see Table 3.3.1), in megapascals

F = casting quality factor.

5.13 LEAK TEST

5.13.1 General Where specified by the purchaser on the order, leak tests shall be carried out in accordance with this Clause (5.13).

5.13.2 Test methods Methods of testing and acceptance criteria shall be by agreement
A3 between the purchaser and manufacturer. See AS/NZS 3992, BS 3915 or BS 4208 for various tests.

5.13.3 Tightness of applied linings A test for tightness of the applied lining that will be appropriate for the intended service is recommended (see Clause 5.10.2.8).

5.13.4 Preliminary leak test Preliminary leak tests shall be carried out in accordance with AS 4037.

5.13.5 Sensitive leak test Sensitive leak tests shall be carried out in accordance with AS 4037.

Clauses 5.14, 5.15 and 5.16 Not allocated.

5.17 SPECIAL EXAMINATIONS AND TESTS Where specified by the purchaser, special examinations and tests shall be carried out to determine the suitability of materials or procedures new to the manufacturer. (See AS 4037.)

SECTION 6 ASSURANCE OF PRODUCT QUALITY

Inspection including design verification and fabrication inspection by a third party inspection body shall be carried out where required and in accordance with AS 3920.1. Where inspection by a third party is not required, the manufacturer's inspector shall perform duties specified for the inspector.

SECTION 7 MARKING

7.1 MARKING REQUIRED Each completed pressure vessel complying with this Standard shall be marked with the following:

(a) Manufacturer's name or identification symbol.

(b) Inspector's identification.

(c) Design pressure, in kilopascals.

(d) Hydrostatic test pressure, in kilopascals.

(e) Date of hydrostatic test, month and year, e.g. 5/1997.

(f) Design temperature in degrees Celsius.

(g) For vessels intended for low temperature service, the minimum operating temperature in degrees Celsius and the maximum allowable pressure at that temperature, in kilopascals.

(h) The vessel designation number (see Clause 1.12), except that it is not necessary to stamp B, C or F.

(i) The manufacturer's serial number for the vessel.

(j) Where appropriate, the registered number.

NOTES:

1 When a pressure vessel is expected to operate at more than one pressure and temperature condition, other values of design pressure with the coincident design temperature may be added as required.

2 The applicable units must appear in the marking.

7.2 METHODS OF MARKING The markings shall be carefully and legibly applied in such a way that the marking will not be obliterated in the service.

The markings shall be stamped or etched directly on the vessel or stamped, cast or etched on a nameplate which shall be or has been permanently attached to the vessel by suitable means. When attached by welding the welding requirements of this Standard shall be complied with. For vessels constructed of Group F or Group G steel less than 12 mm thick, the markings shall be on a nameplate, except as permitted in AS 4458.

A nameplate is recommended for—

(a) carbon and carbon-manganese steels less than 6 mm thick;

(b) non-ferrous materials less than 12 mm thick;

(c) alloy and high alloy steels;

(d) quenched and tempered alloy steels; and

(e) ferritic steels intended for use at low temperature service.

7.3 LOCATION OF MARKING All required markings shall be located in a conspicuous place on the vessel, preferably near a manhole, other inspection opening other part which is accessible after installation. The marking shall be left bare, or where the vessel must be fully insulated, the insulation over the marking shall be identified and readily removable.

Markings applied directly to the vessel shall be in a position not subject to high stresses, e.g. on the rim of a flange, or thickened portion of forged ends remote from the corner radius.

7.4 SIZE AND TYPE OF MARKING Letters and figures shall be at least 6 mm high when marked directly on the vessel, and at least 3 mm high when marked on nameplates.

The stamps for direct marking of the vessel should have letters and figures with radiused edges to minimize the stress-raising effects of the stamped mark.

7.5 MULTI-CHAMBER VESSELS Special combination units consisting of more than one independent pressure chamber or vessel shall have each pressure chamber separately marked as required for a single vessel, except where otherwise agreed.

7.6 WITNESSING OF MARKING The marking of the vessel shall be applied under the supervision of the Inspector after the hydrostatic or pneumatic test and other inspections have been completed to the satisfaction of the inspection body.

SECTION 8 PROTECTIVE DEVICES AND OTHER FITTINGS

8.1 GENERAL REQUIREMENTS

8.1.1 General Each pressure vessel shall be provided with protective devices and other fittings in accordance with the requirements of this Section. Clauses 8.2 to 8.9 deal with pressure-relief devices, Clause 8.10 with vacuum-relief devices, Clauses 8.11 and 8.12 with temperature-sensing devices, and Clauses 8.13 to 8.17 with other fittings.

The number, size, type, location and performance, of protective devices and other fittings required by this Standard and for the safe operation of the vessel shall be agreed between the parties concerned. When any such device or fitting is not provided by the manufacturer, the purchaser shall be responsible for ensuring that it is supplied and fitted prior to placing the vessel into service.

8.1.2 Design, manufacture and connection for protective devices and fittings Protective devices, and other fittings shall be of material, design and manufacture to permit the devices to perform their required function under the expected conditions of service. They shall be acceptable to the purchaser and where required, to the inspection body and where appropriate, comply with AS 1271.

All connections to the vessel shall comply with the requirements of Clause 3.19.

8.2 VESSELS REQUIRING PRESSURE-RELIEF DEVICES

8.2.1 Pressure relief—general requirement Each pressure vessel shall be protected with one or more pressure-relief devices except as provided in Clauses 8.2.5 and 8.2.6.

Each chamber or compartment of a multi-chamber vessel shall be treated as a separate vessel and shall be suitably connected to a pressure-relief device unless the compartments are interconnected in accordance with Clause 8.2.4.

Each pressure vessel shall be protected by a pressure-relieving device that shall prevent the pressure from rising to more than 110 percent of the design pressure of the vessel except as follows (see Section 8.7 for pressure settings):

(a) Where multiple pressure-relief devices are provided and set in accordance with Clause 8.7.1, they shall prevent the pressure within the vessel rising to more than 116 percent of the design pressure, provided that the lower set pressure-relief device(s) is capable of relieving any surge condition anticipated during normal operation.

(b) Where excess pressure is caused by exposure to fire or other unexpected source of heat, the pressure-relief device(s) shall comply with Clause 8.2.2.

(c) Where the relevant application code specifies otherwise (e.g. AS 1596 or AS 2022).

8.2.2 Pressure relief for fire conditions Where an additional hazard can be created by exposure of a vessel to fire or other similar unexpected source of heat (e.g. vessels used to store flammable liquefied gases), the pressure-relief devices shall be capable of preventing the pressure from rising to more than 121 percent of the design pressure of the vessel. See Clause 8.6.2, 8.7.3, 8.11 and 8.12.

The same pressure-relief device may be considered to meet the requirements of both Clauses 8.2.1 and 8.2.2 provided it meets the individual requirements of each clause.

8.2.3 Liquid full vessels Vessels that are to operate completely filled with liquid shall be equipped with a liquid-relief valve(s) unless otherwise protected against over-pressure. (See Clause 8.3(a)(ii)).

8.2.4 Interconnected vessels and chambers Vessels or chambers of vessels, which are connected together in a system by piping of adequate capacity, may be considered as one unit in determining the number and capacity of pressure-relief devices provided that no valve is fitted that could isolate any vessel from the relief devices unless that vessel is simultaneously opened to atmosphere.

8.2.5 Systems of limited or reduced pressure Where the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the design pressure at the operating temperature, the requirements of Clause 8.2.1 above need not apply, but suitable provision shall be made to comply with Clause 8.2.2.

Pressure-reducing valves and similar mechanical or electrical pressure control instruments, except for pilot-operated relief valves as permitted in Clause 8.4.4, are not considered as sufficiently positive in action to prevent excess pressures from being developed.

8.2.6 Lethal fluids and other special fluids Under special conditions of service and by agreement between the parties concerned, vessels containing lethal fluids or other special fluids may be exempt from the requirement of this Section.

8.3 TYPES OF PRESSURE-RELIEF DEVICES Pressure-relief devices are devices designed to relieve excess pressure and for the purpose of this Standard are of the following types:

(a) *Pressure-relief valve* A safety valve or relief valve as defined in Item (i) or Item (ii).

  (i) *Safety valve*—a valve which automatically discharges fluid to atmosphere so as to prevent a predetermined pressure being exceeded. It is normally used for compressible fluids which require quick over-pressure relief. It is activated by the static pressure upstream of the valve.

  NOTE: These valves may also be referred to as safety relief valves when they are suitable for use as a safety valve or a relief valve depending on application.

  (ii) *Relief valve*—a valve which automatically discharges fluid to atmosphere or a reduced pressure system so as to prevent a predetermined pressure being exceeded. It is used primarily for non-compressible fluids (i.e. liquids). It is activated by the static pressure upstream of the valve.

NOTE: The valves in Items (i) and (ii) are designed to reclose after normal conditions have been restored.

(b) *Bursting disc and other non-reclosing pressure relief device* A bursting disk type pressure relief device has an operating part in the form of a disc or diaphragm normally of metal, which initially blocks a discharge opening in the vessel but bursts at a predetermined pressure to discharge fluid. It does not re-close automatically.

Other non-reclosing pressure relief devices include breaking-pin devices, buckling-pin devices and spring loaded non-closing pressure relief valves which have similar function to bursting disc.

(c) *Vent system* Where a vessel is open to atmosphere through a vent pipe (with or without a liquid trap) the vent pipe may be regarded as a pressure (or vacuum) relief device, provided that the vent system meets the requirements of Clause 8.2.1, is connected as directly as possible to atmosphere, is used for this purpose only, and cannot be closed or blocked by ice formation or collection of deposits.

(See Clauses 8.11, 8.12 and 8.13 for other protective devices which may limit pressure.)

8.4 PRESSURE-RELIEF VALVES

8.4.1 Application In general, pressure-relief valves are preferred for protection of vessels against excessive pressure but bursting discs or other non-reclosing pressure relief devices may be used as agreed. If the fluid is compressible, a pressure-relief valve and bursting disc may be arranged in series, and such arrangement may be preferable as indicated in Clause 8.5.1.

8.4.2 Design, manufacture testing and marking The design, manufacture, testing and marking of pressure-relief valves shall comply with AS 1271.

8.4.3 Type and minimum bore Pressure-relief valves shall be of the spring-loaded type, however deadweight-type valves may be used for static vessels by special agreement between the parties concerned. Lever and weight types shall not be used.

The minimum bore (see Note) for any relief valve used on a vessel shall be as follows:

(a) For steam where some corrosion or deposit may cause blockage or sticking . 10 mm

(b) For a gas or vapour which may cause sticking of the valve disc . . . . 10 mm

(c) For other gas or vapour . . . . 6 mm

(d) For a liquid which may cause sticking of the valve disc . . . . 20 mm

(e) For other liquid . . . . 12 mm

NOTE: The bore is the diameter at the minimum cross-sectional flow area (but not the curtain area) between the inlet and the seat with no reduction for any obstruction. It is sometimes referred to as the orifice diameter or by a letter designation representing its equivalent effective area.

To limit loss of fluid with any short term over pressure and to provide a back-up in the event of valve sticking or blockage, it is recommended that where one valve is fitted, its bore (see above Note) not exceed 75 mm nominal, unless otherwise agreed. If a discharge capacity greater than that provided by one 75 mm nominal, or other accepted valve is necessary, then two or more valves should be fitted. Where more than one valve is fitted, one or more such valves may exceed 75 mm nominal, provided that the discharge capacity of the smallest valve is not less than the smaller of 50 percent of the discharge capacity of the largest valve or 25% of the required total discharge capacity.

8.4.4 Pilot operation Pilot-valve control or other indirect operation of safety valves is not permitted as part of the required pressure-relief system and contributing to the required relieving capacity unless—

(a) the design is acceptable to the purchaser and the inspection body;

(b) the fluid to be relieved is clean vapour; and

(c) the design is such that the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot or auxiliary device should fail to operate, or the complete valve is designed to have fail-safe characteristics approaching those of the above type of system.

8.4.5 Easing gear Easing gear shall be fitted to pressure-relief valves for use with steam, air and those fluids which promote sticking of the valve disc to the seat but do not create a hazard when released, (e.g. leakage of the fluid is prevented at all places other than through the discharge piping to a safe location).

Easing gear shall be such that the disc can be positively lifted off its seat when the valve is subjected to its set pressure minus 690 kPa or to 75 percent of its set pressure, whichever is the higher pressure.

8.4.6 Gumming and thermal effects The design of pressure-relief valves and the choice of their materials of manufacture shall take into consideration the possible effect of differential expansion and contraction, of possible icing of external components during discharge and of gumming or deposits. Valves with plain flat discs without bottom guides shall be used when gumming or deposits are probable on the inside. The valve spring should be protected by a suitable seal where it is liable to corrosion or blockage due to products discharged.

8.4.7 Drainage Where liquid can collect on the discharge side of the disc of a pressure-relief valve, the valve shall be equipped with a drain at the lowest point where liquid can collect.

8.4.8 Vapour tightness For toxic or flammable fluids safety and relief valves shall meet the requirements for vapour tightness where specified by the purchaser.

8.5 BURSTING DISCS AND OTHER NON-RECLOSING PRESSURE-RELIEF DEVICES

8.5.1 Application Bursting discs or a combination of bursting discs and other pressure-relief devices (see Clause 8.3) are recommended for the following conditions, as relevant:

(a) Where pressure rise may be so rapid as to be analogous to combustion or explosion.

(b) Where even minute leakage of the fluid cannot be tolerated during normal service, e.g. with highly toxic or valuable materials.

(c) Where service conditions may involve heavy deposits or gumming up such as could render a pressure-relief valve inoperative.

Where a system is subject to pulsating pressure, reversal of pressure, corrosion, or elevated temperatures, bursting discs shall be used with caution. There should also be a substantial margin between the maximum operating pressure and the bursting pressure of bursting discs (see Clause 8.7.2).

NOTE: A register of bursting disc data is to be kept by the user for each vessel protected by a bursting disc. The register should relate the service conditions at which a vessel operates to the serial letters and numbers stamped on the disc or marked on the envelope in which the disc was contained.

8.5.2 Design, manufacture, testing and marking The design, manufacture, testing and marking of bursting discs shall comply with AS 1358.

8.5.3 Discs located between pressure-relief valve and vessel A bursting disc may be installed between a spring-loaded pressure-relief valve and the vessel provided that—

(a) the valve is ample in capacity to meet the requirements of Clause 8.6;

(b) the maximum pressure of the range at which the disc is designed to burst does not exceed the design pressure of the vessel;

(c) the discharge capacity of the bursting disc after rupture is not less than the capacity of the associated valve;

(d) the open area of the bursting disc after rupture is no less than the inlet area of the valve;

(e) following rupture there is no possibility of interference with the proper functioning of the valve; and

(f) the space between the bursting disc and the valve is provided with a pressure gauge, trycock, free vent, or other suitable indicator for the detection of disc rupture or leakage.

NOTE: Users are warned that a bursting disc will not burst at its design pressure or may fail in reverse bending if back-pressure builds up in the space between the disc and the relief valve, e.g. where leakage develops in the bursting disc due to corrosion or other causes.

8.5.4 Disc located on discharge side of pressure relief valve (See Note 2) A bursting disc in series with the pressure-relief valve may be used to minimize the loss by leakage through the valve of hazardous materials, and where a bursting disc alone or a disc located on the inlet side of the safety valve is impracticable. The distance between the valve and the bursting disc shall be a practical minimum.

A bursting disc may be installed on the outlet of a spring-loaded pressure-relief valve which is opened by direct action of the pressure in the vessel provided that—

(a) the valve is of a type which will open at its set pressure regardless of back pressure (see Note 1);

(b) a valved vent is located between the valve disc and the bursting disc to permit venting of the valve to a safe location;

(c) the valve is ample in capacity to meet the requirements of Clause 8.6;

(d) the maximum pressure of the range for which the disc is designed to burst does not exceed the design pressure of the vessel (see also Item (k));

(e) the discharge capacity of the bursting disc after rupture is not less than the capacity of the associated valve, and the open area through the disc after rupture is not less than the outlet area of the valve;

(f) piping beyond the bursting disc cannot be obstructed by the bursting disc or fragments;

(g) all valve parts and joints subject to stress due to the pressure from the vessel and all fittings up to the bursting disc are designed for not less than the maximum operating pressure of the vessel;

(h) any small leakage or a larger flow through a break in the operating mechanism that may result in back-pressure accumulation within enclosed spaces of the valve housing other than between the bursting disc and the discharge side of the pressure-relief valve, so as to hinder the pressure-relief valve from opening at its set pressure, will be relieved adequately and safely to atmosphere through telltale vent openings;

(i) the content of the vessel is a clean fluid, free from gumming or clogging matter, so that deposits in the space between the valve and the bursting disc (or in any other outlet that may be provided) will not clog the outlet:

(j) the installation is acceptable to the parties concerned;

(k) the bursting pressure at atmospheric temperature does not exceed the maximum operating pressure of the vessel at atmospheric temperature.

NOTES:

1 Users are warned that an ordinary spring-loaded pressure-relief valve will not open at its set pressure if back pressure builds up in the space between the valve and bursting disc. A specially designed pressure-relief valve is required, such as a diaphragm valve or a valve equipped with a bellows above the disc.

2 Users are warned that replacing a bursting disc on the outlet of a pressure-relief valve may be attended by some danger if done without first reducing the pressure in the vessel, particularly when hazardous contents might be discharged.

8.5.5 Other non-reclosing pressure relief of devices These devices shall comply with similar requirements as for bursting discs and shall—

(a) be fully open at the set pressure;

(b) have a set pressure tolerance not greater than ±5%;

(c) be limited to service temperature of −30°C to 150°C for buckling pin devices;

(d) have a calculated discharge capacity based on the minimum discharge area and a discharge co-efficient not greater than 0.62 unless a higher value is proven by adequate tests; and

A1 (e) be suitably protected from contamination or interference.

8.6 REQUIRED DISCHARGE CAPACITY OF PRESSURE-RELIEF DEVICES

8.6.1 Aggregate capacity The aggregate capacity of the pressure-relief devices connected to a vessel or system of vessels for the release of fluid shall be sufficient to allow the discharge of the maximum quantity that can be generated by or supplied to the equipment without a rise in pressure to more than the maximum limits specified in Clause 8.2.1 and Clause 8.2.2. (See Clause 8.2.1(a) for required relieving capacity of the lowest set pressure-relieving device.)

8.6.2 Aggregate capacity for fire conditions

8.6.2.1 *General* Relief devices required by Clause 8.2.2 as protection against fire or other unexpected sources of external heat, shall have relieving capacity sufficient to prevent pressure from rising to more than 121% of the vessel design pressure. The relieving capacity shall be determined in accordance with Clauses 8.6.2.3 or 8.6.2.4. See also Appendix S.

8.6.2.2 *Notation* For the purpose of this Clause (8.6.2), the notation given below applies:

A_e = external area of vessel adjacent to the maximum feasible wetted area below 7.5 m height above any potential sizeable source of flame or heat, in square metres which may be taken as:

(a) For cylindrical vessel with spherical ends—

$\pi \times$ overall length $\times$ outside diameter.

(b) For cylindrical vessel with 2:1 ellipsoidal and torispherical ends—

$\pi \times$ (overall length + 0.19 outside diameter) $\times$ outside diameter.

(c) For spherical vessel—

π (outside diameter)^2.

NOTE: The source of flame or heat usually refers to ground level but may be at any level at which a sizeable fire could be sustained.

C = constant for gas

$$= 3.948 \left[k \left[\frac{2}{k+1} \right]^{(k+1)/(k-1)} \right]^{½}$$

A1 where $3.948 = \dfrac{3600 \text{ (hr to sec)} \times 0.1 \text{ (bar to MPa)}}{R^{0.5}}$

C_w = specific heat per unit volume of vessel wall, in kilojoules per cubic metre kelvin

= 2425 for aluminium

= 3550 for steel

= 3970 for nickel

= 3430 for copper

F = insulation factor

The following are recommended minimum values of *F*, but may require adjustment where special conditions exist:

For bare uninsulated vessel 1.0

For insulated vessels having thermal conductance at 889°K temperature difference of:

22.7 W/m^{2}K 0.3

11.4 W/m^{2}K 0.15

5.7 W/m^{2}K 0.075

For underground vessels 0

For aboveground vessels covered with earth 0.03

For bare vessels with water sprays 1.0

For transportable vacuum-insulated vessels where the outer shell will remain completely in place when subjected to 650°C 0.0132U

where

U = total thermal conductance of the container insulating material, in watts per square metre kelvin, when saturated with gaseous cargo or air at atmospheric pressure, whichever is greater. The value of U shall take into account any heat flow through nozzles and supports.

For transportable foam-insulated vessels where the foam will remain substantially in place when subjected to 650°C . . . . 0.1 + 0.01188U

where

U = total thermal conductance of the foam insulation, in watts per square metre kelvin, assuming that the insulation has lost 25 mm of its thickness and is saturated with gaseous cargo or air at atmospheric pressure, whichever provides the greater value of thermal conductance. The value of U shall take into account any heat flow though nozzles and supports.

A2 NOTE: This factor is based on the assumption that all insulation has been removed over 10 percent of the total vessel surface area.

f = design stress of vessel wall at design temperature (from Table 3.3.1), in megapascals

k = isentropic exponent (ratio of specific heats for constant pressure and volume) for gas, $\frac{C_p}{C_v}$

L = latent heat of vaporization of vessel contents, in joules per kilogram

M = molecular weight of stored fluid, in kilograms per kilomole

m = maximum mass of stored gas in vessel, in kilograms

m' = initial flow of gas when relief device opens at relieving conditions, in kilograms per second

m'_p = maximum gas flow from plant and compressor into the vessel, in kilograms per second

p = vessel design pressure, in megapascals

Q_a = minimum required aggregate vapour capacity of relief devices, in cubic metres per minute of air at 15°C and 101.5 kPa (abs)

R = Universal gas constant

= 8314 joule per kilomole kelvin

T = design temperature, in kelvin

T_o = minimum operating temperature at design pressure, in kelvin

T_r = relieving temperature, in kelvin

= temperature corresponding to 1.21p + 0.1 megapascals (absolute) on vapour saturation curve for vessels containing liquified gas or liquids

A1 = relieving temperature of any temperature relief device for vessels containing gas, which shall not exceed the temperature corresponding to $\frac{Z}{1.21} \cdot f$ (used in the design) on the f versus T curve or on the 1/1.3 creep rupture strength (mean in 2 hours) versus T curve as agreed by the parties concerned

t = corroded vessel wall thickness, in millimetres

Y_t, Y_p = relieving constant, in (seconds)$^{-1}$

Y_t = 110 000/$C_w t T_r$

A1 Y_p = 10 000/$C_w t T_o$

Z = compressibility of gas or vapour at relieving conditions

n = weld joint efficiency

8.6.2.3 *Fire relief of vessels containing liquefied gas or liquid* The minimum total discharge rate of the relief devices shall be:

$$m' = \frac{7.2 \times 10^4 F \ A_e^{0.82}}{L} \qquad \ldots 8.6.2.3\ (1)$$

Where drainage beneath the vessel will avoid collection of large quantities of flammable material and other site factors will limit the intensity or proximity of a fire, the relief valve capacity for static vessels determined by the above equation may be reduced by up to 40 percent.

Thus the minimum total discharge capacity of the relief devices shall be:

$$Q_a = 41.44 \ \frac{m'}{C} \left[\frac{T_r Z}{M}\right]^{½} \qquad \ldots 8.6.2.3\ (2)$$

8.6.2.4 *Fire relief of vessels containing gas or vapour* For vessels containing gas or vapour above its boiling point under fire conditions, excessive distortion or loss of containment cannot always be prevented by a pressure relief device only. Excessive temperature may weaken the vessel wall enough to cause distortion or rupture before or during relief device operation.

The following cases should be considered:

(a) *No protection* Fire protection is not required on vessels—

(i) whose location is such that it cannot experience an accidental heat flux exceeding 10 kW/m^2;

(ii) which do not pose any other unacceptable additional risk due to loss of containment (e.g. does not release large quantities of toxic or flammable fluid);

(iii) which are insulated having an insulation thermal conductance of less than 20 W/m^{2}K at 800°C; or

(iv) which have shown from experience or tests to suitably withstand fire.

(b) *Over-temperature protection* Vessels requiring fire protection shall be protected by both temperature and pressure sensitive relief devices or comply with Clause 8.12.

Temperature sensitive relief devices shall be sized so that the initial flow under fire conditions is at least:

$$m' = mY_t + m'_p \qquad \ldots 8.6.2.4(1)$$

Such temperature sensitive relief devices may take the form of fusible elements which melt at or below T_r, or valves actuated by temperature sensors e.g. thermocouples set at T_r or gaskets and seals which leak on exposure to fire. In any case the design of such temperature sensitive relief devices shall have the following features:

(i) Their position, number and distribution of sensors around a vessel shall provide early detection of high wall temperature to prevent excessive thermal weakening.

(ii) For temperature actuated relief valves (i.e. other than fusible elements), the components of the relief system exposed to fire shall have a minimum fire rating of 30 minutes.

(c) *Over-pressure protection* Over-pressure protection devices shall be sized so that the initial flow is at least:

$$m' = mY_p + m'_p \qquad \ldots 8.6.2.4(2)$$

Such protection is afforded by conventional pressure relief devices.

(d) *Alternative* As an alternative to Items (b) and (c), the method given in ANSI/API RP 520 may be used.

8.6.3 Capacity for burst tube Where a vessel is fitted with a heating coil or other element whose failure might increase the normal pressure of the fluid in the vessel, e.g. in heat exchangers, calorifiers and evaporators, and the shell design pressure is lower than the design pressure of such element, the relieving capacity of the pressure-relief device shall be adequate to limit the increase in the shell pressure in the event of such failure.

Such vessels which are liquid-filled in both the shell and tubes and which may be subject to shock loading in the event of tube failure shall be fitted with a bursting disc or similar device of size determined by Equation 8.6.3(1). Such bursting disc shall be in addition to the otherwise required pressure-relief devices.

$$A = 2a\left(\frac{P_t - P_v}{P_v}\right)^{1/2} \qquad \ldots 8.6.3(1)$$

where

A = minimum effective area of bursting disc, in square millimetres

a = area of bore of one tube, or of inlet pipe to tubes, or of any restricting orifice fitted in the inlet side, whichever is least, in square millimetres

P_t = design pressure of tubes, in megapascals

P_v = design pressure of vessel shell, in megapascals

For other vessels including evaporators and similar vessels, the safety valves shall have a discharge capacity sufficient to limit pressure under normal operation and shall have a minimum total effective discharge area determined by the following equation:

$$A = \frac{2a}{1.10}\left(\frac{P_t + 0.1}{P_v + 0.1}\right) \qquad \ldots 8.6.3(2)$$

where

A = minimum total effective discharge area of safety valves, in square millimetres

Where a restricting orifice is fitted to limit the flow which the pressure-relief device is required to relieve, it shall be constructed of corrosion-resistant material and shall have the orifice parallel for at least 6 mm.

8.6.4 Capacity for calorifiers and similar vessels The capacity of pressure-relief valves for these vessels shall be based on the manufacturer's rated output of the calorifier and shall be at least equal to the maximum steam capacity capable of being developed at 110 percent of the design pressure. The minimum required discharge capacity may be determined as follows:

$$\text{Capacity, kg/h} = 5.4 \times 10^6 \frac{R}{L} \left(\frac{T_1 - T_2}{T_1 - T_3} \right) \quad \ldots 8.6.4$$

where

R = rated capacity, in kilowatts

L = latent heat of steam at 1.10 times set pressure, in joules per kilogram

T_1 = design steam temperature in tubes, in degrees Celsius

T_2 = saturation steam temperature at 1.10 times set pressure, in degrees Celsius

T_3 = design water temperature in shell, in degrees Celsius

For vessels using fluids other than water, or steam, the capacity of relief devices shall be based on the same principles.

8.6.5 Certified capacity of safety and relief valves The capacity of safety and relief valves selected to meet the requirements of this Section (8.6) shall be the capacity certified in accordance with AS 1271 as adjusted to suit the particular fluid concerned, using data in AS 1271.

8.6.6 Liquid relief capacity of pressure-relief devices The capacity of pressure-relief devices discharging liquid, selected to meet the requirements of this Section, may be the manufacturer's rated capacity determined in accordance with AS 1271 as adjusted to suit the particular fluid concerned.

8.6.7 Capacity for refrigerated or vacuum-insulated vessels. The capacity of pressure-relief devices for refrigerated, insulated, and vacuum-insulated vessels shall provide adequate venting capacity to meet requirements of Clauses 8.6.1 and 8.6.2 on the basis of failure of refrigeration systems or saturation of insulation space with vessel contents or with air at atmospheric pressure.

8.7 PRESSURE SETTING OF PRESSURE-RELIEF DEVICES

8.7.1 Pressure-relief valves Where pressure-relief valves are fitted, at least one valve shall be set to discharge at or below the design pressure of the vessel, except as permitted in Clause 8.7.3. Any additional valves fitted may be set to discharge at a pressure not exceeding 105 percent of the design pressure provided that the aggregate valve capacity complies with Clause 8.6.1. (See Clause 3.2.1.1 concerning margin between set pressure and maximum working pressure.)

8.7.2 Bursting discs Bursting discs fitted in place of or in series with pressure-relief valves shall have a rated bursting pressure such that rupture of the disc will occur at a pressure not exceeding the design pressure of the vessel at the operating temperature (see Clause 3.2.1.1).

Where a bursting disc is fitted in parallel with relief valves to protect the vessel against explosion hazard and is not required to contribute to the required aggregate relieving capacity, the disc may have a maximum bursting pressure at atmospheric temperature (i.e. specified bursting pressure plus positive tolerance) not greater than the standard hydrostatic test pressure for the vessel.

8.7.3 Pressure-relief devices for fire conditions Pressure-relief devices permitted by Clause 8.2.2 primarily as protection against excessive pressure due to exposure to fire or other unexpected sources of external heat shall be set to open at a pressure not exceeding 110 percent of the design pressure of the vessel unless otherwise permitted by the application Standard.

If such a device is used to meet the requirements of both Clauses 8.2.1 and 8.2.2 it shall be set to open in accordance with Clause 8.7.1.

8.7.4 Superimposed back pressure The pressure at which a pressure relief device is set to open shall take into account the effect of superimposed back pressure.

8.7.5 Minimum set pressure Where vessels contain flammable or toxic materials which may cause a hazard in the event of safety devices venting, the set pressure of safety devices shall be as high as practicable and as permitted by this Section.

8.8 INSTALLATION OF PRESSURE-RELIEF DEVICES

8.8.1 Safety valves and non-reclosing devices Safety valves, bursting discs and other non-reclosing relief devices shall be connected to the vessel in the vapour space above any contained liquid, or to piping connected to the vapour space in the vessel which is to be protected. Safety valves shall be mounted with the spindle vertical and pointing up, except that for valves not exceeding 32 mm nominal bore, other spindle positions may be used, provided that the installation complies with the valve manufacturer's recommendation. With vessels containing viscous liquids, special precautions shall be taken to place safety valves in a position where contact with such fluid will not prevent the valve from performing satisfactorily.

8.8.2 Relief valves Relief valves for liquid service shall be connected below the normal operating liquid level.

8.8.3 Inlet connection The connection between the relief device and the vessel shall be as short as practicable, shall have a bore area at least equal to the area of the relief device inlet, and shall not reduce the discharge capacity of the relief device below the capacity required for the vessel. Where the relief device is not close to the vessel, allowance shall be made for the pressure drop from the vessel to the relief device orifice and the arrangement shall be such that the pressure drop will not exceed three percent of the set pressure based on the actual flow capacity of the valve provided that the device is of a type that would preclude the possibility of rapid opening and closing.

The opening in the vessel wall shall be designed to provide direct and unobstructed flow between the vessel and its pressure-relief device. Rounding the edges of the entrance will assist in limiting the pressure drop to the device.

When two or more required pressure-relief devices are placed on one connection, the internal cross-sectional area of this connection shall be at least equal to the combined inlet areas of the relief devices connected to it and in all cases shall be sufficient to avoid restriction of the combined flow of the attached devices.

The inlet connection shall be arranged to prevent collection of foreign matter or liquid at the inlet to the relief device, and should be located where turbulence is not excessive.

No connection other than such as will cause no flow (e.g. pressure gauge) shall be made between the vessel and its relief device.

8.8.4 Stop valves between pressure-relief device and vessel Unless the installation complies with the requirements of either Item (a) or (b) hereof, no means of isolation shall be provided between the vessel and any pressure relief device.

(a) Where isolation is desired for periodic inspection or maintenance of a relief device on a vessel required to operate continuously, the vessel may be fitted with an array of pressure relief devices and isolating valves so mechanically interlocked that the capacity of the relief devices remaining in service cannot under any conditions be reduced below that required by Clauses 8.2.1 and 8.2.2. Any such isolating valve shall be of the full-way type with port area not less than the area of the inlet of its associated relief device, and shall be of a type and so located that the obturator (e.g. valve disc) cannot be inadvertently disconnected and block the connection between the vessel and the relief device.

Where agreed between the parties concerned a procedure of locking by authorized personnel may be used as an alternative to mechanical interlocking. Each isolating valve shall be capable of being locked or sealed in the open position.

(b) Where the pressurizing of a vessel can originate only from an outside source, an isolating valve may be fitted between the vessel and the relief device, provided that the same valve simultaneously isolates the vessel from the means of pressurizing and a suitable device to protect against excess pressure in the event of fire (see Clause 8.6.2), is directly fitted to the vessel without any means of isolation.

8.9 DISCHARGE FROM PRESSURE-RELIEF DEVICES

8.9.1 Safe discharge The discharge from pressure-relief devices shall be made in such a manner as to prevent danger to persons, damage to equipment or environment and preferably to a place where the discharge is visible. Discharge to lower pressure systems is permissible provided that the receiving system can accept the additional load without causing an unacceptable back pressure.

8.9.2 Discharge to atmosphere Unless otherwise provided in the relevant application code, toxic or flammable fluids (where agreed by the parties concerned and other relevant statutory authorities), and other fluids, may be discharged from a static vessel to atmosphere provided that the discharge is outside of and away from buildings, preferably through a vertical pipe to a height of at least 2 m above the vessel or the building in which the vessel is installed. All relief devices shall be arranged so that the discharge does not impinge on the vessel, and the cooling effect will not prevent effective operation of the device, e.g. vessels containing carbon dioxide or nitrous oxide.

8.9.3 Discharge pipes Discharge pipes from pressure-relief valves shall be sized in accordance with AS 4041, so that, under maximum discharge conditions, the build-up of back pressure at the outlet of the valve as the result of the valve discharging does not reduce the relieving capacity of the valve below that required to protect the vessel.

The bore of the discharge pipe shall be not less than the bore of the outlet of the pressure-relief device.

Discharge piping shall run as directly as practicable to the point of final release.

Discharge piping shall be adequately and independently supported to prevent transmittal of forces due to the mass of the tube, discharge reaction and thermal expansion strain. Forces acting on a safety or relief valve should be kept to a minimum under all conditions of operation.

8.9.4 Common discharge pipes Where it is not feasible to provide each pressure-relief device with a separate discharge pipe, a discharge pipe common to a number of devices on one or more vessels may be used by agreement of the parties concerned. In such installations where it is necessary to provide stop valves to permit relief valve maintenance—

(a) a valve or valving arrangement shall be connected to the outlet of the pressure-relief valve which shall be designed to connect the outlet of the valve to the atmosphere while disconnecting the outlet from the common discharge pipe and vice versa; and

(b) the valve or valving arrangement referred to in Item (a) shall meet the requirements of Clause 8.8.4.

The size of a common discharge pipe serving two or more pressure-relief devices that may reasonably be expected to discharge simultaneously, shall ensure that the required total discharge capacity can be achieved. The total pipe area should at least equal the sum of their outlet areas, with due allowance for pressure drop in the downstream sections. Pressure-relief valves specially designed for use on high or variable back pressure should be considered.

8.9.5 Drainage In addition to the requirements of Clause 8.4.7, discharge pipes shall be designed to facilitate drainage or shall be fitted with an open drain to prevent liquid from lodging on the discharge side of the device. Precautions shall be taken to prevent rainwater from collecting in vertical discharge pipes.

8.9.6 Bonnet and pilot valve venting The venting of the bonnet of valves which require venting, and of pilot-operated valves, shall also comply with the above requirements. Precautions shall be taken in the design of the vent piping to avoid any possibility of back pressure on the pilot.

8.9.7 Noise Discharge from pressure relief devices may create excessive noise. Depending on frequency, duration of discharge and location, silencers may need to be fitted to discharge lines. Care shall be taken to ensure that they do not create an obstruction or excessive downstream pressure drop.

8.10 VACUUM-RELIEF DEVICES

8.10.1 Application Where sub-atmospheric pressures may occur (including reduced pressure due to cooling of the contents) and the vessel is incapable of withstanding such conditions, a vacuum-relief device shall be fitted to prevent collapse.

8.10.2 Design, manufacture, testing and marking The design, manufacture, testing and marking of vacuum-relief devices shall comply with the general requirements of AS 1271.

8.10.3 Required capacity and setting The capacity and setting of the vacuum-relief device(s) shall be such as to provide the necessary rate of air (or gas) flow, so that the absolute pressure will not fall below that for which the vessel is designed.

8.10.4 Installation Vacuum-relief devices shall be installed in the same manner as pressure-relief devices (see Clauses 8.8 and 8.9), suitably amended for vacuum conditions. Particular care shall be exercised in the design and installation of the air inlet to such devices to prevent possible blockage.

8.11 FUSIBLE PLUGS

8.11.1 Definition A fusible plug is an operating part, usually in the form of a plug of suitable low melting-point material (usually a metal alloy), which initially blocks a discharge opening in the vessel under normal conditions, but yields or melts at a predetermined temperature to discharge fluid for the relief of pressure.

8.11.2 Application By agreement between the parties concerned, one or more fusible plugs may be used in lieu of pressure-relief devices only in special applications, e.g. to provide protection in the event of fire around a vessel which is isolated from a safety valve, and under the following conditions:

(a) A pressure-relief device is required only for the protection of the vessel in the event of a fire or other unexpected source of extreme heat.

(b) The service conditions and installation are such that deposits will neither shield the device (causing an increase in temperature necessary to fuse the plug) nor restrict the discharge.

(c) The contents of the vessel are non-toxic and non-flammable and the water capacity of the vessel does not exceed 500 L, or the content of the vessel is toxic or flammable and the water capacity of the vessel does not exceed 100 L.

(d) The plugs comply with the remaining requirements of this Clause (8.11).

In special instances and with agreement of the parties concerned, a soft brazed or soldered joint with appropriate yield temperature may be used in lieu of a fusible plug.

8.11.3 Design, manufacture, testing and marking Plugs shall be in accordance with AS 2613.

8.11.4 Required discharge capacity The minimum discharge capacity required to protect the vessel shall be determined in accordance with Clause 8.6.2 or, if appropriate, with AS 2613.

The size and number of fusible plugs shall be sufficient to relieve the above minimum discharge capacity.

8.11.5 Required yield temperature Fusible plugs shall have a maximum yield temperature (i.e. a specified yield temperature plus 3°C) not exceeding the temperature which would result in a rise in vessel pressure to 120 percent of the design pressure of the vessel.

For vessels containing liquefied flammable or toxic gases at ambient temperatures, the specified yield temperature shall comply with the above requirement and shall be not less than 5°C above the temperature used as a basis for the design pressure.

For vessels containing permanent gases at ambient temperatures, the specified yield temperature shall not exceed 80°C and should not be less than 70°C, except that for air receivers using plugs for the protection required by Clause 8.11.2(d) the specified yield temperature shall not exceed 150°C.

8.11.6 Installation Fusible plugs shall be connected to the vapour space and located in positions which will represent the highest temperature of the vessel and its contents.

Where the vessel length exceeds 750 mm, at least one fusible plug shall be installed at each end of the vessel and each shall have the full capacity required to protect the vessel.

The installation shall comply with Clause 8.9. Where the vessel is in a location where the collection of discharged gas would be dangerous, e.g. toxic or flammable or carbon dioxide gas, it is recommended that the discharge from the fusible plug be piped to atmosphere. The connection of piping shall be designed to minimize its influence on the yield temperature of the plug.

8.12 PROTECTION AGAINST EXCESSIVE TEMPERATURE Where the temperature of a pressure-containing part of a vessel may exceed the maximum design temperature while still subject to the design pressure (or where the maximum stress in a part may exceed the design strength for the temperature of the part) due to a credible failure of a single temperature, flow or level control device, consideration shall be given to the fitting of one or more safety devices which will limit the temperature at the operating pressure, or to the fitting of temperature actuated devices capable of relieving pressure (see Clause 8.11). Such safety devices should be independent of, and additional to, the single control device and of a fail-safe design, and shall be agreed by the parties concerned. (See also Clause 8.6.2).

In as much as pressure-relief devices may not protect a vessel from excessive temperature in a fire (e.g. in an LP gas vessel the vessel wall temperature in a fire may reach sufficiently high temperature to cause bursting at or below the maximum accumulation permitted), consideration should be given in critical localities to the fitting of a pressure-reducing system to avoid bursting of vessels containing lethal or flammable gases and/or to water spray or fire protection systems which will limit the temperature of the vessel.

8.13 PRESSURE GAUGES

8.13.1 Application Unless otherwise agreed between the parties concerned, at least one pressure gauge shall be provided for each vessel fitted with a pressure-relief device.

8.13.2 Type and size Gauges shall comply with AS 1349 or other Standard agreed by the parties concerned. It is recommended that static vessels be fitted with a bourdon tube type pressure gauge and transportable vessels with a Schaffer or diaphragm type of gauge.

The nominal size shall be not less than 75 mm diameter except that in vessels less than 380 mm diameter, a 50 mm diameter gauge may be used by agreement between the parties concerned. The operating pressure shall fall within the middle third of the graduated range of the gauge and a red line shall mark the operating pressure. Where a gauge is compensated for head of liquid between the gauge and the vessel connection, the amount of such compensation should be marked on the dial.

As an alternative digital type pressure gauges may be used provided they have clear readability, reliability and accuracy equivalent to AS 1349.

8.13.3 Connection The pressure gauge should preferably be located on the vessel itself, but may be adjacent to the vessel on the inlet pipe. Where a number of vessels are connected to the same system, one gauge will suffice for all vessels provided that these vessels operate at the same pressure and the gauge may at all times be capable of connection so as to indicate the pressure at any relevant relieving device.

It is recommended that a shut-off valve be fitted between the vessel and the gauge, particularly where a vessel cannot be readily removed from service for replacement of the gauge.

Gauges shall be visible from the position where the operator controls the vessel pressure or opens quick-acting covers and shall be fitted with some device such as a syphon pipe to prevent excessive temperature reaching the operating element of the pressure gauge.

8.14 LIQUID LEVEL INDICATORS

8.14.1 General Where liquid level indicators are required, the pressure retaining components of the indicators shall comply with the general design and manufacture requirements of AS 1271 (or other equivalent Standard) or this Standard (AS 1210) and the indicator shall be capable of indicating the liquid level to the required accuracy.

8.14.2 Tubular glass indicators Tubular glass indicators shall comply with AS 1271 and all passageways shall be so constructed that a cleaning instrument can be passed through them. They shall be adequately protected against damage, and be suitably guarded to prevent injury to persons in the event of failure.

Tubular glass indicators shall not be used for lethal or toxic materials or on transportable vessels.

8.15 ISOLATION FITTINGS Where it is necessary for inspection, maintenance or other purposes, suitable provision shall be made to isolate the vessel from all pressure sources.

Where the source of pressure is from another connected vessel which may be in operation during inspection, the provision for isolation shall be one of the following:

(a) One stop valve and a blanking plate.

(b) Two stop valves with an atmospheric vent between.

(c) Removal of a section of interconnecting pipework.

All provisions for isolation are located between the vessel and each connected source of pressure. Where the source of pressure serves only one vessel, one stop valve only is required provided the pressure source can be rendered inoperative.

NOTE: Where other valves are fitted and comply with the requirements of Clause 8.8.4, such valves may be considered for compliance with the requirements of (a) or (b) above. Where such valves comply with the requirements of Clause 8.15, no further valves should be necessary.

8.16 DRAINAGE

8.16.1 Provision for drainage Unless otherwise permitted in the relevant application code, provision shall be made for the complete drainage of a vessel which contains or is likely to contain material which is corrosive to the vessel (e.g. water in air receivers) or which is toxic or flammable. This may involve a suitable drain located at the lowest part of the vessel and a full-way valve. The size of the valve should be at least 20 mm but shall not be less than 10 mm.

8.16.2 Discharge Where a drain valve is required to discharge toxic or flammable material, discharge piping shall be attached to the valve and shall lead to a safe location. The discharge shall be made in a manner to prevent danger to persons or damage to equipment and environment and preferably so that the discharge is visible.

8.17 VENTS Provision shall be made to vent air from the highest parts of the vessel during hydrostatic test. Where openings provided for other purposes are not suitable, openings shall be provided and shall be sealed by any suitable means after testing.

8.18 PROTECTION OF VALVES AND FITTINGS

8.18.1 Location for inspection and maintenance Pressure-relief devices, other safety devices and important vessel fittings shall be located and installed so that they are readily accessible for operation, inspection, maintenance and removal.

8.18.2 Protection against interference Where the pressure setting or other adjustment is external to the safety device, the adjustment shall be locked and/or sealed, unless otherwise agreed between the parties concerned. Such devices and fittings shall be installed and protected so that they cannot be readily rendered inoperative or be tampered with, and so that entrance of dirt, water, wildlife and other deleterious material to the valve outlet will be at a minimum. Devices shall be protected or located to prevent freezing from making the device inoperative.

8.18.3 Protection against damage All safety valves and fittings on vessels shall be arranged, where possible, to afford maximum protection against accidental damage. See Clause 3.26 for protection in relation to transportable vessels.

SECTION 9 PROVISIONS FOR DISPATCH

9.1 CLEANING On completion of the vessel and prior to dispatch, all vessels shall be cleaned and shall be free from loose scale and other foreign matter. (See AS 4458.)

NOTE: Specific requirements for cleaning and surface treatment should be agreed between the purchaser and manufacturer.

9.2 PROTECTION Prior to dispatch, the vessel shall be protected as necessary against damage during transport and storage prior to erection. The extent and responsibility for such protection shall be agreed between the purchaser and the manufacturer and should have due regard to physical damage and/or corrosion which may occur due to the method and conditions of transport and storage and the time which may elapse before erection.

Particular attention shall be given to the protection of machined surfaces, and the compatibility therewith, as regards corrosion, of any material used for physical protection. The possibility of distortion of the vessel and any of its parts shall receive special consideration. Where appropriate, suitable provision shall be made for lifting, supporting and anchoring the vessel.

9.3 ASSOCIATED FITTINGS AND COMPONENTS Arrangement for the protection or the separate supply of the vessel's protective devices and associated fittings shall be agreed between purchaser and manufacturer where applicable.

SECTION 10 NON-METALLIC VESSELS

10.1 SCOPE Previous Sections of this Standard deal specifically with metallic vessels. This Section applies to pressure vessels or vessel pressure parts made of plastics, fibre-reinforced plastics, glass or other non-metallic materials, except for gaskets (see Clause 3.21.5.1).

10.2 GENERAL REQUIREMENTS Non-metallic vessels should comply with the general principles of this Standard. They shall comply with the following:

(a) The following Sections and Clauses which apply to all vessels:

Section 1—except in Clause 1.12 a suitable designation shall identify the type of construction.

Section 2—Clause 2.1 only, with the requirement that all materials shall be suitable for all anticipated service conditions and should be used within the conditions recommended by the material manufacturer. Allowance shall be made for any ageing or embrittlement and for suitable performance under foreseeable fire conditions (with or without protection).

Section 3—Clauses 3.1, 3.2, 3.3, 3.4 and 3.26 as appropriate.

Section 4—does not apply, see Item (b).

Section 5—Applicable Clauses only.

Section 6—Clause 6.1 only.

Section 7—Equivalent marks and reports.

Section 8—Applicable Clauses only.

Section 9—All Clauses apply.

(b) ANSI/ASME BPV-X, BS 4994, AS 2971, AS 2634 or other national Standard agreed by parties concerned but within the limits of each Standard and for AS 2634 only, to hazard level E to AS 4343. A3

(c) The specific engineering design and any applicable regulations.

(d) All conditions agreed by the parties concerned.

NOTE: Materials equivalent to Australian Standards may be used in lieu of materials listed in Standards referred to in this Clause (10.2).

APPENDIX A

BASIS OF DESIGN TENSILE STRENGTH

(Normative)

A2,A3 **A1 INTRODUCTION** The stresses given in Table 3.3.1 and Table 3.3.9 (and Table 3.21.5 for bolting) are the design tensile strengths, *f*, and are intended to be interpreted as the maximum allowable primary membrane stresses. They are based on the criteria given below using mechanical properties as indicated, with some exceptions.

The stresses given in Table 3.21.5 are the design strengths for use in the design of bolting in accordance with Clause 3.21, and the criteria for these stresses are also given below.

In some instances the design strengths listed are applicable to a limited range of thicknesses. This has been done to simplify presentation where specified properties vary with range of thickness. For design strengths beyond these thickness limits, the material data in the material specification shall be used.

These design strengths do not include an allowance for weld joint efficiency (except for welded tubes complying with ASTM specifications) or casting quality factor, as this is provided for in the appropriate clauses of this Standard.

A2 ASTM materials not listed in Table 3.3.1 may be used with the design strength permitted by ANSI/ASME BPV VIII-1 provided that the design tensile strength does not exceed $\frac{R_m}{4}$ except as permitted by Clause 3.3.9.

A2 NOTATION The notation used for material properties is as follows:

R_m = specified minimum tensile strength for the grade of material concerned at room temperature (tested in accordance with AS 1391 or equivalent)

A3 Alternatively, this may be increased for each item of material, by 50% of the difference in strength R_m and the value of the actual tensile strength of the item of material used in the vessel, as recorded on the steel maker's material test certificate. In this case the actual tensile strength is also limited to 125% of R_m. Also suitable tests are required to assess the actual strength of formed ends or other parts where fabrication methods may reduce tensile strength

ε_u = specified minimum elongation (50 mm gauge length) or percentage reduction in area or equivalent

R_T = specified minimum tensile strength for the grade of material concerned at design temperature *T* (tested in accordance with AS 2291 or equivalent)

R_e = specified minimum yield strength for the grade of material concerned at room temperature (tested in accordance with AS 1391 or equivalent)

Where a material Standard specifies minimum values of R_{eL} or $R_{p0.2}$ ($R_{p1.0}$ for austenitic steels) or $R_{t0.5}$, these values are taken as corresponding to R_e

$R_{e(T)}$ = specified minimum value of R_e or $R_{p0.2}$ ($R_{p1.0}$ for austenitic steels) for the grade of material concerned at design temperature *T* (tested in accordance with AS 2291 or equivalent)

S_{Rt} = estimated mean stress to cause rupture in time *t* (at temperature *T*) for the particular grade of material

S_R = estimated mean stress to cause rupture in 100 000 h at the design temperature *T* for the grade of material concerned; if the width of the scatter band of test results exceeds ±20 percent of the mean value, then S_R shall be taken as 1.25 times the minimum rupture stress

S_c' = estimated mean stress to cause an elongation (creep) of one percent in 100 000 h at design temperature T for the grade of material concerned. A3

A3 CARBON, CARBON-MANGANESE AND ALLOY STEEL PLATE

A3.1 Materials The basis given herein are limited to steels having adequate qualities for plastic deformation at stress concentration points in connection with the service temperature and the design strength considered. This requirement will be met by all of the steels listed in Table 3.3.1.

A3 For materials of low ductility, see Paragraph A11.

A3.2 For design temperatures up to and including 50°C The design strength is the lower of—

A2 $$\frac{R_m{}^*}{4} \text{ and } \frac{R_e}{1.5}$$

A3.3 For design temperatures between 50°C and 150°C The design strength is based on linear interpolation between values determined from Paragraph A3.2 and Paragraph A3.4.

A3.4 For design temperatures 150°C and above

A3.4.1 *Material with specified elevated temperature values* The design strength is the lowest of—

A2 $$\frac{R_m{}^*}{4},\ \frac{R_{e(T)}}{1.5} \text{ and } \frac{S_R}{1.5}$$

A3.4.2 *Material without specified elevated temperature values* The design strength is the lowest of—

A2 $$\frac{R_m{}^*}{4},\ \frac{R_{e(T)}}{1.6} \text{ and } \frac{S_R}{1.5}$$

NOTE: Values of $R_{e(T)}$ have been taken as equal to those specified for otherwise similar materials having specified temperature values, except where—

(a) no $R_{e(T)}$ values are available; or

(b) design strengths in Table 3.3.1 for similar materials having specified elevated temperature values are not directly based on specified $R_{e(T)}$ values.

Where no relevant $R_{e(T)}$ values were available, design strength values have been based upon consideration of—

A2 (i) the trend of relevant properties of equivalent materials in other product forms related to the $R_m/4$* at 300°C to 350°C for the material in question; or

(ii) the design strength permitted for equivalent materials in other national Standards.

A3.5 Values of S_R Values of S_R are conservatively estimated mean values as follows:

(a) For steel complying with AS 1548, the values quoted in the Appendix giving creep rupture properties in that Standard (for non-verified and non-hot-tested steels as well as 'H' steels listed).

(b) For steel complying with other agreed specifications, authoritative data applicable to the steel concerned.

Notwithstanding the value of S_R obtained above, the resultant strength in the creep range shall not exceed the design stress in ANSI/ASME BPV-VIII for the same or almost identical material.

A4 CARBON, CARBON-MANGANESE AND ALLOY STEEL FORGINGS, CASTINGS AND SECTIONS The design strengths for forgings, castings and sections are the design strengths listed for plate of equivalent type, grade, thickness, heat treatment

---

A2 *$R_m/4$ may be replaced by $R_m/3.5$ under the conditions given in Clause 3.3.9.

and properties. Where the steel is not equivalent, the basis of design strengths for plate
A2 shall be used. For castings, see also Clause 3.3.9.

A5 CARBON, CARBON-MANGANESE AND ALLOY STEEL PIPES AND TUBES The design strengths for pipes are the design strengths listed in AS 4041 except
A2 that in no case does the design strength exceed $R_m/4$*.

The design strengths for tubes are the design strengths listed for pipe of equivalent type, grade, heat treatment and properties.

A3 For materials of low ductility, see Paragraph A11.

A6 HIGH ALLOY STEEL (GROUPS H TO M) PLATE, CASTINGS, SECTIONS, PIPES AND TUBES

A6.1 Material to ASTM specifications For high alloy (Groups H to M) steels to ASTM specifications, the design strengths are the lowest of—

A2 $\frac{R_m^*}{4}, \frac{R_e}{1.5}, \frac{R_{e(T)}}{1.5}$ (see Note) and $\frac{S_R}{1.5}$

This basis and the resultant design strengths are the same as adopted by ANSI/ASME.

NOTE: Two sets of design strength values are given for austenitic (Group K) steels, the higher value being determined using a factor of 1.11 with $R_{e(T)}$ in lieu of a factor of 1.5. The higher value should be used only where slightly greater deformation is acceptable (see also Note 1 to Table 3.3.1(B)).

A3 For materials of low ductility, see Paragraph A11.

A6.2 Materials to other than ASTM specifications For high alloy (Groups H to M) steels to other than ASTM specifications, the basis for the determination of design strengths is to be as follows:

(a) *For design temperatures up to and including 50*°C The design strength is the lower of—

A2 $\frac{R_m^*}{4}$ and $\frac{R_e}{1.5}$

(b) *For design temperatures between 50*°C *and 150*°C The design strength is based on linear interpolation between values determined from Item (a) above and Item (c)(i) or Item (c)(ii) below as appropriate.

(c) *For design temperatures 150*°C *and above*

(i) *Material with specified elevated temperature values* The design strength is the lowest of—

A2 $\frac{R_m^*}{4}, \frac{R_{e(T)}}{1.35}$ and $\frac{S_R}{1.5}$

(ii) *Material without specified elevated temperature values* The design strength is the lowest of—

A2 $\frac{R_m^*}{4}, \frac{R_{e(T)}}{1.45}$ and $\frac{S_R}{1.5}$

NOTE: Values of $R_{e(T)}$ may be taken as those specified for otherwise similar materials having specified elevated temperature values or where values of $R_{e(T)}$ are not available, on conservative interpretation of other available information.

Factors 1.35 and 1.45 are to be used only where $R_{e(T)}$ values are based on $R_{p1.0}$.

A3 For materials of low ductility, see Paragraph A11.

A2 *$R_m/4$ may be replaced by $R_m/3.5$ under the conditions given in Clause 3.3.9.

A7 STEEL BOLTING The design strengths for steel bolting have the same basis as
A2 for plate (see Paragraphs A3 and A6) except as provided in Clause 3.3.9 and with the added requirement for heat-treated materials at temperatures below the creep range (i.e. where S_R does not determine design strength) that the stress does not exceed the lower of $0.20R_m$ and $0.25R_e$.

A3 **A8 IRON CASTINGS** The design stength is obtained from the lower of—

$$R_m\,(0.1 + 1.5\,\varepsilon_u) \text{ and } \frac{R_m}{3.5}$$

where

R_m = specified minimum tensile strength at room temperature using test bars of section appropriate to the vessel thickness

A9 NON-FERROUS METALS

A9.1 Plate, sheet, forgings, castings and sections The design strengths listed in Table 3.3.1 are based on the lowest of—

A2 $$\frac{R_m{}^*}{4.0}, \frac{R_e}{1.5}, \frac{R_T}{4.0}, \frac{R_{e(T)}}{1.5}, S'_c \text{ and } S_R$$

where

R_e = minimum 0.2 percent proof stress (or stress at 0.5 percent total strain for copper and its alloys), as specified in the material Standard, at room temperature, in megapascals

$R_{e(T)}$ = conservatively estimated minimum proof stress (0.2 percent offset or 0.5 percent total strain as appropriate), at design temperature, in megapascals

R_m, R_T, S'_c and S_R are defined in Paragraph A2.

This basis is the same as adopted by ANSI/ASME and results in the same design strength except for some alloys.

A3 For materials of low ductility, see Paragraph A11.

A9.2 Bolting The design strengths listed in Table 3.3.1 are based on the lowest of—

$$\frac{R_m}{5}, \frac{R_e}{4}, \frac{R_{e(T)}}{4}, \frac{R_T}{5}, S'_c \text{ and } S_R$$

The basis and resultant stresses are the same as adopted by ANSI/ASME.

A10 DESIGN STRENGTHS FOR SPECIFIC DESIGN LIFETIME IN CREEP RANGE For all steels, the time-dependent design strength for a specific design lifetime in the creep range shall be the *f* value based on this Appendix but with—

$$\frac{S_R}{1.5} \text{ replaced by } \frac{S_{Rt}}{1.3}$$

Where material specifications do not contain appropriate values of S_{Rt}, the values selected for S_{Rt} shall be by agreement.

See AS 1228 and BS 5500 for time-dependent design strength values for selected steels.

A2 *$R_m/4$ may be replaced by $R_m/3.5$ under the conditions given in Clause 3.3.9.

A3 **A11 DESIGN STRENGTH FOR WROUGHT MATERIALS OF LOW DUCTILITY** Where the ductility is less than 12% (on 50 mm gauge length or equivalent), the design strength shall be no greater than the lower of—

$$R_m\,(0.1 + 2\,\varepsilon_u) \text{ and } \frac{R_m}{3.5}$$

APPENDIX B
FINITE ELEMENT ANALYSIS
(Normative)

B1 GENERAL This Appendix provides guidance for using and interpreting finite element analysis (FEA) stress results. Such guidance is necessary because the output from such an analysis, despite the sophistication of the software, is difficult to classify, that is total stresses are not readily separated into primary versus secondary, membrane versus bending and the like.

Finite element stress analysis should only be used—

(a) alongside conventional analytical techniques, e.g.—

  (i) nozzle local loads e.g. WRC 107 and 297;

  (ii) standard results for plates and shells;

  (iii) well established specialist code techniques e.g. ANSI B31.3 equations for mitre bends;

  (iv) stress concentration factors as listed in Shigley*; and

  (v) other commonly employed results as listed in Roark† and Timoshenko's‡ analytical methods. (Where these analytical results exist, they should be preferred.)

(b) to verify other calculations or analyse problems not amenable to any other technique rather than as a primary design tool; and

(c) by experienced, competent stress analysts.

Finite element stress analysis should never be done in isolation, but should be conducted with other established methods.

B2 CALCULATION METHODS As a minimum, a structure shall be analysed assuming linear elastic behaviour. Nearly all necessary results can be obtained in this way. Other techniques may include for example dynamic eigenvalue, compressive buckling, heat transfer. However, this Appendix is primarily concerned with stress analysis and the interpretation of such from FEA. No further comment will be made on these other types of FEA.

Occasionally further, non-linear (e.g. plastic) analysis will be required, but such analysis should be used with caution; and only with sufficient supporting data to ensure convergence of forces and stresses.

In general, results should be reported as Tresca stresses, i.e. the difference between the maximum and minimum principal stress at any point, i.e. twice the maximum shear stress. It will be assumed that all stresses are Tresca stresses. Exceptions to this are as follows:

(a) Shell and strut structures which could buckle, in which case the magnitude of the membrane compressive stress is important and a more elaborate buckling analysis will be necessary.

(b) Brittle structures (e.g. some cast irons) whose compression/tension failure modes are not symmetric.

---

* Shigley JE *Standard handbook of machine design*, McGraw-Hill, New York 1986.

† Roark RJ *Roark's formulas for stress and strain*, McGraw-Hill, New York 1989.

‡ Timoshenko S *Elements of strength of materials*, 5th edition 1968.

In all cases, the meshing technique should ensure the following:

(i) Large elements are not adjacent to small elements; rather, element size varies through the structure smoothly. (The ratio of adjacent element size should not exceed 2:1).

(ii) The aspect ratio of elements falls between 0.33 and 3.

(iii) Four sided elements are preferable to three sided elements and higher order elements are preferable to lower order elements.

(iv) Structural discontinuities have sufficient elements to capture the local behaviour; e.g. a cylindrical shell has a characteristic length $L = 0.55\sqrt{Dt}$, a hole in a plate has a characteristic length equal to it radius. In such cases, at least two quadratic elements or six linear elements within this length are required to capture local behaviour, where this is important.

(v) Benchmark standard results can be used to help verify the output, e.g. membrane or bending stress well away from structural discontinuities.

(vi) A mesh/grid whose element spacing varies smoothly throughout the structure is selected

(vii) Boundary conditions (e.g. planes of symmetry and imposed loads) can be readily verified.

B3 EVALUATION OF RESULTS In order to evaluate the stresses calculated in Paragraph B2 for non buckling structures, the stresses shall be classified according to their—

(a) distribution through a thickness; and

(b) nature, whether self-limiting (secondary) or non-self-limiting (primary).

When stresses have been suitably classified as above, they can than be compared to the appropriate limits in Appendix SH of AS 1210 Supplement 1 using the appropriate basic design stress, *f*.

Extreme caution and considerable experience is required to evaluate FEA buckling results due to the highly variable sensitivity of structures to initial imperfections. Such sensitivities will greatly influence the choice of safety factors which can vary from 3 for cylinders to more than 14 for spheres.

It is also useful to inspect the results to ensure consistency and credibility using the following criteria:

(i) Output contours are free of local meshing anomalies such as scalloping.

(ii) The deflection of the structure appears reasonable in shape and magnitude.

(iii) The maximum variation in stress across any element as proportion of the total variation in Tresca stress does not exceed the following:

Element order	Maximum stress variation
0	10%
1	20%
2	30%
>2	40%

B4 DISTRIBUTION OF STRESS The distribution between membrane stress σ_m (constant across thickness) and bending stress σ_b (proportional to distance from mid-plane) is found by the following equations:

$$\sigma_m = \frac{1}{t}\int \sigma dx \qquad \text{. . . B4(1)}$$

$$\sigma_b = \frac{6}{t^2}\int \sigma x \; dx \qquad \text{. . . B4(2)}$$

where

x = distance from mid-plane of thickness.

For plate elements whose formulation assumes linear distribution through thickness these stresses are most easily found from:

σ_m = mid-plane stress

σ_b = surface stress − mid-plane stress

B5 NATURE OF STRESS In the absence of elaborate non-linear (plastic) analysis, the nature of stresses (whether self-limiting or not) shall be inferred using linear superposition by:

(a) Separating mechanically induced stresses (e.g. from pressure) from known secondary stresses (e.g. thermal).

(b) Estimating the subtracting out the component of a stress in the vicinity of a structural discontinuity due to known stresses, which can be readily calculated by simple analytical techniques e.g. membrane pressures stresses and flat plate bending stresses.

(c) Calculating the component of a stress due to mismatch, e.g. cladding, interface or other self-limiting effects.

B6 REPORTING RESULTS When finite element results are used to establish the integrity of critical equipment, it is important to report the results in such a way as to facilitate their verification. Such a report shall include, but not be limited to the following:

(a) Plot(s) of the deflected shape(s) of the structure under all relevant loading conditions.

(b) Type of mesh used.

(c) The loads used.

(d) The boundary conditions used.

(e) Evidence that the solution has converged.

(f) Sufficient data to show that away from structural discontinuities the stresses are those of simple shell or strut models.

(g) A description of the model and the assumptions used.

(h) Software package and version used.

APPENDIX C
RISK MANAGEMENT
(Informative)

C1 INTRODUCTION Recently amended regulations in Australia now require the designer/manufacturer to manage risk by identifying hazards, assessing risks and controlling these risks (see National Standard for Plant).

Most of this work should already have been done by the designer when complying with the requirements of this Standard which—

(a) automatically requires consideration of almost all hazards, modes of failure and service conditions for which the designer is directly concerned;

(b) has inherently analysed and assessed risks and the normal risks associated with the above hazards; and

(c) has provided suitable controls for these risks comparable with current world good practice.

This Appendix gives guidance on how to suitably comply with these requirements. It is based on Appendix C of AS 3873 and takes into account AS/NZS 4360 and the WorkSafe guide, Plant design—Making it safe.

C2 DESIGNER'S ROLE

The designer(s) is responsible for the mechanical design of pressure parts and appurtenances such as relief devices and associated work performed by the designer. Selection of pressure, temperature, size, flow and controls may be the responsibility of the process designer while selection of materials, location, installation, security and the like, may be the responsibility of the plant designer.

The designer with respect to AS 1210 should—

(a) recognize that mechanical design is an important part of the overall control of risk associated with the vessel; and

(b) at the design stage, consider all hazards which may feasibly arise with the vessel during its entire life and for which the designer of pressure parts can control or influence.

C3 RISK MANAGEMENT SYSTEM

C3.1 System The designer should have a documented risk management system which is applicable to the vessels designed.

Figure C1 gives a simple form to cover risk management with mechanical design to AS 1210 for most pressure vessels. This form should be used to document the overall assessment and provide evidence of compliance with regulations.

C3.2 Hazards The designer should list any special hazards not already addressed adequately in design to this Standard and related Standards, e.g. bursting, leakage and
A3 distortion. (See Clause 3.1.4 and AS/NZS 3788).

A3 The hazard level in accordance with AS 4343 should be determined and recorded. Where the contents or location are not known, assumed contents and location should be specifically stated.

C3.3 Assessment The analysis and assessment of risk are largely done in the design (e.g. loads and safety factors) to this Standard (AS 1210) but special factors should be listed e.g. if the vessel will be located near large numbers of people, the contents are lethal, or if suitable personal protective equipment may be needed.

C3.4 Control The control of risk is also largely done in the design to this Standard (AS 1210) but again any special controls should be listed. These should include any special control measures that may deal with lifting, transport, installation, operation, inspection (e.g. as the creep or fatigue life is approached), maintenance and the like.

C3.5 Record The final record of the assessment should be signed, dated and verified in a similar manner to that with drawings and calculations.

A Note should be included stating that the vessel has been designed on the basis of reasonable care of the vessel during the operating life (see Clause 1.6) and compliance
A3 with AS 3892, AS 3873 and AS/NZS 3788.

C3.6 Supply of information Consideration should be given to the supply of the completed form (see Paragraph C3.1) by the designer to the manufacturer as a means of assuring the purchaser and of assisting to cover the risk management required by the owner/user.

See also Appendix F for information to be supplied by the designer.

C4 MANUFACTURER'S ROLE The manufacturer should—

(a) record any hazard, risk management, or risk control (additional to that in Paragraph C3) considered by the manufacturer as necessary to ensure safe vessels;

(b) report any design faults which may affect safety to the designer for corrective action; and

(c) Comply with Appendix F for information to be supplied by the manufacturer.

C1 EQUIPMENT IDENTIFICATION Registered design No. . . . . Registered No. . . . .

Workplace/Facility . . . . Plant/Equipment No. . . . .

Vessel title . . . . Date built . . . .

C2 HAZARD IDENTIFICATION (i.e. possible sources of harm)

(a) Pressure energy (contributing to leakage and rupture) Hazard level . . . .

(b) Escape of flammable, toxic or harmful fluid from vessel, components and joints—with risk of subsequent fire, burns, injury or harm to health, property or environment. . . . .

(c) Rapid release of high pressure fluid—with projection of vessel components or fragments or high pressure blast. . . . .

(d) Collapse, vacuum implosion or detachment of vessel from equipment or vehicle (in operation or accident)—with projection of vessel and leakage. . . . .

(e) Furnace explosion with fired vessels—with blast, projection of flame or parts. . . . .

(f) Domino or knock-on effect—with subsequent damage to adjacent plant or property. . . . .

(g) Associated hazards—machinery, collision, fire, fall, confined space etc. . . . .

(h) Special operational hazards e.g. quick actuating door, vehicle, or site. . . . .

(i) Other (owner-user to add if applicable). . . . .

C3 RISK ASSESSMENT (i.e. likelihood or chance of above events and consequences) (Note 1)

Likelihood

(a) Vessel (protective devices & controls)—chance of failure & above event(s) is: *rare*

(b) Installation—chance of failure & above event(s) is: *rare*

(c) Operation, care and maintenance—chance of failure & above event(s) but depends on owner-user, is: *unlikely*

(d) Periodic inspection—chance of undetected deterioration is: *unlikely*

(e) Emergency action—chance of inadequate action is: *unlikely*

Consequences

(f) Persons possibly effected—operator(s) and others in vicinity. *yes*

(g) Possible effects—blast injury, burns, or death to persons, or damage to equipment, property or environment. *yes*

Overall assessment

(h) Risks of harm to any person, property or environment is similar to that with the average pressure vessel provided chances of failure of Items (c) & (g) are kept rare or unlikely *rare* or *unlikely*

Risk level with controls in Item C4 is assessed at: *low risk*

C4 RISK CONTROL (i.e. controls adopted to ensure overall risk in Paragraph C3(h) is acceptable).

(a) Vessel (& protective devices & controls): design, manufacture, tests, inspection comply with Australian Standards or equivalent. *yes*

(b) Vessel installation complies with AS 3892 or AS 1425, or equivalent. *yes*

(c) Operation, care and maintenance by competent persons and comply with AS 3873 or equivalent. *yes*

(d) Vessel and system are subjected to periodic checks in accordance with AS/NZS 3788, AS 1425, AS 2327 or equivalent. *yes*

(e) Special additional controls . . . .

FIGURE C1 (in part) TYPICAL GENERIC RISK ASSESSMENT FOR PRESSURE VESSELS*

NOTES:

1 Qualitative results are given in italics and are applicable in most cases.

2 This form is based on AS/NZS 4360 and may be copied directly.

C5 COMMENT

. . . .

. . . .

C6 CERTIFICATION:

Supplied by Designer/manufacturer — Reviewed & completed by Owner/or Representative

. . . .

Signature or Stamp **Date** — **Signature** **Date**

C7 MANAGEMENT REVIEW
(At least every 5 years) **Signature** . . . . **Date** . . . .

C8 REVISIONS **CHANGES** **By** **Approved** **Date**

A . . . .

B . . . .

C . . . .

FIGURE C1 (in part) TYPICAL GENERIC RISK ASSESSMENT FOR PRESSURE VESSELS*

* This form is based on AS/NZS 4360 and may be copied directly.

APPENDIX D

RECOMMENDED CORROSION PREVENTION PRACTICE

(Informative)

D1 GENERAL Only general provisions have been made in this Standard for protection against corrosion, erosion and the like, (see Clause 3.2.4 and 2.5.3.3). Detailed information on this subject is beyond the scope of this Standard but opportunity is taken in this Appendix to provide some additional data and to suggest good practice in the selection of appropriate corrosion allowance.

D2 DATA ON CORROSION RESISTANCE The corrosion resistance of metals listed in Table 3.3.1 and linings as permitted by Clause 3.2.4.4 varies considerably from material to material depending on the environment conditions. Selection of materials with suitable corrosion resistance is vital in design.

Where actual prior experience is not available on corrosion resistance, information may be obtained from the material manufacturer or from sources such as the following:

(1) Uhlig H.H.—The Electro-chemical Society, *Corrosion Handbook*.

(2) American Society for Metals, *Metals Handbook*.

(3) Industrial and Engineering Chemistry, *Metals of Construction*, Vol. 43, Oct., 1951.

(4) McKay and Worthington, *Corrosion Resistance of Metals and Alloys*.

(5) Erich Rabald, *Corrosion Guide*.

(6) Nelson G.A., *Corrosion Data Survey*, National Association of Corrosion Engineers.

(7) Standards Australia, AS/NZS 2312, *Guide to the protection of iron and steel against exterior atmospheric corrosion*.

(8) U.S. Aluminium Association, *Aluminium with Food and Chemicals* .

(9) National Association of Corrosion Engineers, *Coatings and Linings for Immersion Services*.

D3 SUGGESTED GOOD PRACTICE REGARDING CORROSION ALLOWANCE

D3.1 General Pressure vessels may be classified from a corrosion standpoint into one of the following groups:

(a) Vessels for which corrosion rates may be established definitely from information available to the designer covering the chemical characteristics of the substances they are to contain. Such information may, in the case of standard commercial products, be obtained from published sources, or where special processes are involved, from reliable records compiled from results of previous observations by the user or others under similar conditions of operation.

(b) Vessels in which corrosion rates, while known to be relatively high, are either variable or indeterminate in magnitude.

(c) Vessels in which corrosion rates, while indeterminate, are known to be relatively low.

(d) Vessels in which corrosion effects are known to be negligible or entirely absent.

D3.2 Predictable rate Where the rate of corrosion is closely predictable, additional metal thickness over and above that required for the initial operating conditions should be provided at least equal to the expected corrosion loss during the design life of the vessel.

D3.3 Unpredictable rate When corrosion effects are indeterminate prior to design of the vessel, although known to be inherent to some degree in the service for which the vessel is to be used, or when corrosion is incidental, localized, and/or variable in rate and extent, the best judgment of the designer must be exercised. This should establish a reasonable maximum excess shell thickness at least equal to the expected corrosion loss during the desired life of the vessel, at the same time bearing in mind the provision of Paragraph D3.4, which will, in most cases, govern such vessels. For all vessels coming under this classification a minimum corrosion allowance of 1 mm should be provided unless a protective lining is employed. This lining, whether attached to the wall of a vessel or not, is not to be included in the computed thickness for the required shell thickness.

D3.4 Determination of probable corrosion rate For new vessels and vessels for which service conditions are being changed, one of the following methods should be employed to determine the probable rate of corrosion from which the remaining wall thickness at the time of the inspection can be estimated:

(a) The corrosion rate established by accurate data collected by the owner or user on vessels in the same or similar service, should be used as the probable rate of corrosion.

(b) If accurate measurements are not available, the probable rate of corrosion may be estimated from experience of vessels in similar service.

(c) Where the probable corrosion rate cannot be determined by either of the above methods, thickness measurements should be made after 1000 h, or of other practical period of use, and subsequent sets of thickness measurements should be taken after additional similar intervals. If the probable corrosion rate is determined by this method, the rate found while the surface layer was present may not be applicable after the surface layer has disappeared.

D3.5 No corrosive effect In all cases where corrosion effects can be shown to be negligible or entirely absent, no excess thickness need be provided.

D3.6 Corrosion inspection Where a vessel goes into corrosive service without previous service experience, it is recommended that service inspections be made at frequent intervals until the nature and rate of corrosion in service can be definitely established (see Paragraph D3.4). The data thus secured should determine the subsequent intervals between service inspection and the probable safe operating life of the vessel. See
A3 also AS/NZS 3788 for information.

APPENDIX E

INFORMATION TO BE SUPPLIED BY THE PURCHASER TO THE DESIGNER/MANUFACTURER

(Normative)

E1 GENERAL To assist in ensuring that the completed vessel will comply with the requirements of this Standard the information listed in Paragraphs E2 to E7, inclusive, should be provided by the purchaser to the designer/manufacturer not later than the placement of the order.

The purchaser should include such additional requirements which are necessary to enable the vessel to carry out its intended function in a satisfactory manner.

E2 DESIGN To enable the vessel to be designed in accordance with the minimum requirements (Clause 3.1.2), the following information should be supplied by the purchaser:

NOTE: Where the purchaser is responsible for the design (see Clause 3.1.2) some or all of these items may, by agreement, be omitted.

(a) Size and overall dimensions.

(b) Number, size, location and type of connections and openings.

(c) Type and mode of support.

(d) Design pressure and design temperature.

(e) Operating pressure and operating temperature, and if vessel is to operate below 20°C, the design minimum temperature and coincident pressure.

(f) Number of operating cycles expected from intended service of vessel.

(g) Material to be used and corrosion allowance (if equivalent materials are to be used this should be stated—see Clause 2.3).

(h) Classification of vessel (see Clause 1.7).

(i) Nature of contents and type of gas, if vessel is to be used for liquefied gas storage.

(j) Statement whether vessel is to be used as a transport vessel.

(k) Any excessive loads to be applied to nozzles or other parts of vessel (see Clause 3.19.10.1(b)).

In addition to the minimum requirements of this Standard, the purchaser may require other features to be incorporated. These may rule out permissible alternatives as allowed by the Standard; require a higher quality workmanship; or require optional features to be incorporated. The following additional items may then have to be considered:

(i) Special tolerances on dimensions and machined surfaces.

(ii) Specific weld details.

(iii) Surface treatment and finishes internal and external.

(iv) Insulation—cold or hot—as required.

(v) Additional heat treatments.

(vi) Specific welding procedures to be used.

(vii) Specific inspection techniques to be used, e.g. ultrasonic or magnetic particle examination.

(viii) Supply and installation of instruments, valves, safety valves and the like (see Clause 8.1.1).

(ix) Specific details on flanges, flange to nozzle connections, nozzle to shell connections, tubeplate to shell connections, and the like.

(x) Lifting lugs and associated reinforcements.

(xi) Limitation on weight (e.g. transport vessels).

(xii) Others.

E3 VERIFICATION OF DESIGN Where the vessel is designed by the manufacturer, the purchaser should ensure that the manufacturer obtains the design verification in accordance with the AS 3920.1. The purchaser should also state whether the design, specifications and drawings made by the manufacturer are to be accepted by the purchaser prior to start of manufacture.

NOTE: Where the vessel is designed by the purchaser it is expected that the purchaser will himself be responsible for ensuring appropriate design verification.

E4 INSPECTIONS The purchaser should specify on the order any additional inspections required to be made and the stages at which these are to be carried out.

E5 TESTING Where special tests, such as pneumatic testing (see Clause 5.11), corrosion testing (see Clause 5.17), leak testing (see Clause 5.13.4) and similar, are required, these shall be specified.

E6 DISPATCH The purchaser should specify on the order, any particular requirements regarding cleaning, sealing, transportation and protection during transportation of vessel (see Section 9).

E7 CERTIFICATION AND DOCUMENTATION The purchaser should specify any data required from the manufacturer (see Appendix F).

APPENDIX F

INFORMATION TO BE SUPPLIED BY THE DESIGNER/MANUFACTURER

(Normative)

The following information should be supplied:

(a) *By the designer to the manufacturer*:

(i) General arrangement and other drawings necessary for vessel manufacture.

(ii) Information on the material and method (e.g. heat treatment, examinations, tests and inspection) necessary for manufacture.

(iii) Design information to permit completion of the manufacturer's data report.

A3 (iv) Information on those special or unusual requirements not covered by AS 3892, AS 3873 and AS/NZS 3788, e.g. special transport, installation, commissioning, operation, maintenance, inspection and testing (e.g. special tests when approaching creep design life).

(v) If specified, a risk assessment (see Paragraph C2).

(b) *By the designer to the design verification body:* (Only required where design verification is required by AS 3920.1.)

(i) Information in Items (a)(i)–(iii) above.

(ii) Design calculations.

(iii) Other data necessary for the purposes of design verification.

(c) *By the manufacturer to the fabrication inspection body:* (Only required where independent fabrication inspection is required by AS 3920.1).

NOTE: This data may be alternatively made available to the inspector.

(i) Information in Item (a)(i)–(ii) above.

(ii) Material test certificates, qualified welding procedures, welder qualification, production test results, heat treatment certificates, report on non-destructive examination and other applicable requirements of AS 4458.

(d) *By the manufacturer to the purchaser*:

(i) The manufacturer's data report (and other information agreed by the parties concerned at time of placement of order) see AS 4458.

(ii) Such additional data as is required by the purchaser on the order, e.g. calculations, drawings, specifications, risk statement and operating instructions.

(iii) The information in Item (a)(iv).

NOTE: Unless otherwise agreed by the parties concerned—

(a) the above information should be supplied in the English language;

(b) any required design verification should be done before commencement of manufacture; and

(c) any required design registration should be arranged by the designer.

APPENDIX G
NOT ALLOCATED

APPENDIX H
NOT ALLOCATED

APPENDIX I
NOT ALLOCATED

APPENDIX J
NOT ALLOCATED

APPENDIX K

LOW TEMPERATURE VESSELS

(Informative)

K1 SCOPE This Appendix outlines the main basis of the requirements in this Standard for avoidance of brittle fracture—a mode of failure which requires special consideration for vessels intended for low temperature service.

Brittle fracture is spontaneous fracture of steel in a brittle, non-ductile manner, with low toughness usually at low temperatures, with general applied stress below yield. It is mainly confined to ferritic steels and to temperatures usually below 20°C.

This Appendix also provides—

(a) LODMAT (lowest one day mean ambient temperature) data for Australia (see Figure K1);

(b) a list of clauses in this Standard defining requirements for low temperature vessels; and

(c) examples which illustrate various requirements of this Standard for low temperature vessels.

K2 BASIS OF CODE REQUIREMENTS. The requirements of this Standard relating to low temperature vessels are based on—

(a) BS 5500;

(b) ASME BPV VIII-1 and 2; and

(c) practices proved by experience in leading international organizations and in Australia.

Research and extensive fracture testing coupled with fracture mechanics studies indicate that resistance to brittle fracture of carbon and carbon-manganese steels and other ferritic steels depends on—

(i) notch toughness or fracture toughness of the steel in the vessel—for ferritic steels, toughness is lowered with reduction of temperature;

(ii) material thickness—resistance increases with reduction in thickness;

(iii) size and severity of notches (primarily crack-like defects);

(iv) degree of local embrittlement at the tip of pre-existing defects (in the above steels the specified postweld heat treatment reduces severe embrittlement resulting from welding, flame cutting, forming, and the like); and

(v) the general stress level—applied and residual present in the area of the notch.

For carbon and carbon-manganese steels, the material design minimum temperature/thickness limits are based primarily on the prevention of fracture initiation as determined by a wide range of notched and welded Wells wide plate tests. In these tests through-thickness defects up to 10 mm long located in locally embrittled material, were required to withstand approximately four times yield point strain.

A suitable margin of safety (in terms of temperature) reflecting world practices has been applied to the above data. Where a vessel may be subjected to severe impact loading, e.g. in transportable vessels, notch toughness requirements have been increased to reduce risk of brittle fracture propagation. Also the allowance is made for undetected possible imperfections due to Class 2, 2H and 3 constructions.

FIGURE K1 LODMAT ISOTHERMS °C

K3 CLAUSES, APPENDICES AND STANDARDS RELATING TO LOW TEMPERATURE VESSELS

K3.1 General requirements

Clause 1.8.8—Defines ‘minimum operating temperature’ (MOT), a main service condition for selection of low temperature material.

Clause 1.8.9.1—Defines ‘material design minimum temperature’ (MDMT), a material characteristic, i.e. the lowest temperature the material may normally be used at full design strength.

K3.2 Materials

Clause 2.6—General rules for selection and required properties of parent material for use at low temperatures and for avoidance of brittle fracture. It excludes bolting (see 3.21.5)
A3 and welding (see AS/NZS 3992).

Clause 2.6.2—Selection of material—outlines procedures for selection commencing with MOT and using Figure 2.6.2(A) or Figure 2.6.2(B) for C and C-Mn steels, or Table 2.6.3 for other metals.

Clause 2.6.3—Minimum temperatures—provides guidance for determining MOT and then the MDMT required to suit the MOT, stress level and the like.

Clause 2.6.4—Material reference thickness (T_m), the thickness which is 'equivalent' to the butt weld of the Wells wide-plate tests used as a basis for Figures 2.6.2(A) and 2.6.2(B), i.e. equivalent in terms of resistance to brittle fracture initiation. This reference thickness therefore depends on the actual thickness of the components and the size and type of the weld—the latter controlling the size of any defect likely to be present and the volume of metal mechanically and metallurgically affected by welding.

Clause 2.6.5—Details of impact testing.

Clause 2.6.6—Material for vessels subject to shock.

Clause 2.6.7—Non-metallic materials.

K3.3 Design

Clause 3.2.5—Basic design to avoid details which produce severe notches or thermal stress.

Clause 3.3.2—Design tensile strength for low temperature.

Clause 3.3.3—Reduced design tensile strength for low temperature service, i.e. less than 50 MPa.

Clause 3.21.5—Bolting requirements for low temperature.

K3.4 Manufacture—See the following topics in AS 4458:

(a) Method of marking.

(b) Treatment of thermally cut surfaces.

(c) Treatment of sheared cold surfaces.

(d) Limits on cold forming without subsequent heat treatment.

(e) Continuous backing rings for low temperature service.

(f) Limits on peening of welds.

(g) Vessels requiring post-weld heat treatment (including those for low temperature).

(h) Conditions for thickness up to 50 mm without post weld heat treatment.

A3 **K3.5 Testing and qualification** See the following topics in AS/NZS 3992:

(a) Filler metal group classification.

(b) Impact test requirements including requirements for welding procedure and production test plates.

See AS 4037 for avoidance of brittle practice during hydrostatic and pneumatic testing.

K3.6 Appendices

Appendix E—Purchaser to supply data on low temperature service.

Appendix K—This Appendix.

A3 **K4 EXAMPLES OF APPLICATION OF CLAUSES**

K4.1 Example 1—Design temperature and material design minimum temperature, thermally insulated externally and intended to contain ammonia refrigerant.

A1,A3 Data:	Maximum vessel ambient temperature (see AS 2872)	= + 50°C
	Minimum temperature in service (coincident vapour pressure = 0.095 MPa absolute)	= −35°C
	Vapour pressure (gauge) at 50°C	= 1.93 MPa
	Static head of liquid contents	= 0.01 MPa
	Material—Carbon steel AS 1548	Grade 7-460
	Design strength (f)	= 131 MPa
	Welded joint (spot radiographed) (η)	= 0.85
	Design pressure (= vapour pressure at design temperature + other margins selected) (assumed greater than 1.93 MPa to avoid safety valve leakage. Also greater than the minimum of 1.73 MPa required by AS 2022 due to higher temperature)	= 2.04 MPa
	Calculation pressure (at bottom) = Design pressure + static head	= 2.05 MPa
	See Figure K2.	

Design temperature: i.e. temperature which results in greatest thickness of vessel part, i.e. gives greatest pressure = + 52°C (from Figure K2)

Required (*MDMT*) is needed for selection of steel type with adequate toughness and is obtained from Clause 2.6.3.2 using the lowest temperature from the following three conditions:

Condition 1

θ_1 = lowest temperature when calculated membrane stress $\geq 0.67 f\eta$

Assume the membrane stress due to static head = 0.5 MPa

Vapour pressure corresponding to the design pressure = calculation pressure − static head = 2.05 − 0.01 = 2.04 MPa

Vapour pressure (P' gauge) corresponding to a calculated stress ($\eta f'$) is given by—

$$\frac{P'}{2.04} = \frac{\eta f' - 0.5}{111.3 - 0.5}$$

Thus when $\eta f' = 0.67 f\eta$, $P' = 2.04\,(0.67 \times 111.3 - 0.5)/110.8$ = 1.36 MPa

Corresponding vapour temperature = 38°C = θ_1

Condition 2

Vapour pressure (P'' gauge) corresponding to a calculated stress ($\eta f''$) of 50 MPa is calculated as follows:

$P'' = 2.04(50 - 0.5)/111.3$ = 0.91 MPa

Corresponding vapour temperature = 25°C

Required temperature = vapour temperature + 10°C = 35°C = θ_2

Condition 3

Calculated stress at MOT is clearly less than 50 MPa.

Thus: θ_3 = MOT + 50°C = −35 + 50 = + 15°C

Required MDMT

A3 = lowest value of θ_1, θ_2 and θ_3 = + 15°C

K4.2 Example 2—Materials reference thickness (T_m) for weld neck flange.

Data: 150 mm Class 300 flange to ASME B16.5 attached to branch 168 mm OD × 9.5 mm nominal thickness

Flange thickness (t_1) = 47.6 mm
Neck and branch thickness (t_3 and t_2) = 9.5 mm
T_m for flange—see Figure 2.6.4(e):

(a) Postweld heat treated is the greatest of—
(t_w = 9.5 mm; t_2 = 9.5 mm; 0.25t_1 = 11.9 mm) = 11.9 mm.

(b) As-welded. Since the dimension L is approximately 60 mm, i.e. more than 4t_3, the reference thickness in applying Figure 2.6.2(A) is the greater of t_3 and t_2 = 9.5 mm. However, the material should also be checked by reference to Figure 2.6.2(B) using a reference thickness 0.25t_1 = 11.9 mm.

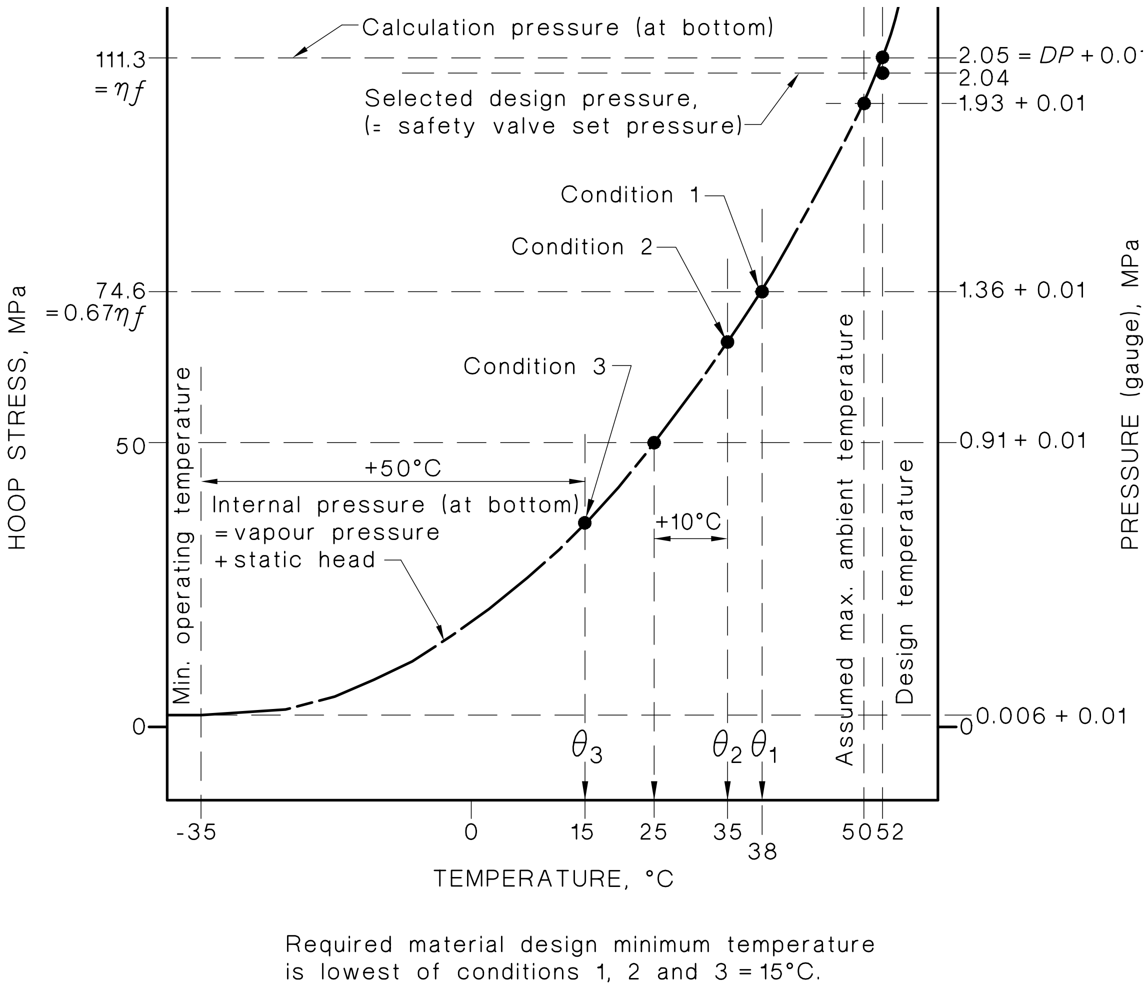


FIGURE K2 EXAMPLE OF DETERMINATION OF MATERIAL DESIGN MINIMUM TEMPERATURE

A3 **K4.3 Example 3**—Material reference thickness (T_m) for branch connection.

Data: A branch 9.5 mm thick is attached to a 15 mm thick shell and provided with a compensating pad 15 mm thick.

T_m for each component is 9.5 mm, 15 mm and 15 mm, respectively.

K4.4 Example 4—Material selection—butt welded plate

Data:
Required material design minimum temperature = −40°C
Material reference thickness (= plate thickness) = 2,6,12,16, and 60 mm
Specified minimum tensile strength = 460 and 490 MPa
As-welded and postweld heat treated.

Find: Suitable AS 1548 grades.

2 mm thick:

As-welded, 460 MPa and 490 MPa steel: From Figure 2.6.2(A)—any grade acceptable.

Postweld heat treated, 460 MPa and 490 MPa steel: From Figure 2.6.2(B)—any grade acceptable.

NOTE: Impact tests are not required see Table 2.6.5.1.

6 mm thick

As-welded: From Figure 2.6.2(A), steel should meet Curve B requirements, as follows:

(a) For 460 MPa steel—31 J at 0°C or fine-grained C-Mn steel.

Suitable grades are: 7-460 or 7-460 L0, L20 or L40.

(b) For 490 MPa steel—40 J at 0°C.

Suitable grades are: 5-490 L0, L20, L40 or L50.

NOTE: Alternatively the vessel manufacturer may elect to test other grades listed in this Standard for compliance, preferably normalized and not intended for use where elevated temperature properties are required, Charpy tested to give equivalent to 27 J, 31 J or 40 J at 0°C (10 mm specimen), as applicable, e.g. Clause 2.6.5.5 gives 5 mm substandard specimens the equivalent of—

$31 \times \frac{7}{10}$, 22 J. If this reached, the steel is acceptable.

Postweld heat treated: From Figure 2.6.5.1—any C or C-Mn steel grade is acceptable.

12 mm thick:

As-welded: From Figure 2.6.2(A), steel should meet Curve D (or E) requirements, as follows:

(a) For 460 MPa steel, Curve D requires 31 J at −40°C and fine-grained C-Mn steel. Grade 7-460-L40 with 31 J at −40°C, complies. Figure 2.6.2(A) also permits linear interpolation of test temperature. Intersection of −40°C line and 12 mm is midway between C and D curves, i.e. at −30°C. Thus minimum requirement is 31 J at −30°C or equivalent. Note 3 to Figure 2.6.2(A) assists here. If Grade 7-460 L20 gives 47 J at −20°C it is equivalent to—

$$31 \text{ J at } \left[-20 - \frac{47 - 31}{1.5} \right] {}^\circ\text{C}$$

i.e. 31 J at 31°C

This meets the above requirements and thus this grade is acceptable also.

(b) For 490 MPa steel, Curve D requires 40 J at −40°C and fine-grained C-Mn steel. Grade 5-490 L40 with 31 J at −40°C, does not comply. Allowing for interpolation

A3 as above, the requirement is 40 J at −30°C or equivalent. Using Note 3 to Figure 2.6.2(A), again, 31 J at −40°C is equivalent to—

31 J + [−30 − (−40)] 1.5 J at −30°C

i.e. 46 J at −30°C.

This grade is therefore acceptable. This is also permitted by the same Note 3 to Figure 2.6.2(A), i.e. 490 MPa steel with 31 J at −40°C may be used at temperatures 10°C above Curve D, i.e. 12 mm plate at −40°C.

Postweld heat treated: From Figure 2.6.2(B)—any grade is acceptable.

16 mm thick:

As-welded: From Figure 2.6.2(A), steel should meet Curve D (or E) requirements as follows:

(a) For 460 MPa steel, Curve D requires 31 J at −40°C and fine grained C-Mn steel. Grade 7-460 L40 is acceptable.

(b) For 490 MPa steel, Curve D requires 40 J at −40°C and fine-grained C-Mn steel. Grade 5-490 L40 with 31 J at −40°C does not comply. Hence postweld heat treatment must be considered or low alloy steel (Ni) with suitable properties used.

Postweld heat treated: From Figure 2.6.2, steel should meet Curve B (or C) requirements as follows:

(a) For 460 MPa steel, Curve B requires 31 J at 0°C, or fine-grained C-Mn steel. Grades 7-460, 460 L0, L20, L40 comply.

NOTE: Alternatively the vessel manufacturer may elect to use other grades listed in this Standard for compliance, preferably normalized and not intended for use where elevated temperature properties are required and Charpy tested for 27 J, 31 J or 40 J at 0°C, as applicable. If this is reached, the steel is acceptable.

(b) For 490 MPa steel, Curve B requires 40 J at 0°C.
Grades 5-490 L0, L20, L40, L50 comply.

60 mm thick:

From Figure 2.6.2(B), i.e. postweld heat treated (as-welded is not permitted in this thickness), steel should meet Curve C requirements as follows:

(a) For 460 MPa steel, Curve C requires 31 J at −20°C. Grade 7-460 L20, with 31 J at −20°C, complies.

(b) For 490 MPa steel, Curve C requires 40 J at −20°C. Grade 7-490 L20, with 47 J at −20°C, complies.

K4.5 Example 5—Fixed tubeplate heat exchanger (Figure 2.6.4(d)).

Data:	Required design minimum temperature	= −80°C
	Shell thickness	= 9 mm
	Tubeplate thickness	= 40 mm
	Thickness of 25 mm OD tube	= 3.5 mm

The shell and its shell to tubeplate welds are postweld heat treated but it is desired the tube to tubeplate welds are not.

Find: Suitable grades to AS 1548.

Tube to tubeplate weld:

Tube reference thickness = 3.5 mm (see Clause 2.6.4(d), Figure 2.6.2(A) (as-welded) and Table 2.6.2.2 requires tubes to meet 27 J at −40°C. The tubeplate must also satisfy this requirement.

A3 Shell to tubeplate: (Without consideration of tube/tubeplate welds). Tubeplate reference thickness = 0.25 × plate thickness, or shell thickness, whichever is greater = (0.25 × 40 = 10 mm, or 9 mm) = 10 mm.

From Figure 2.6.2(B), the tubeplate should also meet requirements of Curve C, i.e. 31 J at −20°C for 460 MPa steel.

Governing criteria for tubeplate: The tubeplate must satisfy Clause 2.6.5.4(b). If the tube-tubeplate weld is not postweld heat treated, a curve cannot be selected from Figure 2.6.2(A). Postweld heat treatment must be applied. From Figure 2.6.2(B), Curve C applies, i.e. 31 J at −40°C. Grade 7-460 L40 applies.

Shell: From Figure 2.6.4(b) the shell reference thickness is the same as for the tubeplate, i.e. 10 mm. Thus from Figure 2.6.2(B) the shell should comply with Curve C, i.e. 31 J at −20°C. Grade 7-460 L20 complies.

For other shell strakes, using 9 mm reference thickness and Figure 2.6.2(B), the shell should comply with Curve C also.

APPENDIX L

NOT ALLOCATED

APPENDIX M

NOT ALLOCATED

APPENDIX N

NOT ALLOCATED

APPENDIX O

NOT ALLOCATED

APPENDIX P

NOT ALLOCATED

APPENDIX Q

NOT ALLOCATED

APPENDIX R

LIST OF REFERENCED DOCUMENTS

(Normative)

AS	
1056	Storage water heaters
1056.1	Part 1: General requirements
1074	Steel tubes and tubulars for ordinary service
1111	ISO metric hexagon commercial bolts and screws
1112	ISO metric hexagon nuts, including thin nuts, slotted nuts and castle nuts
1170	Minium design loads on structures (known as the SAA Loading Code)
1170.2	Part 2: Wind loads
1170.4	Part 4: Earthquake loads
1210 Supp1	Unfired Pressure Vessels—Advance design and construction (Supplement to AS 1210—1997)
1228	Boilers—Water-tube
1252	High strength steel bolts with associated nuts and washers for structural engineering
1271	Safety valves, other valves, liquid level gauges, and other fittings for boilers and unfired pressure vessels
1275	Metric screw threads for fasteners
1349	Bourdon tube pressure and vacuum gauges
1358	Bursting discs and bursting disc devices—Guide to application, selection and installation
1391	Methods for tensile testing of metals
1425	LP gas systems for vehicle engines (know as the SAA Automotive LP Gas Code)
1442	Carbon steels and carbon-manganese steels—Hot-rolled bars and semifinished products
1544	Methods for impact tests on metals
1544.2	Part 2: Charpy V-Notch
1548	Steel plates for pressure equipment
1565	Copper and copper alloys—Ingots and castings
1566	Copper and copper alloys—Rolled flat products
1567	Copper and copper alloys—Wrought rods, bars and sections
1569	Copper and copper alloys—Seamless tubes for heat exchagers
1594	Hot-rolled steel flat products
1596	LP Gas—Storage and handling
1663	Method for dropweight test for nil-ductility transition temperature of ferritic steels
1721	General purpose metric screw threads

AS	
1722	Pipe threads of Whitworth form
1722.1	Part 1: Sealing pipe threads
1722.2	Part 2: Fastening pipe threads
1734	Aluminium and aluminium alloys—Flat sheet, coiled sheet and plate
1796	Certification of welders and welding supervisors
1830	Iron castings—Grey cast iron
1831	Iron castings—spheroidal or nodular graphite cast iron
1832	Iron castings—Malleable cast iron
1833	Iron castings—Austenitic cast iron
1865	Aluminium and aluminium alloys—Drawn wire, rod and strip
1874	Aluminium and aluminium alloy—Ingots and castings
2022	Anhydrous ammonia—Storage and handling (known as the SAA Anhydrous Ammonia Code)
2074	Steel castings
2129	Flanges for pipes, valves and fittings
2291	Methods for tensile testing of metals at elevated temperatures
2451	Bolts, screws and nuts with British standard Whitworth threads
2465	Unified hexagon bolts, screws and nuts (UNC and UNF threads)
2528	Bolts, studbolts and nuts for flanges and other high and low temperature applications
2613	Safety devices for gas cylinders
2634	Chemical plant equipment made from glass-fibre reinforced plastics (GRP) based on thermosetting resins
2809	Road tank vehicles for dangerous goods
2809.1	Part 1: General requirements
2809.3	Part 3: Tankers for compressed liquefiable gases
2809.4	Part 4: Tankers for toxic and corrosive cargoes
2809.6	Part 6: Tankers for cryogenic liquids
2812	Welding, brazing and cutting of metals—Glossary of terms
2865	Safe working in a confined space
2872	Atmospheric heating of vessels containing fluids—Estimation of maximum temperature
2971	Serially produced pressure vessels
3142	Approval and test specification—Electric water heaters
3500	National Pluming and Drainage Code
3500.4	Part 4: Hot water supply systems
3509	LP gas fuel vessels for automotive use
3597	Structural and pressure vessel steel—Quenched and tempered plate
3600	Concrete structures
3653	Boilers—Safety, management, combustion and other ancillary equipment
3678	Structural steel—Hot-rolled plates, floor-plates and slabs

	AS	
	3679	Structural steel
	3679.1	Part 1: Hot-rolled bars and sections
	3857	Heat exchangers—Tubeplates—Method of design
	3873	Pressure equipment—Operation and maintenance
	3892	Pressure equipment—Installation
	3920	Assurance of product quality
	3920.1	Part 1: Pressure equipment manufacture
	3990	Mechanical equipment—Steelwork
	4037	Boilers and pressure vessels—Examination and testing
	4041	Pressure piping
	4087	Metallic flanges for waterworks purposes
	4100	Steel structures
A3	4343	Pressure equipment—Hazard levels
	4458	Pressure equipment—Manufacture
	B148	Unified black hexagon bolts, screws and nuts (UNC and UNF threads) and plain washers—Heavy series
	AS/NZS	
	1110	ISO metric precision hexagon bolts and screws
	1200	Pressure equipment
	2312	Guide to the protection of iron and steel against exterior atmospheric corrosion
	3711	Freight containers
	3711.6	Part 6: Tank containers
	3788	Pressure equipment—In-service inspection
A3	3992	Pressure equipment—Welding and brazing qualification
	4331	Metallic flanges
	4331.1	Part 1: Steel flanges,
	4331.2	Part 2: Cast iron flanges
	4331.3	Part 3: Copper alloy and composite flanges
	4360	Risk management
	ISO 9001	Quality systems—Model for quality assurance in design, development, production, installation and servicing
	ISO	
	5730	Stationary shell boilers of welded construction (other than water-tube boilers)
	ANSI/API	
	5B	Threading, gauging and thread inspection of casing, tubing and line pipe threads
	5L	Line pipe
	520	Sizing, selection and installation of pressure-relieving devices in refineries
	620	Design and construction of large, welded, low-pressure storage tanks

ANSI/API	
RP 530	Calculation of heater-tube thickness in petroleum refineries
ANSI/ASME	
B1.20.1	Pipe threads, general purpose (inch)
B16.5	Pipe flanges and flanged fittings
B16.9	Factory-made wrought steel buttwelding fittings
B16.47	Large diameter steel flanges
B31.3	Chemical plant and petroleum refinery piping
B36.10	Welded and seamless wrought steel pipe
BPV-IID	Boiler and Pressure Vessel Code Part B: Properties
BPV-VIII-1	Boiler and Pressure Vessel Code Section VIII—Rules for construction of pressure vessels: Division 1
BPV-VIII-2	Boiler and Pressure Vessel Code Section VIII—Rules for construction of pressure vessels: Division 2—Alternative rules
BPV-X	Boiler Pressure Vessels Code Section X: Fibre-reinforced plastic pressure vessels
PVHO-1	Safety standard for pressure vessels for human occupancy
ANSI/ASTM	
E 112	Estimating the average grain size of metals
ANSI/AWS	
A5.8	Specification for brazing filler metals
ASTM	
A 53	Specification for pipe, steel, black and hot-dipped, zinc-coated, welded and seamless
A 105	Specification for forgings, carbon steel, for piping components
A 106	Specification for seamless carbon steel pipe for high-temperature service
A 181	Specification for forgings, carbon steel for general-purpose piping
A 182	Specification for forged or rolled alloy-steel pipe flanges, forged fittings, and valves and parts for high-temperature service
A 193	Specification for alloy-steel and stainless steel bolting materials for high-temperature service
A 194	Specification for carbon and alloy steel nuts for bolts for high-pressure and high-temperature service
A 203	Specification for pressure vessels plates, alloy steel, nickel
A 204	Specification for pressure vessels plates, alloy steel, molybdenum
A 213	Specification for seamless ferritic and austenitic alloy-steel boiler, superheater and heat-exchange tubes
A 216	Specification for steel castings, carbon, suitable for fusion welding, for high-temperature service
A 217	Specification for steel castings, martensitic stainless and alloy, for pressure-containing parts, suitable for high-temperature service
A 240	Specification for heat-resisting chromium and chromium nickel stainless steel plate, sheet and strip for pressure vessels

ASTM

A249	Specification for welded austenitic steel boiler, superheater, heat exchanger, and condenser tubes
A 263	Specification for corrosion-resisting chromium steel-clad plate, sheet and strip
A 264	Specification for stainless chromium-nickel steel-clad plate, sheet and strip
A 265	Specification for nickel and nickel-base alloy-clad steel plate
A 266	Specification for carbon steel forgings for pressure vessel components
A 268	Specification for seamless and welded ferritic and martensitic stainless steel tubing for general service
A 302	Specification for pressure vessel plates, alloy steel, manganese-molybdenum and manganese-molybdenum-nickel
A 312	Specification for seamless and welded austenitic stainless steel pipes
A 320	Specification for alloy steel bolting materials for low-temperature service
A 336	Specification for steel forgings, alloy, for pressure and high-temperature parts
A 350	Specification for carbon and low-alloy steel, requiring notch toughness testing for piping components
A 351	Specification for castings, austenitic, austenitic-ferritic for pressure-containing parts
A 352	Specification for steel castings, ferritic and martensitic, for pressure-containing parts, suitable for low-temperature service
A 353	Specification for pressure vessel plates, alloy steel, 9 percent nickel, double-normalized and tempered
A 370	Test methods and definitions for mechanical testing of steel products
A 376	Specification for seamless austenitic steel pipe for high-temperature central-station service
A 387	Specification for pressure vessel plates, alloy steel, chromium-molybdenum
A 420	Specification for piping fittings of wrought carbon steel and alloy steel for low-temperature service
A 430	Specification for austenitic steel forged and bored pipe for high-temperature service
A 452	Specification for centrifugally cast austenitic cold-wrought pipe for high-temperature service
A 479	Specifications for stainless and heat-resisting steel bars and shapes for use in boilers and other pressure vessels
A 517	Specification for pressure vessel plates, alloy steel, high-strength, quenched and tempered
A 524	Specification for seamless carbon steel pipe for atmospheric and lower temperatures
A 553	Specification for pressure vessel plates, alloy steel, quenched and tempered 8 and 9 percent nickel

ASTM	
A 789	Specification for seamless and welded ferritic/austenitic stainless steel tubing for general purposes
A2 A 790	Specification for seamless and welded ferritic/austenitic stainless steel pipe
B 42	Specification for seamless copper pipe, standard sizes
B 75	Specification for seamless copper tube
B 127	Specification for nickel-copper alloy (UNS N04400) plate, sheet and strip
B 148	Specification for aluminium-bronze sand castings
B 152	Specification for copper sheet, strip, plate, and rolled bar
B 160	Specification for nickel rod and bar
B 162	Specification for nickel plate, sheet and strip
B 164	Specification for nickel-copper alloy rod, bar and wire
B 166	Specification for nickel-chromium-iron alloys (UNS N06600, N06601, N06690, N06025, and N06045) and nickel-chromium-cobalt-molybdenum alloy (UNS N06617) rod bar
B 168	Specification for nickel-chromium-iron alloys (UNS N06600, N06601 N06690, N06025, and N06045) and nickel-chromium-cobalt-molybdenum alloy (UNS N06617) plate, sheet and strip
B 187	Specification for copper bar, bus bar, rod and shapes
B 209	Specification for aluminium-alloy sheet and plate
B 210	Specification for aluminium and aluminium-alloy drawn seamless tubes
B 211	Specification for aluminium and aluminium-alloy bar, rod and wire
B 221	Specification for aluminium-alloy extruded bars, rods, wire, shapes, and tubes
B 234	Specification for aluminium and aluminium-alloy drawn seamless tubes for condensers and heat exchangers
B 241	Specification for aluminium and aluminium-alloy seamless pipe and seamless extruded tube
B 247	Specification for aluminium and aluminium-alloy die forgings, hand forgings and rolled ring forgings
B 265	Specification for titanium and titanium alloy strip, sheet, and plate
B 308	Specification for aluminium-alloy 6061-T6 standard structural shapes, rolled or extruded
B 333	Specification for nickel-molybdenum alloy plate, sheet and strip
B 335	Specification for nickel-molybdenum alloy rod
B 348	Specification for titanium and titanium alloy bars and billets
B 381	Specification for titanium and titanium alloy forgings
B 407	Specification for nickel-iron-chromium alloy seamless pipe and tube
B 408	Specification for nickel-iron-chromium alloy rod and bar
B 409	Specification for nickel-iron-chromium alloy plate, sheet and strip
B 424	Specification for nickel-iron-chromium-molybdenum-copper alloy (UNS N08825 and US N08821) plate, sheet and strip

ASTM	
B 425	Specification for nickel-iron-chromium-molybdenum-copper alloy (UNS N08825 and US N08821) rod and bar
B 443	Specification for nickel-chromium-molybdenum-columbium alloy (UNS N06625) plate, sheet and strip
B 446	Specification for nickel-chromium-molybdenum-columbium alloy (UNS N06625) rod and bar
B 523	Specification for seamless and welded zirconium and zirconium alloy tubes
B 550	Specification for zirconium and zirconium alloy bar and wire
B 551	Specification for zirconium and zirconium alloy strip, sheet, and plate
B 564	Specification for nickel alloy forgings
B 574	Specification for low-carbon nickel-molybdenum-chromium, low-carbon nickel-chromium-molybdenum and low-carbon nickel-chromium-molybdenum-tungsten alloy rod
B 575	Specification for low-carbon nickel-molybdenum-chromium and low-carbon nickel-chromium molybdenum alloy plate, sheet and strip
B 625	Specification for UNS N08904, UNS N08925, UNS N08031, UNS N08932, UNS N08926, and UNS R20033 plate, sheet and strip
B 649	Specification for Ni-Fe-Cr-Mo-Cu low-carbon alloy (UNS N08904), Ni-Fe-Cr-Mo-Cu-N low carbon alloys(UNS N08925, UNS N08031 and UNS N08921), and Cr-Ni-Fe-N low carbon alloy (UNS R20033) bar and wire
B 658	Specification for seamless and welded zirconium and zirconium alloy pipe
B 709	Specification for iron-nickel-chromium-molybdenum alloy (UNS N08028) plate, sheet and strip
BS	
1501	Steels for pressure purposes
1501.3	Specification for corrosion and heat-resisting steels: plates, sheet and strip
1503	Specification for steel forgings for pressure purposes
1504	Specification for steel castings for pressure purposes
1740	Specification for wrought steel pipe fittings (screwed BS 21 R-series thread)
2693	Screwed studs
2693.1	Part 1: General purpose studs
A2 3293	Specification for carbon steel pipe flanges (over 24 inches nominal size) for the petroleum industry
3799	Specification for steel pipe fittings, screwed and socket-welding for petroleum industry
3915	Specification for carbon and low alloy steel pressure vessels for primary circuits of nuclear reactors
4076	Specification for steel chimneys
4208	Specification for carbon and low-alloy steel containment structures for stationary nuclear reactors
4439	Specification for screwed studs for general purposes. Metric series

ASTM

4504 Circular flanges for pipe valves and fittings (PN designated)

4504.3.2 Section 3.2: Specification for cast iron flanges

4504.3.3 Section 3.3: Specification for copper alloy and composite flanges

BS

4882 Specification for bolting for flanges and pressure containing purposes

4994 Specification for design and construction of vessels and tanks in reinforced plastics

5154 Specification for copper alloy globe, globe stop and check, check and gate valves

5352 Specification for steel wedge gate, globe and check valves 50 mm and smaller for the petroleum, petrochemical and allied industries

5500 Specification for unfired fusion welded pressure vessels

6374 Lining of equipment with polymeric materials for the process industry

6374.1 Part 1: Specification for lining with sheet thermoplastics

6374.2 Part 2: Specification for lining with non-sheet applied thermoplastics

6374.3 Part 3: Specification for lining with stoved thermosetting resins

6374.4 Part 4: Specification for lining with cold curing thermosetting resins

6374.5 Part 5: Specification for lining with rubbers

PD 6510 A review of the present state of the art of assessing remanent life of pressure vessels and pressurized systems designed for high temperature service

TEMA Standards of Tubular Exchanger Manufacturers Association, Inc.

EJMA Standards of the Expansion Joint Manufacturer's Association

Bednar Henry H Pressure Vessel Design Handbook 2nd edition Van Nostrand Reinhold Publication

Freese C.E. Vibration of Vertical Pressure Vessels.
ASME Paper 58-PET-13 July 1958

De Ghetto K.
& Long W. Design Method To Check Towers For Dynamic Stability. Hydrocarbon Processing Feb 1966.

Mahajan Kanti K. Tall Stack Design Simplified.
Hydrocarbon Processing Sept. 1975.

Moody Gene B. Mechanical Design To Tall Stacks. Hydrocarbon Processing Sept 1969.

AGA/ALPG

AG 102 Approval requirements for gas water heaters

WRC

107 Welding Research Council Bulletin 107, Local stresses in spherical and cylindrical shells due to external loading

297 Welding Research Council Bulletin 297, Local stresses, in spherical and cylindrical shells due to external loadings. Supplement to WRC-107.

NOHSC National Standard for Plant

NOHSC Worksafe guide, Plant design—Making it safe

IMDG International maritime dangerous goods code

APPENDIX S
FIRE PROTECTION OF PRESSURE VESSELS
(Informative)

Fire close to a vessel may lead to—

(a) pressure rise, causing safety valve venting or vessel to burst; or

(b) overheating and weakening vessel walls, again causing vessel to burst. This mode of failure can occur at or below design pressure of vessel.

In deciding on vessel protection, the following options should be considered:

(i) No protection.

(ii) Over-temperature protection.

(iii) Over-pressure protection.

Fire protection would normally not be provided on vessels—

(A) whose location is such that it cannot experience an accidental heat flux exceeding $10 kW/m^2$;

(B) which do not pose any other unacceptable secondary risk due to loss of containment (i.e. release of contents); or

(C) which are insulated having an insulation thermal conductance of less than $10\ W/m^2K$ at 800°C.

In many cases vessels are filled with liquids or liquefied gases and the danger of overheating the vessel walls in case of fire is small. Such vessels are then protected by conventional pressure relief valves, set to lift at a predetermined pressure. If it is judged that such vessels need protection, the relief capacity is calculated from Equation 8.6.2.2(1) in Clause 8.6.2.

In those cases where, the vessel contents is gas or vapour and, in case of fire, the vessel is not cooled by the evaporating liquid. The walls may then quickly overheat and the vessel may burst. This may occur before the set pressure of a safety relief valve is reached.

If it is deemed necessary to protect such a gas filled vessel, the relief mechanism needs to be both heat and pressure controlled. The protection should be provided by temperature and pressure sensitive relief devices.

Temperature sensitive relief devices may take the form of fusible elements which melt at or below T_r (see Clause 8.6.2.3(b)), or valves actuated by temperature sensors, e.g. thermocouples set at T_r. In any case, the design of such temperature sensitive relief devices should have the following features:

(1) Position, number and distribution of sensors of fusible elements around a vessel shall provide early detection of high wall temperature to prevent thermal weakening.

(2) For temperature actuated relief valves (i.e. other than fusible elements) the components of the relief system exposed to fire shall have a minimum fire rating of 30 minutes.

INDEX

AMENDMENT CONTROL SHEET

AS 1210 — 1997

Amendment No. 3 (2002)

REVISED TEXT

SUMMARY: This Amendment applies to Clauses 1.8.32 (new), 1.8.33 (new), 2.3.2, 3.3.1.2, 3.3.6, 3.3.8 and 3.3.9, Tables 3.3.1(A) and 3.3.1(D), Clauses 3.5.1.3, 3.5.1.4.3, 3.5.3.1, 3.7.2, 3.7.3, 3.7.4, 3.7.5, 3.7.6, 3.7.7 (new) and 3.9.2, Figure 3.9.6.2, Clauses 3.10.2, 3.11.2, 3.12.3, 3.12.5.1, 3.12.5.2, 3.12.5.3, and 3.15.2, Figure 3.15.1, Clause 3.19.3.5, Figures 3.19.4 and 3.19.6, Clauses 3.19.10.2, 3.21.5.3.2, 3.21.5.3.3, 3.21.5.3.7 and 3.21.5.3.8, Table 3.21.5, Figure 3.21.6.2, Tables 3.21.6.4(A) and 3.21.6.6(B), Clauses 3.24.3.3, 3.26.3.7, 3.27, 3.32.2.1, 3.32.2.2, 5.2.2.1, 8.9.4 and 10.2, Appendices A, C, K and R.

Published on 16 April 2002.

NOTES

NOTES

Standards Australia

Standards Australia is an independent company, limited by guarantee, which prepares and publishes most of the voluntary technical and commercial standards used in Australia. These standards are developed through an open process of consultation and consensus, in which all interested parties are invited to participate. Through a Memorandum of Understanding with the Commonwealth government, Standards Australia is recognized as Australia's peak national standards body.

Australian Standards

Australian Standards are prepared by committees of experts from industry, governments, consumers and other relevant sectors. The requirements or recommendations contained in published Standards are a consensus of the views of representative interests and also take account of comments received from other sources. They reflect the latest scientific and industry experience. Australian Standards are kept under continuous review after publication and are updated regularly to take account of changing technology.

International Involvement

Standards Australia is responsible for ensuring that the Australian viewpoint is considered in the formulation of international Standards and that the latest international experience is incorporated in national Standards. This role is vital in assisting local industry to compete in international markets. Standards Australia represents Australia at both ISO (The International Organization for Standardization) and the International Electrotechnical Commission (IEC).

Electronic Standards

All Australian Standards are available in electronic editions, either downloaded individually from our Web site, or via on-line and CD ROM subscription services. For more information phone 1300 65 46 46 or visit us at

www.standards.com.au

Standards Australia

GPO Box 5420 Sydney NSW 2001

Administration Phone (02) 8206 6000 Fax (02) 8206 6001 Email mail@standards.com.au

Customer Service Phone 1300 65 46 46 Fax 1300 65 49 49 Email sales@standards.com.au

Internet www.standards.com.au

ISBN 0 7337 1012 3

Printed in Australia