PD 5500:2012+A3:2014

BSI Standards Publication

Specification for unfired fusion welded pressure vessels

This publication is not to be regarded as a British Standard

Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

ICS 23.020.30

ISBN 978 0 580 85188 9

Published by BSI Standards Limited 2014

The following BSI references relate to the work on this standard:

Committee reference PVE/1

Publication history

First published as BS 5500 March 1976;
Second edition January 1982;
Third edition January 1985;
Fourth edition January 1988;
Fifth edition January 1991;
Sixth edition January 1994;
Seventh edition January 1997;
First published as PD 5500 January 2000;
Second edition January 2003;
Third edition January 2006;
Fourth edition January 2009;
Fifth (present) edition June 2012

Amendments issued since publication

Issue Date	Effective Date	Amendment designation	Comments
September 2012	January 2013	Amendment 1, tagged ⟩A1⟨	See Foreword
September 2013	January 2014	Amendment 2, tagged ⟩A2⟨	See Foreword
November 2013	January 2014	Corrigendum 1, tagged	Correction to form X and removal of duplicated contents list
September 2014	January 2015	Amendment 3, tagged ⟩A3⟨	See Foreword

Foreword

Publishing information

This Published Document is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 September [A3] 2014 [A3], to supersede [A3] PD 5500:2012+A2:2013 [A3]. It provides a specification for the design, manufacture, inspection and testing of pressure vessels manufactured from carbon, ferritic alloy and austenitic steels, [A1] aluminium and aluminium alloys, copper and copper alloys, nickel and nickel alloys, and titanium and titanium alloys. [A1]

Supersession

[A3] PD 5500:2012+A3 [A3] supersedes [A3] PD 5500:2012+A2 [A3], which is withdrawn.

Information about this document

The start and finish of text introduced or altered by Amendment No. 1 and No. 2 are indicated in the text by tags [A1] [A1] and [A3] [A3]. Minor editorial changes are not tagged but are provided as replacement pages. Details of the changes can be found in the Summary of Changes.

PD 5500 is updated annually and the DPC (draft for public comment) is normally issued in January each year. Users of the specification are encouraged to review and comment on the proposed amendments in the DPC. This can be done by registering on the BSI draft review website at http://drafts.bsigroup.com or by obtaining a hard copy from BSI Customer Services.

The form and content of the original issue of PD 5500 was derived, without technical amendment, from the 1997 edition of BS 5500, *Specification for unfired fusion welded pressure vessels*, and all amendments issued thereto, up to and including No. 6 (September 1999). At the time PD 5500 differed from BS 5500 only insofar as it did not retain the latter's status as a national standard. This specification is thus, founded on the experience derived from the application of BS 5500 and the first edition of PD 5500, providing an integrated set of rules which have been shown to provide vessels of suitable integrity for a wide range of duties and risk environments.

BS 5500:1997 was withdrawn because its status as a national standard was incompatible with BSI's obligations to CEN consequent to the development of the European Standard EN 13445, *Unfired pressure vessels*. That European Standard was first published in May 2002. A new edition of EN 13445 was published in July 2009.

The process of development of EN 13445 by CEN and its reference in the Official Journal of the European Communities creates, for equipment which conforms to that standard, a presumption of conformity with the essential safety requirements of the EU's pressure equipment directive, 97/23/EC (see article 5 of that directive). This Published Document does not provide that presumption of conformity. However, this Published Document can be used, for vessels within the scope of directives, subject to:

– adherence of the directive's conformity assessment requirements;

– the manufacturer satisfying himself that this PD covers all the technical requirements of the Directive relevant to the vessel in question.

This use may be to cover the full range of applicable vessel requirements or to cover an issue not, at the time, appropriately supported in EN 13345.

The normative form of wording is used in this Published Document, even though this does not have the status of a national standard, in order to ensure clarity in the definition of its requirements and recommendations.

Reference is made in the text to a number of standards which have been withdrawn. Such standards are identified in the list of references (see page V). Consideration is currently being given as to whether replacement standards are available or are being developed, for example, in the European programme, and to the implications for PD 5500 of such replacement standards. When a decision is made about any replacements standards, these will be identified by the issue of an amendment.

The British Standards Institution will be pleased to receive constructive proposals based on experience or research that may lead to improvements in this Published Document. PVE/1 intends to keep the content and technical status of this specification under review along with the need to publish appropriate supplements covering other types of pressure vessels. If there is sufficient demand from industry, this Published Document will be extended to cover other non-ferrous materials.

The requirements for materials not listed in Section 2. Materials, are given in supplements to the main text, which are to be read in conjunction with the main text so as to provide comprehensive requirements for pressure vessels produced in the relevant material. Annexes to the main text are provided which can be either normative (i.e. requirements) or informative (i.e. recommendations). These annexes can include additional requirements to the main text or informative guidance or recommendations, or can provide worked examples. Enquiry cases are published primarily to give guidance and clarification of possible ambiguities in the main text and will be incorporated into the main text or into an annex at an appropriate stage. Some Enquiry cases are published to provide new information and are identified as "preliminary rules".

It should be noted that the effective date of amendments to this Published Document will be later than the publication date to allow users time to amend their own working procedures and documentation. See the introduction to the summary of pages table.

The following figures are reproduced by courtesy of the American Welding Research Council.

Figure G.2.5-1 was originally published as Figure 2 on page 21 of WRC Bulletin 90 September 1963.

Figure G.2.5-2 was originally published as Figure 3 on page 21 of WRC Bulletin 90 September 1963.

Figure G.2.5-3 was originally published as Figure 7 on page 24 of WRC Bulletin 90 September 1963.

Figure G.2.5-4 was originally published as Figure 8 on page 24 of WRC Bulletin 90 September 1963.

Figure G.2.5-5 was originally published as Figure 9 on page 25 of WRC Bulletin 90 September 1963.

Figure G.2.5-6 was originally published as Figure 10 on page 25 of WRC Bulletin 90 September 1963.

Figure G.2.5-7 was originally published as Figure 11 on page 26 of WRC Bulletin 90 September 1963.

Figure G.2.5-8 was originally published as Figure 12 on page 26 of WRC Bulletin 90 September 1963.

Figure G.2.6-1 to Figure G.2.6-8 are reproduced by courtesy of the *International Journal of Solids and Structures*, 1967.

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

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document cannot confer immunity from legal obligations.

Summary of Changes

This specification is kept up to date by the issue, from time to time, of replacement pages.

Tags (A1 〈A1〉, A2 〈A2〉, A3 〈A3〉) on replacement pages will indicate that changes of technical reference significance have been made at that point. The tags applied for any particular amendment or corrigendum carry the same designation number, commencing with 1 for the first amendment, then 2 for the second amendment, and 1 for the first corrigendum, then 2 for the second corrigendum, and so on. Minor editorial changes are not tagged.

The following table identifies for each page of the specification whether or not an amendment or corrigendum has been made to that page and the designation number of the amendment or corrigendum made. Each amended page becomes part of the authorized version at the effective date given for each amendment or corrigendum on the inside front cover.

Page No.	Status/Amendment designation
Front cover	Amendment 3
Inside front cover	Amendment 3
i to ii	Amendment 3
iii to iv	No amendment
v to vi	Amendment 3
vii to xii	No amendment
xiii	Amendment 1
xiv	*blank*
xv to xx	Amendment 3
Section 1	
1/1 to 1/8	No amendment
1/9 to 1/10	Amendment 2
1/11 to 1/12	Corrigendum 1
1/13 to 1/14	No amendment
Section 2	
2/1 to 2/2	Amendment 3
2/3 to 2/20	No amendment
2/21 to 2/22	Amendment 1
2/23 to 2/24	No amendment
2/25 to 2/26	Amendment 3
2/27 to 2/29	Amendment 2
2/30	*blank*
Section 3	
3/1 to 3/2	No amendment
3/3 to 3/4	Amendment 2
3/5 to 3/34	No amendment
3/35 to 3/36	Amendment 1

(continued)

Page No.	Status/Amendment designation
3/37 to 3/42	Amendment 2
3/43 to 3/80	No amendment
3/81 to 3/82	Amendment 3
3/83 to 3/98	No amendment
3/99 to 3/100	Amendment 2
3/101 to 3/102	Amendment 3
3/103 to 3/108	No amendment
3/109 to 3/110	Amendment 2
3/111 to 3/134	No amendment
3/135 to 3/136	Amendment 1
3/137 to 3/150	No amendment
3/151 to 3/156	Amendment 3
3/157 to 3/158	Amendment 1
3/159 to 3/194	No amendment
3/195 to 3/222D	Amendment 3
3/223 to 3/230	No amendment
3/231 to 3/234	Amendment 2
Section 4	
4/1 to 4/2	No amendment
4/3 to 4/4	Amendment 1
4/5 to 4/18	No amendment
4/19 to 4/20	No amendment
4/21 to 4/22	No amendment
Section 5	
5/1 to 5/2	No amendment
5/3 to 5/4	Amendment 2
5/5 to 5/8	Amendment 3
5/9 to 5/10	No amendment
5/11 to 5/16	Amendment 3
5/17 to 5/18	Amendment 2
5/19 to 5/26	No amendment
5/27 to 5/28	Amendment 3
5/29 to 5/33	No amendment
5/34	*blank*
Annex A	
A/1 to A/2	Amendment 2
A/3 to A/4	Amendment 3
A/5 to A/10	No amendment
A/11 to A/14	Amendment 2
A/15	No amendment
A/16	*blank*
Annex C	
C/1 to C/22	No amendment
C/23 to C/24	Amendment 2
C/25 to C/28	No amendment
C/29 to C/30	Amendment 1

(continued)

Page No.	Status/Amendment designation
C/31	No amendment
C/32	*blank*
Annex D	
D/1 to D/2	No amendment
D/3 to D/4	Amendment 2
D/5 to D/6	Amendment 1
D/7 to D/8	Amendment 2
D/9 to D/27	No amendment
D/28	*blank*
Annex E	
E/1 to E/8	No amendment
E/9 to E/14	Amendment 1
E/15 to E/50	No amendment
E/51 to E/52	Amendment 3
E/53 to E/59	No amendment
E/60	*blank*
Annex G	
G/1 to G/2	Amendment 2
G/3 to G/4	Amendment 3
G/5 to G/22	No amendment
G/23 to G/24	Amendment 2
G/25 to G/28	No amendment
G/29 to G/36	Amendment 2
G/37 to G/38	No amendment
G/39 to G/40	Amendment 2
G/41 to G/56	No amendment
G/57 to G/58	Amendment 3
G/59 to G/60	Amendment 2
G/61 to G/64	No amendment
G/65 to G/68	Amendment 3
G/69 to G/72	No amendment
G/73 to G/82B	Amendment 3
G/83 to G/86	Amendment 2
G/87 to G/92	No amendment
G/93 to G/94	Amendment 2
G/95 to G/114	No amendment
G/115 to G/116	Amendment 2
G/117 to G/122	No amendment
G/123 to G/124	Amendment 2
G/125 to G/140	No amendment
Annex Q	
Q/1 to Q/2	Amendment 2
Q/3	No amendment
Q/4	*blank*

(continued)

Page No.	Status/Amendment designation
Annex T	
T/1 to T/10	No amendment
T/11 to T/12	Amendment 3
T/13 to T/16	No amendment
Annex W	
W/1 to W/2	Amendment 1
W/3 to W/4	Amendment 2
W/5 to W/12	No amendment
W/13 to W/14	Amendment 3
W/15 to W/50	No amendment
W/51 to W/52	Amendment 2
W/53 to W/84	No amendment
Aluminium supplement	
Al/1 to Al/2	Amendment 3
Al/3 to Al/12b	Amendment 1
Al/13 to Al/14	No amendment
Al/15 to Al/16B	Amendment 3
Al/17 to Al/20	No amendment
Al/21 to Al/22	Amendment 1
Al/23 to Al/26	No amendment
Copper supplement	
Cu/1 to Cu/2	Amendment 3
Cu/3 to Cu/8	Amendment 1
Cu/9 to Cu/10	Amendment 2
Cu/11 to Cu/12	Amendment 3
Cu/13 to Cu/14	Amendment 1
Cu/15 to Cu/19	No amendment
Cu/20	*blank*
Nickel supplement	
Ni/1 to Ni/2	Amendment 3
Ni/3 to Ni/9	Amendment 1
Ni/10	*blank*
Titanium supplement	
Ti/1 to Ti/2	Amendment 2
Ti/3 to Ti/10	Amendment 1
Index	
I to II	Amendment 1
III	No amendment
IV	*blank*
List of references	
V to VI	Amendment 2
VII to VIII	Amendment 1
IX to XIV	Amendment 3
Enquiry Case: Introduction	
EC/1 to EC/3	Amendment 3
EC/4	*blank*

(continued)

Page No.	Status/Amendment designation
Enquiry Case 73	
EC/1 to EC/2	Amendment 1
Enquiry Case 87	
EC/1 to EC/2	Amendment 3
EC/3 to EC/4	No amendment
Enquiry Case 91	
EC/1 to EC/2	Amendment 3
EC/3 to EC/7	No amendment
EC/8	*blank*
Enquiry Case 127	
EC/1 to EC/11	Amendment 1
EC/12	*blank*
Enquiry Case 133	
EC/1 to EC/4	No amendment
EC/5 to EC/8	Amendment 2
Enquiry Case 134	
EC/1 to EC/2	Amendment 3
Enquiry Case 139	
EC/1 to EC/18	Amendment 2

This page deliberately left blank

Contents

Foreword *xv*

Section 1. General
1.1 Scope *1/1*
1.2 Interpretation *1/3*
1.3 Definitions *1/3*
1.4 Responsibilities *1/4*
1.4.1 Responsibilities of the purchaser *1/4*
1.4.2 Responsibilities of the manufacturer *1/5*
1.4.3 Responsibilities of the Inspecting Authority *1/9*
1.4.4 Certificate of Conformance *1/9*
1.5 Information and requirements to be agreed and to be documented *1/12*
1.5.1 Information to be supplied by the purchaser *1/12*
1.5.2 Information to be supplied by the manufacturer *1/12*
1.6 Thicknesses *1/13*

Section 2. Materials
2.1 Selection of materials *2/1*
2.1.1 General *2/1*
2.1.2 Materials for pressure parts *2/1*
2.1.3 Materials for non-pressure parts *2/24*
2.2 Materials for low temperature applications *2/24*
2.3 Nominal design strength *2/26*
2.3.1 General *2/26*
2.3.2 Notation *2/27*
2.3.3 Time-independent design strength *2/27*
2.3.4 Time-dependent design strength *2/29*

Section 3. Design
3.1 General *3/1*
3.2 Application *3/2*
3.2.1 Consideration of loads *3/2*
3.2.2 Design criteria *3/3*
3.2.3 Design pressure *3/4*
3.2.4 Maximum design temperature *3/4*
3.2.5 Minimum design temperature *3/5*
3.2.6 Thermal loads *3/5*
3.2.7 Wind and earthquake loads *3/5*
3.3 Corrosion, erosion and protection *3/5*
3.3.1 General *3/5*
3.3.2 Additional thickness to allow for corrosion *3/6*
3.3.3 Linings and coatings *3/6*
3.3.4 Wear plates *3/6*
3.4 Construction categories and design stresses *3/7*
3.4.1 Construction categories *3/7*
3.4.2 Design stresses *3/8*
3.5 Vessels under internal pressure *3/9*
3.5.1 Cylindrical and spherical shells *3/9*
3.5.2 Dished ends *3/11*
3.5.3 Cones and conical ends *3/16*
3.5.4 Openings and nozzle connections *3/24*
3.5.5 Flat ends and flat plates *3/77*
3.5.6 Spherically domed and bolted ends of the form shown in Figure 3.5-39 *3/89*
3.6 Vessels under external pressure *3/96*
3.6.1 General *3/96*
3.6.2 Cylindrical shells *3/99*
3.6.3 Conical shells *3/104*

3.6.4 Spherical shells *3/107*
3.6.5 Hemispherical ends *3/107*
3.6.6 Torispherical ends *3/107*
3.6.7 Ellipsoidal ends *3/108*
3.6.8 Procedure by which the departure from the mean circle may be obtained *3/108*
3.7 Supports, attachments and internal structures *3/133*
3.7.1 General *3/133*
3.7.2 Supports *3/133*
3.8 Bolted flanged connections *3/134*
3.8.1 General *3/134*
3.8.2 Notation *3/142*
3.8.3 Narrow-faced gasketted flanges *3/144*
3.8.4 Full-faced flanges with soft ring type gaskets *3/151*
3.8.5 Ungasketted seal welded flanges *3/152*
3.8.6 Reverse narrow-face flanges *3/152*
3.8.7 Reverse full-face flanges *3/153*
3.8.8 Full-faced flanges with metal to metal contact *3/154*
3.9 Flat heat exchanger tubesheets *3/196*
3.9.1 Notation *3/197*
3.9.2 Characteristics of perforated plates *3/200*
3.9.3 Tubesheets of exchangers with floating heads or U-tubes *3/205*
3.9.4 Tubesheets of fixed tubesheet exchangers *3/214*
3.9.5 Allowable shell and tube longitudinal stresses *3/221*
3.9.6 Allowable tube joint end load *3/222*
3.9.7 Tubesheet flanged extension with narrow-face gasket *3/222A*
3.10 Design of welds *3/222A*
3.10.1 General *3/222D*
3.10.2 Welded joints for principal seams *3/223*
3.10.3 Welded joints for other than principal seams *3/225*
3.10.4 Welded joints in time dependent applications *3/226*
3.11 Vessels with external jackets or limpet coils *3/226*
3.11.1 General *3/226*
3.11.2 Jacketted cylindrical shells *3/226*
3.11.3 Welded jacket connections *3/227*
3.11.4 Cylindrical shells with limpet coils *3/230*
3.12 Manholes, inspection openings and quick release openings *3/232*
3.13 Protective devices for excessive pressure or vacuum *3/232*
3.13.1 Application *3/232*
3.13.2 Capacity of relief device(s) *3/233*
3.13.3 Pressure setting of pressure relieving devices *3/233*

Section 4. Manufacture and workmanship
4.1 General aspects of construction *4/1*
4.1.1 General *4/1*
4.1.2 Material identification *4/1*
4.1.3 Order of completion of weld seams *4/2*
4.1.4 Junction of more than two weld seams *4/2*
4.1.5 Localized thinning *4/2*
4.1.6 Rectification of departures from tolerance *4/2*
4.2 Cutting, forming and tolerances *4/2*
4.2.1 Cutting of material *4/2*
4.2.2 Forming of shell sections and plates *4/3*
4.2.3 Assembly tolerances *4/6*
4.2.4 Tolerances for vessels subject to internal pressure *4/7*
4.2.5 Tolerances for vessels subject to external pressure *4/11*
4.2.6 Structural tolerances *4/12*
4.3 Welded joints *4/12*
4.3.1 General *4/12*
4.3.2 Welding consumables *4/12*

4.3.3 Preparation of plate edges and openings *4/13*
4.3.4 Assembly for welding *4/13*
4.3.5 Attachments and the removal of temporary attachments *4/13*
4.3.6 Butt joints *4/14*
4.3.7 Welding: general requirements *4/15*
4.4 Heat treatment *4/15*
4.4.1 Preheat requirements *4/15*
4.4.2 Normalizing: ferritic steels *4/16*
4.4.3 Post-weld heat treatment *4/16*
4.4.4 Methods of heat treatment *4/17*
4.4.5 Post-weld heat treatment procedure *4/18*
4.4.6 Mechanical properties after heat treatment *4/21*
4.5 Surface finish *4/22*

Section 5. Inspection and testing
5.1 General *5/1*
5.2 Approval testing of fusion welding procedures *5/2*
5.3 Welder and operator approval *5/5*
5.4 Production control test plates *5/6*
5.4.1 Vessels in materials other than 9% Ni steel *5/6*
5.4.2 9% Ni steel vessels *5/6*
5.5 Destructive testing *5/6*
5.6 Non-destructive testing *5/7*
5.6.1 General *5/7*
5.6.2 Parent materials *5/7*
5.6.3 Components prepared for welding *5/8*
5.6.4 Non-destructive testing of welded joints *5/8*
5.6.5 Choice of non-destructive test methods for welds *5/11*
5.6.6 Non-destructive testing techniques for welds *5/11*
5.7 Acceptance criteria for weld defects revealed by visual examination and non-destructive testing *5/14*
5.7.1 General *5/14*
5.7.2 Assessment of defects *5/14*
5.7.3 Repair of welds *5/15*
5.8 Pressure tests *5/24*
5.8.1 General *5/24*
5.8.2 Basic requirements *5/24*
5.8.3 Hydraulic testing *5/26*
5.8.4 Pneumatic tests *5/26*
5.8.5 "Standard" test pressure *5/27*
5.8.6 Proof hydraulic test *5/29*
5.8.7 Combined hydraulic/pneumatic tests *5/31*
5.8.8 Leak testing *5/31*
5.8.9 Vessel nameplate *5/32*
5.8.10 Final inspection *5/32*
5.9 Inspection requirements for cast components *5/33*
5.9.1 Examination *5/33*
5.9.2 Defects *5/33*
5.9.3 Identification and marking *5/33*

Annexes
Annex A: Requirements for design where loadings and components are not covered by Section 3 *A/1*
Annex B: Requirements for cylindrical, spherical and conical shells under combined loadings, including wind and earthquakes *B/1*
Annex C: Assessment of vessels subject to fatigue *C/1*
Annex D: Requirements for vessels designed to operate below 0°C *D/1*
Annex E: Recommendations for welded connections of pressure vessels *E/1*
Annex G: Recommendations for the design of local loads, thermal gradients, etc. *G/1*

Annex H: Recommendations for post-weld heat treatment of dissimilar ferritic steel joints *H/1*
Annex J: Recommendations for pressure relief protective devices *J/1*
Annex K: Requirements for design stresses for British Standard materials *K/1*
Annex L: Guidance on structural tolerances *L/1*
Annex M: Requirements for establishing the allowable external pressure for cylindrical sections outside the circularity limits specified in **3.6** *M/1*
Annex N: Requirements for vessel design and the provision of information concerning UK statutory requirements for the demonstration of the continued integrity of pressure vessels throughout their service life *N/1*
Annex Q: Recommendations for preparation and testing of production control test plates *Q/1*
Annex R: Guidance on additional information for flat ends and flat plates *R/1*
Annex S: Guidance on optional documentation for supply with vessel *S/1*
Annex T: Recommendations for arc welded tube to tubeplate joints *T/1*
Annex U: Guidance on the use of fracture mechanics analyses *U/1*
Annex V: Requirements for testing and inspection of serially produced pressure vessels *V/1*
Annex W: Worked examples *W/1*
Annex Z: Guidance on the application of PD 5500 to pressure vessels falling within the scope of the European Pressure Equipment Directive *Z/1*

Supplements

Aluminium supplement: Requirements for aluminium and aluminium alloys in the design and construction of unfired fusion welded pressure vessels *Al/1*
Copper supplement: Requirements for copper and copper alloys in the design and construction of unfired fusion welded or brazed pressure vessels *Cu/1*
Nickel supplement: Requirements for nickel and nickel alloys in the design and construction of unfired fusion welded pressure vessels *Ni/1*
Titanium supplement: Requirements for titanium and titanium alloys in the design and construction of unfired fusion welded pressure vessels *Ti/1*

Index *I*

List of references *V*

List of figures

Figure 1.6-1 – Relationship of thickness definitions *1/14*
Figure 3.5-1 – Dished ends *3/12*
Figure 3.5-2 – Design curves for unpierced dished ends *3/14*
Figure 3.5-3 – Conical shells: Vapour belt arrangement *3/17*
Figure 3.5-4 – Values of coefficient β for cone/cylinder intersection without knuckle *3/20*
Figure 3.5-5 – Geometry of cone/cylinder intersection: large end *3/22*
Figure 3.5-6 – Geometry of cone/cylinder intersection: small end *3/24*
Figure 3.5-7 – Offset cone *3/24*
Figure 3.5-8 – Positions of openings or nozzles in dished ends *3/28*
Figure 3.5-9 – Design curves for protruding nozzles in spherical vessels *(d/D* < 0.5*)* and for protruding nozzles in cylindrical and conical vessels *(d/D* < 1/3) *3/31*
Figure 3.5-10 – Design curves for flush nozzles in spherical shells (*d/D* < 0.5) and for flush nozzles in conical shells (*d/D* < 1/3) *3/32*
Figure 3.5-11 – Design curves for flush nozzles in cylindrical shells (0 < *d/D* < 0.3) *3/33*
Figure 3.5-12 – Design curves for flush nozzles in cylindrical shells (0.2 < *d/D* ≤ 1.0) *3/34*
Figure 3.5-13 – Nozzle in a conical shell *3/42*
Figure 3.5-14 – Notation applicable to spheres *3/42*

Figure 3.5-15 – Notation applicable to spheres *3/43*
Figure 3.5-15a – Notation applicable to oblique nozzles in spheres *3/43*
Figure 3.5-16 – Notation applicable to spheres *3/44*
Figure 3.5-17 – Notation applicable to spheres *3/44*
Figure 3.5-18 – Notation applicable to cylinders *3/44*
Figure 3.5-19 – Notation applicable to cylinders *3/45*
Figure 3.5-20 – Notation applicable to cylinders *3/45*
Figure 3.5-21 – Notation applicable to cylinders *3/46*
Figure 3.5-22 – Protruding rim *3/46*
Figure 3.5-23 – Flush rim *3/47*
Figure 3.5-24 – Arrangement factor *g* *3/47*
Figure 3.5-25 – Nozzle compensation *3/48*
Figure 3.5-26 – Notation applicable to spheres and cylinders *3/49*
Figure 3.5-27 – Notation applicable to spheres and cylinders *3/49*
Figure 3.5-28 – Notation applicable to spheres and cylinders *3/50*
Figure 3.5-29 – Modified flush nozzle compensation *3/51*
Figure 3.5-30 – Modified protruding nozzle compensation *3/52*
Figure 3.5-31 – Maximum branch to body thickness ratio *3/60*
Figure 3.5-32 – Reinforcement of openings and branches *3/61*
Figure 3.5-33 – Reinforcement of non-radial branches *3/73*
Figure 3.5-34 – Typical welded flat ends and covers *3/81*
Figure 3.5-35 – Typical non-welded flat ends and covers *3/82*
Figure 3.5-36 – Factor *C* for welded flat ends for e_{cyl}/e_{cylo} = 1 to 3 *3/83*
Figure 3.5-37 – Factor *C* for welded flat ends for e_{cyl}/e_{cylo} = 3 to > 10 *3/84*
Figure 3.5-38 – Typical stays: areas supported by stays *3/87*
Figure 3.5-39 – Spherically domed and bolted end (narrow faced gasket) *3/91*
Figure 3.6-1 – Effective lengths of cylinder *3/116*
Figure 3.6-2 – Values of ε *3/118*
Figure 3.6-3 – Values of n_{cyl} *3/119*
Figure 3.6-4 – Values of Δ *3/120*
Figure 3.6-5 – Stiffening ring with unsupported section *3/122*
Figure 3.6-6 – Stiffening ring details *3/123*
Figure 3.6-7 – Values of β *3/128*
Figure 3.6-8 – Conical sections: typical stiffeners *3/129*
Figure 3.8-1 – Loose keyed flange with mating components *3/149*
Figure 3.8-2 – Forces and lever arms on loose keyed flange *3/150*
Figure 3.8-3 – Typical lip arrangement for swing bolted flange *3/150*
Figure 3.8-4 – Location of gasket load reaction *3/174*
Figure 3.8-5 – Values of *T, U, Y* and *Z* *3/175*
Figure 3.8-6 – Values of *F* (integral method factors) *3/176*
Figure 3.8-7 – Values of *V* (integral method factors) *3/176*
Figure 3.8-8 – Values of F_L (loose hub flange factors) *3/177*
Figure 3.8-9 – Values of V_L (loose hub flange factors) *3/177*
Figure 3.8-10 – Values of *f* (hub stress correction factors) *3/178*
Figure 3.8-11 – Ungasketted, seal-welded-type flanges *3/178*
Figure 3.8-12 – Contact face between loose and stub flanges in a lap joint where diameters A_2 and B_2 are defined by the same component *3/179*
Figure 3.9-1 – Shell and tube heat exchangers *3/202*
Figure 3.9-2 – Tubesheet layout *3/204*
Figure 3.9-3 – Determination of area *S* *3/205*
Figure 3.9-4 – Design curves: determination of C_0 *3/207*
Figure 3.9-5 – Design curves: determination of F_o *3/208*
Figure 3.9-6 – Design curves: determination of F_o *3/209*
Figure 3.9-7 – Design curves: determination of F_i *3/210*
Figure 3.9-8 – Design curves: determination of F_i *3/211*
Figure 3.9-9 – Typical clamped and simply supported configurations for floating head or U-tubesheets *3/212*
Figure 3.9-10 – Flexural efficiency: triangular layout *3/213*
Figure 3.9-11 – Flexural efficiency: square layout *3/214*

Figure 3.9-12 – Tubesheet: determination of F_q *3/217*
Figure 3.9-13 – Tubesheet: determination of H for $X_a > 4.0$ *3/218*
Figure 3.9-14 – Tubesheet: determination of H for $X_a < 4.0$ *3/219*
Figure 3.9-15 – Determination of the buckling length L_k *3/222*
Figure 3.10-1 – Butt welds in plates of unequal thickness *3/224*
Figure 3.10-2 – Butt welds with offset of median lines *3/225*
Figure 3.11-1 – Some acceptable types of jacketted vessels *3/229*
Figure 3.11-2 – Typical blocking ring and sealer ring construction *3/230*
Figure 3.11-3 – Typical limpet coil *3/231*
Figure 3.11-4 – Limpet coil arrangements *3/231*
Figure 4.2-1 – Profile gauge details and application *4/11*
Figure 4.3-1 – A thin limpet coil weld detail *4/14*
Figure 5.6-1 – Illustration of welded joints for non-destructive testing *5/10*
Figure 5.7-1 – Partial non-destructive testing (NDT) category 2 constructions *5/19*
Figure A.1 – Stress categories and limits of stress intensity *A/7*
Figure A.2 – Curve for the evaluation of Δ *A/12*
Figure A.3 – Use of templates to check tolerances *A/14*
Figure B.1 – Stresses in a cylindrical shell under combined loading *B/4*
Figure B.2 – Stresses in a spherical shell under combined loading *B/5*
Figure B.3 – Stresses in a conical shell under combined loading *B/6*
Figure B.4 – Global loads *B/8*
Figure C.1 – Illustration of fluctuating stress *C/2*
Figure C.2 – Example of pressure vessel fatigue loading cycle and determination of stress ranges *C/7*
Figure C.3 – Fatigue design *S–N* curves for weld details applicable to ferritic steels up to and including 350 °C, austenitic stainless steels up to and including 430 °C, aluminium alloys up to and including 100 °C, nickel alloys up to and including 450 °C and titanium alloys up to and including 150 °C *C/8*
Figure C.4 – Fatigue design *S–N* curves for bolting applicable to ferritic steels up to and including 350 °C, austenitic stainless steels up to and including 430 °C, aluminium alloys up to and including 100 °C, nickel alloys up to and including 450 °C and titanium alloys up to and including 150 °C *C/8*
Figure C.5 – Interaction criteria for assessing coplanar embedded slag inclusions *C/23*
Figure C.6 – Stress measurement points for determining structural hot spot stress at a weld toe *C/24*
Figure C.7 – Deviations from design shape at seam welds *C/28*
Figure C.8 – Weld toe dressing *C/30*
Figure D.1 – Permissible design reference temperature/design reference thickness/required impact test temperature relationships for as-welded components *D/3*
Figure D.2 – Permissible design reference temperature/design reference thickness/required impact test temperature relationships for post-weld heat-treated components *D/4*
Figure D.3 – Examples of details for attaching non-critical components to pressure shell *D/7*
Figure D.4 – Location of Charpy V-notch specimens in weld metal (as-welded vessels) *D/25*
Figure D.5 – Location of Charpy V-notch specimens in weld metal (stress relieved vessels) *D/25*
Figure D.6 – Location of Charpy V-notch specimens in heat affected zone *D/25*
Figure D.7 – Example of detail for avoidance of severe thermal gradients *D/27*
Figure E.1 – Typical weld preparations for butt welds using the manual metal-arc process *E/2*
Figure E.2 – Typical weld preparations for circumferential welds where the second side is inaccessible for welding *E/3*

Figure E.3 – Typical weld preparations for butt welds using the submerged arc welding process *E/6*
Figure E.4 – Typical weld preparations for butt welds using the manual inert gas arc welding for austenitic stainless and heat resisting steels only *E/7*
Figure E.5 – Typical weld details for circumferential lap joints *E/8*
Figure E.6 – Standard weld details *E/14*
Figure E.7a) – Limitations on geometry of fillet weld applied to the edge or a part *E/15*
Figure E.7b) – Transverse and longitudinal sections of branch connections *E/15*
Figure E.8 – Weld details for set-in branches *E/16*
Figure E.9 – Set-on branches *E/18*
Figure E.10 – Set-on branches *E/19*
Figure E.11 – Set-on branches *E/20*
Figure E.12 – Set-on branches *E/21*
Figure E.13 – Set-on branches *E/22*
Figure E.14 – Set-on branches *E/23*
Figure E.15 – Set-on branches *E/24*
Figure E.16 – Set-in branches: fillet welded connections *E/25*
Figure E.17 – Set-in branches: partial penetration butt welded connections *E/26*
Figure E.18 – Set-in branches: full penetration connections *E/27*
Figure E.19 – Set-in branches: full penetration connections *E/28*
Figure E.20 – Set-in branches: full penetration connections with asymmetrical butt joints *E/29*
Figure E.21 – Set-in branches: full penetration connections welded from one side only *E/30*
Figure E.22 – Forged branch connections *E/31*
Figure E.23 – Forged branch connections *E/32*
Figure E.24 – Set-on branches with added compensation rings *E/33*
Figure E.25 – Set-in branches with added compensation rings *E/34*
Figure E.26 – Set-in branches with added compensation rings *E/35*
Figure E.27 – Set-in branches with added compensation rings *E/36*
Figure E.28 – Set-in branches with added compensation rings *E/37*
Figure E.29 – Studded connections *E/38*
Figure E.30 – Socket welded and screwed connections *E/40*
Figure E.31 – Flanges *E/41*
Figure E.32 – Flanges *E/42*
Figure E.33 – Flanges *E/44*
Figure E.34 – Jacketted vessels: typical vessel/blocking ring attachments *E/45*
Figure E.35 – Jacketted vessels: typical blocking ring/jacket attachments *E/46*
Figure E.36 – Jacketted vessels: typical sealer rings *E/48*
Figure E.37 – Jacketted vessels: typical through connections *E/49*
Figure E.38 – Flat ends and covers *E/50*
Figure E.39 – Tubeplate to shell connections: accessible for welding on *both* sides of the shell *E/53*
Figure E.40 – Tubeplate to shell connections: accessible for welding from *outside* of shell only *E/54*
Figure E.41 – Tubeplate to shell connections: accessible for welding on *both* sides of shell *E/55*
Figure E.42 – Tubeplate to shell connections *E/56*
Figure E.43 – Tubeplate to shell connections *E/58*
Figure E.44 – Tubeplate to shell connections *E/59*
Figure G.2.2-1 – Restriction on vessel/attachment geometry *G/5*
Figure G.2.2-2 – Vessel with central radial load *G/6*
Figure G.2.2-3 – Vessel with radial load out of centre *G/6*
Figure G.2.2-4 – Graph for finding equivalent length L_e *G/7*
Figure G.2.2-5 – Chart for finding $64\frac{r}{t}\left(\frac{C_x}{r}\right)^2$ *G/9*
Figure G.2.2-6 – Cylindrical shells with radial load: circumferential moment per millimetre width *G/10*

Figure G.2.2-7 – Cylindrical shells with radial load: longitudinal moment per millimetre width *G/11*
Figure G.2.2-8 – Cylindrical shells with radial load: circumferential membrane force per millimetre width *G/12*
Figure G.2.2-9 – Cylindrical shells with radial load: longitudinal membrane force per millimetre width *G/13*
Figure G.2.2-10 – Circumferential bending moment due to a radial line load variation round circumference *G/16*
Figure G.2.2-11 – Longitudinal moment from radial line load variation round circumference *G/17*
Figure G.2.2-12 – Circumferential membrane force from radial line load variation round circumference *G/18*
Figure G.2.2-13 – Longitudinal membrane force from radial line load variation round circumference *G/19*
Figure G.2.2-14 – Circumferential bending moment due to a radial line load variation along cylinder *G/20*
Figure G.2.2-15 – Longitudinal moment due to a radial line load variation along cylinder *G/21*
Figure G.2.2-16 – Circumferential membrane force due to a radial line load variation along cylinder *G/22*
Figure G.2.2-17 – Longitudinal membrane force due to a radial line load variation along cylinder *G/23*
Figure G.2.2-18 – Maximum radial deflection of a cylindrical shell subjected to a radial load *W* for *r/t* between 15 and 100 *G/25*
Figure G.2.2-19 – Maximum radial deflection of a cylindrical shell subjected to a radial load *W* for *r/t* between 100 and 300 *G/26*
Figure G.2.2-20 – Graphs for finding the square $2C_1 \times 2C_1$ equivalent to a rectangular loading area $2C_x \times 2C_\phi$ *G/27*
Figure G.2.3-1 – Circumferential moment *G/30*
Figure G.2.3-2 – Longitudinal moment *G/30*
Figure G.2.3-3 – Sector stresses *G/35*
Figure G.2.3-4 – Notation for external loads at a nozzle or attachment on a cylindrical shell *G/36*
Figure G.2.4-1 – Chart for finding *s* and *u* *G/43*
Figure G.2.4-2 – Spherical shell subjected to a radial load *G/44*
Figure G.2.4-3 – Deflections of a spherical shell subjected to a radial load *W* *G/45*
Figure G.2.4-4 – Meridional moment M_x in a spherical shell subjected to radial load *W* *G/46*
Figure G.2.4-5 – Circumferential moment M_ϕ in a spherical shell subjected to a radial load *W* *G/47*
Figure G.2.4-6 – Meridional force N_x in a spherical shell subjected to a radial load *W* *G/48*
Figure G.2.4-7 – Circumferential force N_ϕ in a spherical shell subjected to a radial load *W* *G/49*
Figure G.2.4-8 – Spherical shell subjected to an external moment *G/51*
Figure G.2.4-9 – Deflections of a spherical shell subjected to an external moment *M* *G/52*
Figure G.2.4-10 – Meridional moment M_x in a spherical shell subjected to an external moment *M* *G/53*
Figure G.2.4-11 – Circumferential moment M_ϕ in a spherical shell subjected to an external moment *M* *G/54*
Figure G.2.4-12 – Meridional force N_x in a spherical shell subjected to an external moment *M* *G/55*
Figure G.2.4-13 – Circumferential force N_ϕ in a spherical shell subjected to an external moment *M* *G/56*
Figure G.2.5-1 – Maximum stress in sphere for internal pressure (flush nozzles) *G/61*

Figure G.2.5-2 – Maximum stress in sphere for internal pressure (protruding nozzles) *G/62*
Figure G.2.5-3 – Maximum stress in sphere for thrust loading (flush nozzles) *G/63*
Figure G.2.5-4 – Maximum stress in sphere for thrust loading (protruding nozzles) *G/63*
Figure G.2.5-5 – Maximum stress in sphere for moment loading (flush nozzles) *G/64*
Figure G.2.5-6 – Maximum stress in sphere for moment loading (protruding nozzles) *G/64*
Figure G.2.5-7 – Maximum stress in sphere for shear loading (flush nozzles) *G/65*
Figure G.2.5-8 – Maximum stress in sphere for shear loading (protruding nozzles) *G/66*
Figure G.2.6-1 – Shakedown values for pressure loading (flush nozzle) *G/68*
Figure G.2.6-2 – Shakedown values for pressure loading (protruding nozzle) *G/68*
Figure G.2.6-3 – Shakedown values for thrust and moment loadings (flush nozzle) *G/69*
Figure G.2.6-4 – Shakedown values for thrust and moment loadings (protruding nozzle) *G/70*
Figure G.2.6-5 – Shakedown values for thrust and moment loadings (flush nozzle) *G/71*
Figure G.2.6-6 – Shakedown values for thrust and moment loadings (protruding nozzle) *G/72*
Figure G.2.6-7 – Shakedown values for thrust and moment loadings (flush nozzle) *G/72*
Figure G.2.6-8 – Shakedown values for thrust and moment loadings (protruding nozzle) *G/73*
Figure G.2.8-1 – Moment and force vectors *G/75*
Figure G.2.8-2 – Allowable axial nozzle load *G/77*
Figure G.2.8-3 – Allowable nozzle moment *G/78*
Figure G.2.8-4 – Calculation factor C_2 *G/82*
Figure G.2.8-5 – Calculation factor C_3 *G/83*
Figure G.2.8-6 – Calculation factor C_4 *G/83*
Figure G.3.1-1 – Typical brackets *G/91*
Figure G.3.1-2 – Typical reinforcing plates on cylindrical shells *G/92*
Figure G.3.2-1 – Typical ring support *G/94*
Figure G.3.2-2 – Typical steelwork under ring support *G/95*
Figure G.3.2-3 – Leg supports for vertical vessels *G/95*
Figure G.3.2-4 – Typical ring girder *G/98*
Figure G.3.3-1 – Typical supports for horizontal vessels *G/100*
Figure G.3.3-2 – Cylindrical shell acting as beam over supports *G/102*
Figure G.3.3-3 – Factor for bending moment at mid-span *G/103*
Figure G.3.3-4 – Factors for bending moment at supports *G/104*
Figure G.3.3-5 – Portion of shell ineffective against longitudinal bending *G/105*
Figure G.3.3-6 – Circumferential bending moment diagrams *G/110*
Figure G.3.3-7 – Saddle supports *G/113*
Figure G.3.3-8 – Typical ring stiffeners *G/114*
Figure G.3.3-9 – Graph of rigid end factor, F_A *G/119*
Figure G.3.3-10 – Graph of saddle width factor, F_B *G/120*
Figure G.3.3-11 – Graph of saddle interaction factor, F_I *G/121*
Figure G.3.3-12 – Graph of length change factor, F_L *G/122*
Figure G.3.3-13 – Graph of saddle wrap-round factor, F_θ *G/123*
Figure G.4.3-1 – Nozzle geometry *G/129*
Figure G.4.3-2 – Transient fluid and metal temperatures *G/129*
Figure G.4.3-3 – Inner surface thermal stress factors K_1 and k_1 *G/130*
Figure G.4.3-4 – Outer surface thermal stress factors K_2 and k_2 *G/131*
Figure G.4.3-5 – Mean temperature factors K_b and k_s *G/132*

Figure J.1 – Typical pressure term relationships *J/2*
Figure L.1 – Tolerances on nozzles *L/2*
Figure L.2 – Tolerances after erection of a vertical vessel *L/3*
Figure L.3 – Tolerances on saddles and supports for horizontal vessels *L/4*
Figure L.4 – Tolerances on saddles and supports for vertical vessels *L/5*
Figure T.1 – Tube to tubeplate connections, tube end fusion *T/4*
Figure T.2 – Tube to tubeplate connections, castellated weld *T/5*
Figure T.3 – Tube to tubeplate connections, plain fillet weld *T/6*
Figure T.4 – Tube to tubeplate connections, front face bore fillet weld *T/7*
Figure T.5 – Tube to tubeplate connections, groove plus fillet weld *T/8*
Figure T.6 – Tube to tubeplate connections, groove weld *T/9*
Figure T.7 – Tube to tubeplate connections, back face inset bore weld *T/10*
Figure T.8 – Tube to tubeplate connections, back face stub bore weld *T/11*
Figure T.9 – General arrangement of push-out test piece for front face and back face welds *T/14*
Figure T.10 – Push-out test piece for tube ends on triangular pitch *T/15*
Figure T.11 – Push-out test piece for tube ends on square pitch *T/16*
Figure W.1-1 – Stiffener proportions *W/7*
Figure W.2-1 – Vessel on saddle supports *W/16*
Figure W.2-2 – Internal ring stiffener in plane of saddle *W/27*
Figure W.2-3 – External ring stiffeners adjacent to the saddle *W/27*
Figure W.2-4 – Vessel on ring and leg support *W/33*
Figure W.2-5 – Channel and shell as ring girder *W/36*
Figure W.6-1 – Potential failure locations in circumferential lap joint *W/54*
Figure W.6-2 – Maximum axisymmetric principal stress contours in lap joint *W/60*
Figure W.6-3 – Circumferential stress in lap joint *W/61*
Figure W.6-4 – Loading spectrum *W/75*
Figure W.6-5 – Reservoir cycle count *W/76*
Figure Al.E.1 – Typical full penetration joint preparations for one-sided welding only: aluminium and its alloys *Al/23*
Figure Al.E.2 – Typical full penetration joint preparations for two-sided welding only: aluminium and its alloys *Al/24*
Figure Al.E.3 – Typical full penetration joint preparations for one-sided welding with temporary backing or permanent backing: aluminium and its alloys *Al/26*
Figure Cu.E.1(1) – Typical full penetration joint preparation for one-sided welding only: copper and its alloys only *Cu/15*
Figure Cu.E.1(2) – Typical full penetration joint preparation for two-sided welding: copper and its alloys *Cu/16*
Figure Cu.E.1(3) – Typical full penetration joint preparation for one-sided welding with either temporary or permanent backing: copper and its alloys *Cu/17*
Figure Cu.E.1(4) – Alternative joint preparations *Cu/18*
Figure Cu.E.2(1) – Typical brazed joints for gunmetal bosses to copper vessels *Cu/19*

List of tables

Table 1.4-1 – Purchase specification options *1/4*
Table 1.4-2 – Items for manufacturer, purchaser and/or Inspecting Authority agreement *1/6*
Table 2.1-1 – Material grouping *2/3*
Table 2.1-2 – List of materials covered by BS EN material standards *2/5*
Table 2.1-3 – Additional materials that may be used for category 3 construction *2/24*
Table 2.2-1 – Bolting materials for low-temperature *2/25*
Table 2.3-1 – Temperature above which time dependent properties shall be considered *2/26*
Table 3.4-1 – Construction categories *3/7*
Table 3.5-1 – Values of factor for ellipsoidal ends *3/15*

Table 3.5-2 – Values of $e/D \times 10^3$ for unpierced dished ends in terms of h_e/D and p/f *3/15*
Table 3.5-3 – Values of coefficient β or cone/cylinder intersection without knuckle *3/21*
Table 3.5-4 – Thickness of nozzles *3/35*
Table 3.5-5 – Design values of e_{rb}/e_{rs} *3/36*
Table 3.5-6 – Values of Ce_{rs}/e_{ps} for Figure 3.5-9, Figure 3.5-10 and Figure 3.5-11 when $e_{rb}/e_{rs} = 0$ *3/40*
Table 3.5-7 – Allowable taper/taper thread sizes *3/55*
Table 3.5-8 – Values of factor *C* for welded flat ends to Figure 3.5-34b) and Figure 3.5-34c) (for Figure 3.5-36 and Figure 3.5-37) *3/85*
Table 3.6-1 – Values for *G* and *N* *3/109*
Table 3.6-2 – Definitions of cylinder lengths *3/110*
Table 3.6-3 – *E* values for ferritic and austenitic steels (Young's modulus) *3/111*
Table 3.6-4 – Values of $(\sigma_e/E)\ (d/e_w)^2$ for internal flat bar stiffeners *3/112*
Table 3.6-5 – Values of $(\sigma_e/E)\ (d/e_w)^2$ for external flat bar stiffeners *3/113*
Table 3.6-6 – Values of L_e/L_s *3/114*
Table 3.6-7 – Values of Z' *3/115*
Table 3.8-1 – Recommended design stress values for flange bolting materials *3/138*
Table 3.8-2 – Bolt root areas *3/140*
Table 3.8-3 – Recommended surface finish on gasket contact faces for body flanges and flanges fitted with covers *3/141*
Table 3.8-4 – Gasket materials and contact facings: gasket factors (*m*) for operating conditions and minimum design seating stress (*y*) *3/156*
Table 3.8-5 – Values of *T, Z, Y* and *U* (factors involving *K*) *3/160*
Table 3.9-1 – Values of ΔC as a function of F_s and *R* for all tubesheets, and C_o for U-tubesheets only *3/199*
Table 3.9-2 – Values of F_r for typical tube joints *3/222A*
Table 4.2-1 – Circumference *4/7*
Table 4.2-2 – Tolerance on depth of dished ends *4/8*
Table 4.2-3 – Maximum permitted peaking *4/10*
Table 4.2-4 – Maximum permitted peaking when special analysis is used *4/10*
Table 4.4-1 – Requirements for post-weld heat treatment of ferritic steel vessels *4/19*
Table 5.1-1 – Inspection stages in the course of which participation by the Inspecting Authority is mandatory *5/1*
Table 5.1-2 – Other principal stages of inspection *5/2*
Table 5.2-1 – Tensile test temperature *5/3*
Table 5.2-2 – Weld procedure tests for butt welds in 9% Ni steel *5/5*
Table 5.6-1 – Thickness limits for examination of internal flaws *5/8*
Table 5.7-1 – Radiographic acceptance levels *5/16*
Table 5.7-2 – Ultrasonic acceptance levels applicable to ferritic steels and weld metals in the thickness range 7 mm to 100 mm inclusive *5/17*
Table 5.7-3 – Visual and crack detection acceptance level *5/20*
Table 5.7-4 – Radiographic acceptance levels (reassessment of category 2 construction) *5/23*
Table 5.7-5 – Ultrasonic acceptance levels (reassessment of category 2 construction) *5/23*
Table A.1 – Classification of stresses for some typical cases *A/9*
Table C.1 – Details of fatigue design curves *C/6*
Table C.2 – Classification of weld details *C/10*
Table C.3 – Values of M_1, M_2 and M_3 *C/20*
Table C.4 – Weld defect acceptance levels *C/22*
Table C.5 – Fatigue test factor *F* *C/25*
Table D.1 – Design reference temperature for heat exchanger tubes *D/5*
Table D.2 – Required impact energy *D/8*
Table D.3 – Minimum design reference temperature for omission of impact test *D/9*

Table D.4 – Reference thickness of weld joint components *e* *D/10*
Table G.2.2-1 – Values of K_1 and K_2 *G/14*
Table G.2.8-1 – Coefficients to define factors C_2, C_3 or C_4 *G/82*
Table G.3.2-1 – Moments in a ring girder *G/96*
Table G.3.3-1 – Design factors K_1 and K_2 *G/106*
Table G.3.3-2 – Design factors K_3 and K_4 and allowable tangential shearing stresses *G/108*
Table G.3.3-3 – Design factor K_6 *G/109*
Table G.3.3-4 – Values of constants C_4, C_5, K_5, K_7, and K_8 *G/112*
Table G.3.3-5 – Values of K_9 *G/115*
Table G.3.3-6 – Coefficients for F_A, with $x = A/r$ *G/117*
Table G.3.3-7 – Coefficients for F_B, with $x = b_1/r$ *G/117*
Table G.3.3-8 – Coefficients for F_I, with $x = L_s/r$ *G/117*
Table G.3.3-9 – Coefficients for F_L, with $x = L/r$ *G/118*
Table G.3.3-10 – Coefficients for F_θ, with $x = \theta$ *G/118*
Table G.3.3-11 – Values of K_{10} and K_{11} *G/124*
Table G.4.3-1 – Circumferential stress factor C_1 *G/135*
Table G.4.3-2 – Bending stress factor C_2 *G/136*
Table G.4.3-3 – Meridional stress factor C_3 *G/137*
Table G.4.3-4 – Branch bending stress factor C_4 *G/138*
Table H.1 – Classification of materials *H/1*
Table K.1-1 – Design strength values: index of steels *K/2*
Table K.1-2 – Design strength values (N/mm²) *K/4*
Table K.1-3 – Design strength values (N/mm²) *K/8*
Table K.1-4 – Design strength values (N/mm²) *K/12*
Table K.1-5 – Design strength values (N/mm²) *K/14*
Table K.1-6 – Design strength values (N/mm²) *K/17*
Table K.1-7 – Design strength values (N/mm²) *K/23*
Table K.1-8 – Design strength values (N/mm²) *K/26*
Table K.1-9 – Design strength values (N/mm²) *K/29*
Table K.1-10 – Design strength values (N/mm²) *K/31*
Table K.1-11 – Design strength values (N/mm²) *K/33*
Table K.1-12 – Design strength values (N/mm²) *K/35*
Table T.1 – Tube to tubesheet joints: essential tests and the suitability of joint types for optional tests *T/12*
Table W.1-1 – Design data assumed for cylindrical sections *W/4*
Table W.1-2 – Summary of calculation for *e* *W/4*
Table W.1-3 – Derivation of L_e/L_s *W/5*
Table W.1-4 – Design data assumed for complete vessel *W/8*
Table W.1-5 – Values required for stiffener design *W/10*
Table W.1-6 – Design data assumed for cylindrical sections *W/10*
Table W.1-7 – Measured radii and departure from mean circle *W/12*
Table W.1-8 – Values of a_n, b_n and $p_{m(n)}$ *W/12*
Table W.1-9 – Values of $\sigma_{br(n)}$ *W/13*
Table W.2-1 – Design data *W/15*
Table W.2-2 – Interpolation of Table G.3.3-3 for K_6 *W/22*
Table W.2-3 – Summary of stresses *W/37*
Table W.6-1 – Results of calculations of allowable stress range *W/59*
Table W.6-2 – Summary of results from Example 1 *W/62*
Table W.6-3 – Summary of results for Example 2 *W/69*
Table W.6-4 – Cyclic loading regime for case A *W/73*
Table W.6-5 – Fatigue load cycle stress ranges *W/73*
Table W.6-6 – Summary of damage calculation values for case A *W/73*
Table W.6-7 – Cyclic loading regime for case B *W/74*
Table W.6-8 – Fatigue load cycle stress ranges *W/76*
Table W.6-9 – Summary of damage calculation for case B *W/77*
Table W.6-10 – Summary of results *W/78*
Table W.C.1 – Thermal stress *W/82*
Table Z.1 – PD 5500 compliance with PED ESRs *Z/1*

Table Al.2.3-1 – Design strength values: aluminium and aluminium alloys *Al/2*
Table Al.3.4-1 – Construction categories *Al/4*
Table Al.3.6-3 – *E* values for aluminium alloys (Young's modulus) *Al/5*
Table Al.3.8-1 – Recommended design stress values for flange bolting materials *Al/6*
Table Al.5.7-1 – Acceptance levels *Al/13*
Table Al.5.8-1 – Principal stages of inspection *Al/21*
Table Cu.2.3-1 – Design strength values of copper and copper alloys *Cu/2*
Table Cu.3.4-1 – Construction categories for copper and copper alloy construction *Cu/4*
Table Cu.3.5-2 – Thickness of nozzles *Cu/4*
Table Cu.3.6-3 – *E* values for copper and copper alloys (Young's modulus) *Cu/5*
Table Cu.4.2-1 – Hot forming temperatures *Cu/6*
Table Cu.5.5-1 – Mechanical test requirements for butt weld procedure and welder approval *Cu/10*
Table Cu.5.7-1 – Acceptance levels *Cu/12*
Table Ni.2.3-1 – Design strength values for nickel and nickel alloy plate conforming to BS 3072 *Ni/2*
Table Ni.2.3-2 – Design strength values for nickel and nickel alloy seamless tube conforming to BS 3074 *Ni/2*
Table Ni.2.3-3 – Design strength values for nickel and nickel alloy seamless tube conforming to BS 3074 *Ni/3*
Table Ni.2.3-4 – Design strength values for nickel and nickel alloy seamless tube conforming to BS 3074 *Ni/3*
Table Ni.2.3-5 – Design strength values for nickel and nickel alloy forgings conforming to BS 3076 *Ni/4*
Table Ni.3.4-1 – Construction categories *Ni/5*
Table Ni.3.6-3 – *E* values for nickel alloys (Young's modulus) *Ni/6*
Table Ni.4.2-1 – Maximum temperature for heating nickel and nickel alloys *Ni/7*
Table Ni.4.4-1 – Annealing temperature for nickel and nickel alloys *Ni/8*
Table Ti.2.3.1 – Design strength values: commercially pure titanium and titanium alloys of material specifications ASTM B265, B338, B348, B363, B381, B861, and B862 *Ti/2*
Table Ti.3.4-1 – Construction categories *Ti/4*
Table Ti.3.6-3 – *E* values for titanium alloys (Young's modulus) *Ti/4*
Table Ti.4.2.2-1 – Minimum bend radii *Ti/6*
Table Ti.4.4-1 – Heat treatment temperatures for commercially pure titanium and titanium alloys *Ti/8*

Summary of pages

This document comprises a front cover, an inside front cover, pages i to xvi, pages 1/1 to 5/34, pages A/1 to Z/10, pages Al/1 to Ti/7, pages I to XIV, an inside back cover and a back cover.

Section 1. General

1.1 Scope

1.1.1 This Published Document specifies requirements for the design, construction, inspection, testing and verification of compliance of new unfired fusion welded pressure vessels. The materials of construction are specified in Section 2. The term "pressure vessel" as used in this specification includes branches up to the point of connection to the connecting piping by bolting, screwing or welding, and supports, brackets or other attachments directly welded to the pressure containing shell. The term "unfired" excludes vessels that are subject to direct generated heat or flame impingement from a fired process. It does not exclude vessels subject to electrical heating or heated process streams.

NOTE Whilst this specification is limited to the construction of new vessels, with the agreement of the relevant parties it can be used to guide the maintenance or any modification of existing vessels. Where these existing vessels were designed and constructed using an earlier edition of PD 5500, with the agreement of the relevant parties, that earlier edition can be used to guide the maintenance or any modification.

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

1.1.3 This specification applies only to pressure vessels manufactured under the survey of a competent engineering Inspecting Authority or Organization. The competent engineering Inspection Authority or Organization shall either be:

a) a notified body appointed by a member state of the European Union for the Pressure Equipment Directive 97/23/EC for the range of activities covered by this specification; or

NOTE Within the UK the United Kingdom Accreditation Service (UKAS) acts on behalf of the regulating authority in accrediting inspection bodies.

b) accredited to BS EN 45004, to Type A independence criteria, for inspection in the subject matter of this specification; or

c) accredited by an organization authorized by the local Regulatory Authority in countries outside the EU and in circumstances where the Pressure Equipment Directive 97/23/EC does not apply.

The intent of this requirement is regarded as satisfied where inspection is carried out by competent personnel of a separate engineering inspection department maintained by the purchaser of the vessel (in which case Type B independence criteria shall be met). An inspection department maintained by the manufacturer does not satisfy this requirement except:

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

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

This specification applies only to vessels made by manufacturers who can satisfy the Inspecting Authority or Organization that they are competent and suitably equipped to fulfil the appropriate requirements of this specification.

The requirements for testing and inspecting serially manufactured pressure vessels are given in Annex V. In all other respects the appropriate requirements in the specification apply.

Glass lined steel vessels require special design considerations subject to the limits imposed by the method of construction which should have the agreement of the Inspecting Authority.

1.1.4 This specification does not cover the following.

a) Storage tanks designed for the storage of liquids at near atmospheric pressures, i.e. where the pressure additional to that due to the hydrostatic head does not exceed 140 mbar[1)] above or 6 mbar below atmospheric pressure.

b) Low pressure, above ground storage tanks which have a single vertical axis of revolution designed for the storage of liquids at a pressure not exceeding 1 bar[1)] .

c) Vessels in which the stresses calculated in accordance with the Equations given in Section 3 are less than 10 % of the design stress permitted by Section 3.

d) Multilayered, autofrettaged, prestressed vessels or other special designs of vessels which may be appropriate for very high pressures.

e) Transport vessels, i.e. vessels used for transport of contents under pressure.

f) Vessels for specific applications which are covered by standards listed in the *BSI Catalogue*.

NOTE 1 PD 5500 may be used for the design and manufacture of liquid and bulk powder road tankers, provided consideration is given to the following:

– *chapter 6.8.2 of ADR (European Agreement concerning International Carriage of Dangerous Goods by Road); in particular relating to static and dynamic stresses in motion, protection of the shell and supports and fittings, minimum thickness and the provision of anti-surge plates;*

– *chapter 9.7.5.1 of ADR relating to stability.*

BS 3441 gives guidance on the design and construction of tanks for the transport of milk and liquid milk products.

Road tankers used to transport non-hazardous substances in the UK and which operate at a pressure above 0.5 bar are subject to the Pressure Systems Safety Regulations, 2000 (SI 128).

NOTE 2 See Note 1 of 3.2.2 regarding the applicability of PD 5500 Section 3 to thick walled vessels.

NOTE 3 The titles of the publications referred to in this specification are listed at the end of the document.

1.1.5 This specification does not address the nature or consequences of a fire in the vicinity of a pressure vessel. Any consideration of the effect of a fire hazard in the design of a pressure vessel would have to be under the direction of the plant owner or his responsible agent such as the plant architect/engineer, with analysis of the consequences of a fire adjacent to a pressure vessel being undertaken in accordance with a comprehensive specification of the fire conditions, impingement parameters, analytical methods and assessment criteria.

1.1.6 This specification addresses materials in various ways.

a) The main text gives requirements for steels.

[1)] 1 mbar = 10^2 N/m^2 = 100 Pa.
1 bar = 10^5 N/m^2 = 0.1 N/mm^2 = 100 kPa.

b) Certain other materials are covered by supplements which identify either where the main text is applicable or where specific requirements of the supplement apply.

1.1.7 When another standard or specification calls for the provisions of PD 5500 to be applied, the responsibility for defining the manner in which the provisions are applied and their appropriateness for the intended duty, is defined in that other document.

1.1.8 Guidance on the application of PD 5500 to pressure vessels that fall within the scope of the European Pressure Equipment Directive is given in Annex Z.

1.2 Interpretation

If any ambiguity be found or doubt arise as to the meaning or effect of any part of this specification or as to whether anything ought to be done or omitted to be done in order that this specification should be complied with in full, the question shall be referred to the Pressure Vessels Technical Committee (PVE/1) of the British Standards Institution, whose interpretation of the requirements of this specification upon the matter at issue shall be given free of charge and shall be final and conclusive. Parties adopting this specification for the purposes of any contract shall be deemed to adopt this provision unless they expressly exclude it or else import an arbitration provision in terms extending to interpretation of this specification. However, this provision is limited to questions of interpretation and does not confer upon the committee any power, duty or authority to adjudicate upon the contractual rights or duties of any person under a contract except in so far as they may necessarily be affected by the interpretation arrived at by the committee.

Findings or rulings of the committee upon all enquiries, including matters of interpretation, which are of sufficient importance that both enquiries and replies be made public as soon as possible will be published in an enquiry reply form for inclusion in the PD 5500 ring binder as Enquiry Cases. Their availability will be notified in *Update Standards.*

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

1.3 Definitions

For the purposes of this specification the following definitions apply.

1.3.1 purchaser

the organization or individual who buys the finished pressure vessel for its own use or as an agent for the owner

1.3.2 manufacturer

the organization that designs, constructs and tests the pressure vessel in accordance with the purchaser's order. The design function may be carried out by the purchaser or his agent, independently from the organization that constructs and tests the vessel (see **1.4.2**)

1.3.3 Inspecting Authority

the body or organization that verifies that the vessel has been designed, constructed and tested in accordance with this specification