SECTION VIII

Rules for Construction of Pressure Vessels

2025 ASME Boiler and Pressure Vessel Code

An International Code

Division 1

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AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

VIII

RULES FOR CONSTRUCTION OF PRESSURE VESSELS

Division 1

ASME Boiler and Pressure Vessel Committee
on Pressure Vessels

The American Society of Mechanical Engineers

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FOREWORD* (25)

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating to pressure integrity. The rules govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. The Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

The Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

- *Shall* is used to denote a requirement.
- *Should* is used to denote a recommendation.
- *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area. In addition, the term "impregnated" has been revised to "impervious" throughout Section VIII, Division 1.

Page	*Location*	*Change*
xxx	List of Sections	Title of Section XI, Division 1 revised
xxxi	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xxxiv	Personnel	Updated
1	U-1	Subparagraph (b) revised
2	U-2	Subparagraphs (a), (a)(2), (b)(1), (b)(2), (b)(4), (e), and (h)(3) revised
5	U-6	Added
6	Table U-3	Updated
8	UG-1	Revised
8	UG-4	Subparagraphs (a) and (f) revised
9	UG-6	Subparagraphs (a) through (c) revised
10	UG-9	Revised in its entirety
10	UG-10	Revised in its entirety
13	UG-11(e)	Third cross-reference updated
14	UG-14	Revised in its entirety
15	Table UG-14-1	Added
16	Figure UG-14-1	Added
17	Figure UG-14-2	Added
15	UG-15	Revised in its entirety
15	UG-16	Revised in its entirety
18	UG-19	In subpara. (a), last sentence, "r" corrected by errata to "or"
19	UG-23	In subpara. (b)(2), Step 1 revised
21	UG-24	Revised in its entirety
22	UG-25	Subparagraph (a) revised
23	UG-28	*(1)* In definition of L in subpara. (b), item (c) revised *(2)* Subparagraph (f) revised
27	UG-29	In Note of subpara. (a), Step 7(b) , "6(b) and (b)" corrected by errata to "Step 6(b) and Step 7(b)"
34	UG-33	*(1)* In subpara. (b), definition of L_c revised *(2)* In subpara. (f), last sentence added
35	Figure UG-33.1	Sketches (a) and (b) revised
37	UG-34	Definition of W and subparas. (d)(4), (d)(10), and (d)(12) revised

Page	Location	Change
40	UG-35.2	Revised in its entirety
40	UG-35.3	Revised in its entirety
40	Table UG-35.2-1	Added
47	UG-39	In subpara. (b)(3), second sentence revised
48	Figure UG-39	Revised
57	Table UG-44-1	"Size Range" entries and Note (2) revised
59	UG-47	Subparagraph (b) revised
66	UG-75	Revised in its entirety
66	UG-76	Revised in its entirety
66	UG-77	Revised in its entirety
67	UG-78	Revised in its entirety
67	UG-79	Revised in its entirety
70	UG-84	*(1)* Revised in its entirety *(2)* Figures and tables redesignated
73	Figure UG-84.5-1	In former Figure UG-84.1, General Note (b) revised
74	Figure UG-84.5-1M	In former Figure UG-84.1M, General Note (b) revised
77	UG-85	Revised in its entirety
77	UG-90	Revised in its entirety
78	UG-91	Revised in its entirety
79	UG-92	Revised in its entirety
79	UG-93	Revised in its entirety
80	UG-94	Revised in its entirety
80	UG-95	Revised in its entirety
80	UG-96	Revised in its entirety
80	UG-97	Revised in its entirety
81	UG-99	Revised in its entirety
84	UG-100	Revised in its entirety
87	UG-101	Subparagraphs (a)(4)(-d) and (b) revised
92	UG-102	Revised in its entirety
93	UG-103	Revised in its entirety
93	UG-115	Revised in its entirety
93	UG-116	Subparagraph (a)(1)(-a) revised
95	UG-117	Subparagraph (g) revised
96	Figure UG-118	Revised
97	UG-119	Subparagraph (d) revised
97	UG-120	Subparagraphs (a)(1)(-b), (b)(1)(-c), (c)(1), (c)(1)(-a), and (c)(1)(-b) revised

Page	*Location*	*Change*
100	UG-151	Subparagraphs (a) and (c) revised
100	UG-152	Subparagraph (a) revised
100	UG-153	*(1)* Subparagraph (a) revised *(2)* In subpara. (a)(2), "Nonmandatory Appendix MM" corrected by errata to "Nonmandatory Appendix M"
101	UG-154	*(1)* Subparagraph (b)(3) revised *(2)* Subparagraph (c)(3) deleted *(3)* Subparagraphs (e)(3) and (e)(4) added
102	UG-155	Subparagraph (h) revised
104	UW-1	Revised
104	UW-2	Subparagraphs (a), (b)(1), (b)(4)(-a), (b)(4)(-b), and (d)(3) revised
105	UW-3	First paragraph and subparas. (c) and (d) revised
106	Figure UW-3	Category F added
107	UW-6	First paragraph revised
107	UW-8	Revised
109	UW-10	Revised
110	UW-12	First paragraph revised
112	Table UW-12	Type No. (9) added
111	UW-13	Subparagraphs (a), (f)(4), and (g)(1) revised
116	Figure UW-13.2	*(1)* Sketches (m) and (n) revised *(2)* Note (2) deleted and subsequent Note renumbered
120	UW-14	Revised in its entirety
120	UW-15	Revised in its entirety
136	UW-20.2	*(1)* Definition of P_o revised *(2)* Definitions of $S_{y,a}$ and $S_{y,t,a}$ added *(3)* Term "S_{yt}" corrected by errata to "$S_{y,t}$"
137	UW-20.3.4	In subpara. (b) nomenclature, terms "F" and "S" corrected by errata to "F_t" and "S_w," respectively
140	UW-20.4.2	In subpara. (b), first two equations revised
141	Figure UW-20.3	Duplicate Figure UW-20.3 deleted by errata
144	Figure UW-21	Title corrected by errata
143	UW-26	*(1)* Subparagraphs (a), (b), and (d)(4)(-a) [formerly (d)(4)(-b)] revised *(2)* Subparagraph (d)(4)(-a) deleted and subsequent subparagraphs redesignated
144	UW-28	Subparagraph (b) revised
146	Table UW-33	Title added
146	UW-34	*(1)* Revised *(2)* Former Endnote 47 deleted and subsequent Endnotes renumbered
146	UW-35	Revised in its entirety

Page	*Location*	*Change*
147	UW-35-1	In-text table formerly in UW-35(e) designated and titled
146	UW-36	Deleted
146	UW-37	Subparagraph (f)(1) revised
148	UW-38	Second cross-reference updated
148	UW-40	Revised in its entirety
150	UW-46	Revised
150	UW-47	Revised
150	UW-48	Revised
150	UW-49	Revised
151	UW-50	Title and subpara. (a) revised
151	UW-51	Revised
151	UW-52	Subparagraph (b)(3) revised
153	UW-55	Revised in its entirety
154	UF-1	Second sentence revised
154	UF-5	Subparagraph (d) revised
154	UF-12	Second paragraph revised
156	UF-32	Subparagraph (d) added
157	UF-37	Subparagraph (b)(4) added
157	UF-38	Last sentence added
158	UF-43	First sentence revised
158	UF-52	Revised
158	UF-55	Subparagraph (a) revised
160	UB-1	Subparagraph (a) revised
161	UB-9	Revised
164	UB-30	Subparagraphs (a), (b), and (d)(4)(-b) revised
165	UB-40	Revised
165	UB-42	Revised
165	UB-43	Subparagraph (a) revised
166	UB-44	Subparagraph (a) revised
167	UCS-1	Revised
168	UCS-16	Revised
169	Table UCS-23	For SA-372, Type/Grade revised
170	UCS-56	Revised in its entirety
176	Table UCS-56-4	In Note (d)(1), cross-reference updated
181	Table UCS-56-11	In Note (b)(1), cross-reference updated
182	Table UCS-56-12	Former Table UCS-56.1 redesignated

Page	*Location*	*Change*
182	UCS-66	Subparagraphs (a)(1)(-a)(-1) and (a)(1)(-a)(-3) revised
183	Figure UCS-66	Table in Note (c) revised
186	Figure UCS-66M	Table in Note (c) revised
199	UCS-67	Revised in its entirety
199	Table UCS-67.2-1	Added
199	UCS-68	Revised in its entirety
200	UCS-75	Revised
201	UCS-85	Revised in its entirety
202	UCS-90	Revised
204	UNF-1	Revised
205	UNF-15	Subparagraph (b) revised
205	UNF-16	Revised
207	Table UNF-23.3	*(1)* SA-182, SA-213, SA-240, SA-312, SA-403, SA-479, SA-688, and SA-965 added *(2)* For SB-625, SB-649, and SB-677, UNS No. N08354 added
206	UNF-56	*(1)* In subpara. (c), Endnote 54 deleted and subsequent Endnotes renumbered *(2)* Subparagraph (d)(1) and (d)(3)(-a) revised
209	UNF-65	Revised in its entirety
209	UNF-75	Revised
210	UNF-78	Revised
210	UNF-90	Revised
214	UHA-1	Revised
215	UHA-20	Revised
216	Table UHA-23	SA-693 added
215	UHA-32	Subparagraph (d) revised
218	Table UHA-32-1	General Notes (a)(1) and (b) revised
219	Table UHA-32-2	*(1)* General Notes (a)(1), (b), and (c) [formerly (d)] revised *(2)* General Note (c) deleted and subsequent General Note redesignated
220	Table UHA-32-5	Second cross-reference in General Note (a) updated
221	UHA-40	Revised
222	UHA-42	Last sentence revised
222	UHA-50	Revised
222	UHA-51	Revised in its entirety
228	UHA-A-4	Cross-reference in subpara. (a)(5) updated
231	Table UCI-23	*(1)* "Class" column heading revised to "Class or Type" *(2)* SA-439 added
231	UCI-35	Revised

Page	*Location*	*Change*
232	UCI-78	Subparagraphs (a)(3) and (a)(4) revised
232	Table UCI-78.1	DN values added
232	Table UCI-78.2	DN values added
234	UCL-1	Last sentence revised
235	UCL-20	Subparagraph (a) revised
235	UCL-23	Last sentence revised
236	UCL-26	Revised
236	UCL-30	Revised
238	UCL-50	Revised
238	UCL-52	Cross-reference in subpara. (b) updated
239	UCD-3	In subpara. (b), Note revised
240	Table UCD-23	General Notes and Note (1) revised
240	UCD-78	Subparagraphs (a)(3) and (a)(4) revised
241	Table UCD-78.1	DN values added
241	Table UCD-78.2	DN values added
243	UHT-1	First sentence revised
244	UHT-16	Revised
245	UHT-18	Subparagraph (c)(2) revised
249	UHT-56	In subpara. (c), third cross-reference updated
250	UHT-75	Revised
253	UHT-86	Cross-reference updated
253	UHT-90	Revised
254	ULW-1	First sentence revised
265	ULW-18(d)	Revised
272	ULW-57	Subparagraph (a) revised
283	ULT-86	Second cross-reference updated
286	Subsection D	Added
286	Part UAS	Former Mandatory Appendix 48 redesignated
288	Part UCC	Former Mandatory Appendix 24 revised and redesignated
295	Part UDA	Former Mandatory Appendix 17 revised and redesignated
306	Part UEB	Former Mandatory Appendix 26 revised and redesignated
310	Form UEB-1	Former Form 26-1 redesignated and retitled
312	Form UEB-1M	Former Form 26-1M redesignated and retitled
314	Part UEJ	Former Mandatory Appendix 5 revised and redesignated
318	Part UGL	Former Mandatory Appendix 27 redesignated
320	Part UHX	Formerly in Subsection C, moved to Subsection D

Page	*Location*	*Change*
320	UHX-1	Subparagraph (a) revised and Table UHX-1.1 deleted
320	UHX-2	Revised
321	Table UHX-1-1	*(1)* Former Table UHX-1.2 revised and redesignated *(2)* Division 2 cross-reference for “Flexible shell element expansion joints” corrected by errata to 4.20
323	Part UIF	Former Mandatory Appendix 22 revised and redesignated
325	Part UIG	*(1)* Formerly in Subsection C, moved to Subsection D *(2)* In Nonmandatory Introduction, subparas. (b), (d), and (f) revised
325	UIG-1	Revised
326	UIG-3	*(1)* Definitions of *binder system, compound graphite material*, and *impregnated graphite material* added *(2)* Definitions of *certified materials, graphite cement, lot*, and *raw materials* revised *(3)* Definitions of *graphite compound* and *impervious materials* deleted
326	UIG-5	Subparagraph (b) revised
326	UIG-6	Subparagraph (b)(8) added and subpara. (c) revised
327	Table UIG-6-1	Revised in its entirety
327	UIG-7	Revised
327	UIG-8	Subparagraph (d) revised
327	UIG-23	Subparagraphs (c)(2) and (d) revised
327	UIG-27	Last sentence revised
328	UIG-28	Revised
328	UIG-34	Revised
336	Table UIG-34-1	For Operating Load Cases, shell side and tube side design pressures revised
337	Figure UIG-34-4	Sketch (a) revised
339	Table UIG-34-5	Last line revised
340	UIG-35	Added
341	Figure UIG-35-1	Added
341	Figure UIG-35-2	Added
340	UIG-36	Revised in its entirety
343	Figure UIG-36-2	Sketches (a) through (e), (g), and (h) revised
346	UIG-45	First sentence revised
347	UIG-75	Subparagraphs (b) and (d) revised
347	UIG-76	In subparas. (c) through (e), cross-references updated
348	Figure UIG-76-1	Revised
349	Figure UIG-76-1-M	Added
350	Figure UIG-76-2	Revised

Page	Location	Change
351	Figure UIG-76-2M	Added
353	Figure UIG-76-3M	Added
355	Figure UIG-76-4M	Added
357	Figure UIG-76-5M	Added
358	Figure UIG-76-6	Title revised
359	Figure UIG-76-6M	Added
360	UIG-77	Subparagraphs (d)(2) and (f) revised
360	UIG-78	Revised
360	UIG-79	Subparagraphs (b) and (e) revised
361	UIG-81	Revised in its entirety
361	UIG-84	Revised
362	Table UIG-84-1	Revised in its entirety
363	UIG-97	Revised in its entirety
363	UIG-101	Former Mandatory Appendix 36 revised and redesignated
364	UIG-102	Former Mandatory Appendix 37 revised and redesignated
365	UIG-103	Former Mandatory Appendix 38 revised and redesignated
367	UIG-104	Former Mandatory Appendix 39 revised and redesignated
368	UIG-105	Former Mandatory Appendix 40 revised and redesignated
371	UIG-116	Subparagraphs (e) and (f) added
371	UIG-120	Subparagraphs (c) and (d) added
372	UIG-121	Last sentence revised
373	Form CMQ	Revised in its entirety
380	Form CMQ-C	Added
386	Form CCQ	In table on first page, entry for UIG-6 revised
388	Form CPQ	*(1)* On first page, last cross-reference updated *(2)* In table on second page, "Block Joint Material" revised to "Block Joint"
391	Nonmandatory Appendix UIG-A	Cross-references updated throughout and UIG-A-3(d) revised
393	Nonmandatory Appendix UIG-B	Former Nonmandatory Appendix MM redesignated
394	Part UJK	Former Mandatory Appendix 19 redesignated
395	Part UJV	Former Mandatory Appendix 9 revised and redesignated
397	Part UNC	Former Mandatory Appendix 13 revised and redesignated
399	Part UPX	Former Mandatory Appendix 45 revised and redesignated
403	1-4	*(1)* Subparagraphs (a), (f)(1), and (f)(2) revised *(2)* In subpara. (b), definition of S revised
406	1-5	In subpara. (c), Note deleted

Page	Location	Change
409	1-6	*(1)* In subpara. (b), definition of M_o revised *(2)* Subparagraph (d)(3) revised
413	1-8	In subpara. (b)(3), Step 5, "$A = 2\text{–}B/E_x$" corrected by errata to "$A = 2B/E_X$"
418	Mandatory Appendix 2	Revised in its entirety
422	3-2	*(1)* Definition of *acceptance by the Inspector, accepted by the Inspector* revised *(2)* Definition of *Certifying Engineer* deleted *(3)* Term *nominal pipe size (NPS)* revised to *nominal pipe size [NPS (DN)]* *(4)* Definition of *replacement or repair parts* added
433	Mandatory Appendix 5	Revised and redesignated as Part UEJ
434	6-2	Revised
436	7-1	Cross-reference updated
437	7-4	Subparagraph (d) revised
439	8-2	Revised
441	Mandatory Appendix 9	Revised and redesignated as Part UJV
442	10-1	Second paragraph revised
442	10-5	Subparagraphs (c)(1) and (c)(2) revised
443	10-9	Revised
443	10-11	Revised
443	10-13	Subparagraphs (a), (b)(6), (b)(7), (b)(8), and (b)(12) revised
444	10-15	Subparagraph (d) revised
446	Mandatory Appendix 13	Revised and redesignated Part UNC
447	Mandatory Appendix 14	Revised in its entirety
448	Mandatory Appendix 17	Revised and redesignated as Part UDA
450	Mandatory Appendix 19	Redesignated as Part UJK
453	Mandatory Appendix 22	Revised and redesignated as Part UIF
454	23-4	Subparagraphs (a)(3) and (b)(3) revised
456	Mandatory Appendix 24	Revised and redesignated as Part UCC
457	Mandatory Appendix 26	Revised and redesignated as Part UEB
458	Mandatory Appendix 27	Redesignated as Part UGL
461	Table 31-1	*(1)* Entries for Nominal Composition $2^1/_4$Cr–1Mo revised *(2)* General Note added
470	35-4	Subparagraph (c)(10) revised
473	Mandatory Appendix 36	Revised and redesignated as UIG-101
474	Mandatory Appendix 37	Revised and redesignated as UIG-102
475	Mandatory Appendix 38	Revised and redesignated as UIG-103
476	Mandatory Appendix 39	Revised and redesignated as UIG-104

Page	*Location*	*Change*
477	Mandatory Appendix 40	Revised and redesignated as UIG-105
478	41-2	Subparagraph (a) revised
478	41-5	*(1)* Definitions of C, G, h_r, S, and W revised *(2)* Definitions of S_a and W_{m1} deleted
480	41-7	Steps 1(b) and 8 revised
481	41-10.1	Subparagraph (b) and nomenclature in subpara. (d) revised
485	43-2	Subparagraph (a)(5) added
486	44-5	Subparagraph (i) revised
487	44-6.1	Subparagraphs (g)(2) and (g)(3) revised
489	Mandatory Appendix 45	Revised and redesignated as Part UPX
490	46-2	Revised
491	46-4	Cross-references updated and subparas. (c)(4) and (c)(5) revised
492	Mandatory Appendix 47	Revised in its entirety
493	Mandatory Appendix 48	Redesignated as Part UAS
496	E-3	First sentence revised
500	H-1	Revised
500	H-4.1	Second paragraph revised
504	L-1.2	First paragraph revised
504	L-1.4	Subparagraph (c) revised
505	Figure L-1.4-1	General Note (b) revised
508	Figure L-1.4-4	Revised
520	Form U-1	On third page, “Certificate of Shop Inspection” and “Certificate of Field Assembly Inspection” revised
523	Form U-1A	On second page, “Certificate of Shop/Field Inspection” revised
526	Form U-1P	On second page, “Certificate of Shop Inspection” and “Certificate of Field Assembly Inspection” revised
528	Form U-2	On third page, “Certificate of Shop/Field Inspection” revised
531	Form U-2A	On second page, “Certificate of Shop/Field Inspection” revised
541	Form U5-B	Added
542	Table W-3	*(1)* Column U-5B added *(2)* Instructions for items (33), (34), (40), (42), (53), (55), (58), (59), and (70) revised
548	Table W-3.1	Instructions for item (B) revised
550	Y-3	In subpara. (a), definitions of b, m, and y revised
556	Y-5.2	First sentence revised
563	Nonmandatory Appendix EE	Revised in its entirety
564	Nonmandatory Appendix FF	Deleted

Page	*Location*	*Change*
565	GG-2	Subparagraph (f) revised
577	Figure JJ-1.2-1	Cross-references updated
578	Figure JJ-1.2-2	Cross-references updated
579	Figure JJ-1.2-3	Cross-references updated
580	Figure JJ-1.2-4	Cross-references updated
581	Figure JJ-1.2-5	Cross-references updated
583	Form U-DR-1	On second page, Category F added
585	Form U-DR-2	On second page, Category F added
588	Nonmandatory Appendix LL	Deleted
589	Nonmandatory Appendix MM	Redesignated as UIG-B
590	NN-1	Revised
590	NN-2	Subparagraphs (a)(2) through (a)(4) and (b)(1) revised
591	NN-5	Title revised
592	NN-6	Revised
593	Table NN-6-1	Revised
594	Table NN-6-2	Revised
594	Table NN-6-3	First row revised
594	Table NN-6-4	Last row revised
595	Table NN-6-5	Title revised and last row added
596	Table NN-6-6	Title and last row revised
596	Table NN-6-7	Title and entry for "Prior notification of weld repair" revised
597	Table NN-6-8	Revised
597	Table NN-6-9	Entry for "Painting before pressure testing" revised
598	Table NN-6-11	Deleted

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

INTRODUCTION

(25) U-1 SCOPE

(a) See below.

(1) The Foreword provides the basis for the rules described in this Division.

(2) For the scope of this Division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof.

(3) This Division contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. The Code does not address all aspects of these activities, and those aspects which are not specifically addressed should not be considered prohibited. Engineering judgment must be consistent with the philosophy of this Division, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of this Division.

(b) This Division is divided into four Subsections, Mandatory Appendices, and Nonmandatory Appendices.

(1) Subsection A covers general requirements applicable to all pressure vessels.

(2) Subsection B covers specific requirements applicable to the various methods used in the fabrication of pressure vessels.

(3) Subsection C covers specific requirements applicable to the several classes of materials used in pressure vessel construction.

(4) Subsection D covers requirements applicable to specific types of pressure vessels and components.

(5) The Mandatory Appendices address specific subjects not covered elsewhere in this Division, and their requirements are mandatory when the subject covered is included in construction under this Division.

(6) The Nonmandatory Appendices provide information and suggested good practices.

(c) See below.

(1) The scope of this Division has been established to identify the components and parameters considered in formulating the rules given in this Division. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Division of the Code for vessels or components not considered to be within its scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given here.

(2) Based on the Committee's consideration, the following classes of vessels are not included in the scope of this Division; however, any pressure vessel which meets all the applicable requirements of this Division may be stamped with the Certification Mark with the U Designator:

(-a) those within the scope of other Sections;

(-b) fired process tubular heaters;

(-c) pressure containers which are integral parts or components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders where the primary design considerations and/or stresses are derived from the functional requirements of the device;

(-d) structures whose primary function is the transport of fluids from one location to another within a system of which it is an integral part, that is, piping systems;

(-e) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, and fittings, and the pressure-containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, provided that pressure-containing parts of such components are generally recognized as piping components or accessories;

(-f) a vessel for containing water[1] under pressure, including those containing air the compression of which serves only as a cushion, when none of the following limitations are exceeded:

(-1) a design pressure of 300 psi (2 MPa);

(-2) a design temperature of 210°F (99°C);

(-g) a hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(-1) a heat input of 200,000 Btu/hr (58.6 kW);

(-2) a water temperature of 210°F (99°C);

(-3) a nominal water containing capacity of 120 gal (450 L);

(-h) vessels not exceeding the design pressure (see Mandatory Appendix 3, 3-2), at the top of the vessel, limitations below, with no limitation on size [see UG-28(f) and UJV-1(d)]:

(-1) vessels having an internal or external pressure not exceeding 15 psi (100 kPa);

(-2) combination units having an internal or external pressure in each chamber not exceeding 15 psi (100 kPa) and differential pressure on the common elements not exceeding 15 psi (100 kPa) [see UG-19(a)];

(-i) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure;

(-j) pressure vessels for human occupancy.[2]

(d) The rules of this Division have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3,000 psi (20 MPa). For pressures above 3,000 psi (20 MPa), deviations from and additions to these rules usually are necessary to meet the requirements of design principles and construction practices for these higher pressures. Only in the event that after having applied these additional design principles and construction practices the vessel still complies with all of the requirements of this Division may it be stamped with the applicable Certification Mark with the Designator.

(e) In relation to the geometry of pressure-containing parts, the scope of this Division shall include the following:

(1) where external piping; other pressure vessels including heat exchangers; or mechanical devices, such as pumps, mixers, or compressors, are to be connected to the vessel:

(-a) the welding end connection for the first circumferential joint for welded connections [see UW-13(i)];

(-b) the first threaded joint for screwed connections;

(-c) the face of the first flange for bolted, flanged connections;

(-d) the first sealing surface for proprietary connections or fittings;

(2) where nonpressure parts are welded directly to either the internal or external pressure-retaining surface of a pressure vessel, this scope shall include the design, fabrication, testing, and material requirements established for non-pressure-part attachments by the applicable paragraphs of this Division;[3]

(3) pressure-retaining covers for vessel openings, such as manhole or handhole covers, and bolted covers with their attaching bolting and nuts;

(4) the first sealing surface for proprietary fittings or components for which rules are not provided by this Division, such as gages, instruments, and nonmetallic components.

(f) The scope of the Division includes requirements for overpressure protection in UG-150 through UG-156.

(g) *Vessels That Generate Steam*

(1) Unfired steam boilers shall be constructed in accordance with the rules of Section I or this Division [see UG-120(f), UG-150(d), and UW-2(c)].

(2) The following pressure vessels in which steam is generated shall not be considered as unfired steam boilers, and shall be constructed in accordance with the rules of this Division:

(-a) vessels known as evaporators or heat exchangers;

(-b) vessels in which steam is generated by the use of heat resulting from operation of a processing system containing a number of pressure vessels such as used in the manufacture of chemical and petroleum products;

(-c) vessels in which steam is generated but not withdrawn for external use.

(h) Pressure vessels or parts subject to direct firing from the combustion of fuel (solid, liquid, or gaseous), which are not within the scope of Sections I, III, or IV may be constructed in accordance with the rules of this Division [see UW-2(d)].

(i) Gas fired jacketed steam kettles with jacket operating pressures not exceeding 50 psi (345 kPa) may be constructed in accordance with the rules of this Division (see Part UJK).

(j) Pressure vessels exclusive of those covered in (c), (g), (h), and (i) that are not required by the rules of this Division to be fully radiographed, that are not provided with quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively), and that do not exceed the following volume and pressure limits may be exempted from inspection by Inspectors, as defined in UG-91, provided that they comply in all other respects with the requirements of this Division:

(1) 5 ft^3 (0.14 m^3) in volume and 250 psi (1.7 MPa) design pressure; or

(2) 3 ft^3 (0.08 m^3) in volume and 350 psi (2.4 MPa) design pressure;

(3) $1^1/_2$ ft^3 (0.04 m^3) in volume and 600 psi (4.1 MPa) design pressure.

In an assembly of vessels, the limitations in (1) through (3) above apply to each vessel and not the assembly as a whole. Straight line interpolation for intermediate volumes and design pressures is permitted. Vessels fabricated in accordance with this rule shall be marked with the "UM" Designator in Figure UG-116, sketch (b) and with the data required in UG-116. Certificates of Compliance shall satisfy the requirements of UG-120(a).

U-2 GENERAL (25)

(a) The user or the user's designated agent (see Nonmandatory Appendix NN) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration.

(1) Such consideration shall include but shall not be limited to the following:

(-a) all loadings listed in UG-22.

(-b) the need for corrosion allowances;

(-c) damage mechanisms and service restrictions associated with the service fluid at design conditions. Informative and nonmandatory guidance regarding metallurgical phenomena is provided in Section II, Part D, Nonmandatory Appendix A, API RP 571, and WRC Bulletins 488, 489, and 490.

(-d) the need for postweld heat treatment beyond the requirements of this Division and dependent on service conditions;

(-e) for pressure vessels in which steam is generated, or water is heated [see U-1(g) and U-1(h)], the need for piping, valves, instruments, and fittings to perform the functions covered by Section I, PG-59 through PG-61.

(-f) the degree of nondestructive examination(s) and the selection of applicable acceptance standards when such examinations are beyond the requirements of this Division.

(2) User's Design Requirements Form

(-a) A User's Design Requirements Form, or other document with equivalent information, shall be provided when any of the following conditions is a design requirement:

(-1) superimposed static reactions [see UG-22(c)]

(-2) cyclic or dynamic reactions [see UG-22(e)]

(-3) loadings due to wind, snow, or seismic reactions [see UG-22(f)]

(-4) impact reactions [see UG-22(g)]

(-5) temperature effects [see UG-22(h)]

(-6) abnormal pressures [see UG-22(i)]

(-b) A User's Design Requirements Form or other document with equivalent information shall be provided when overpressure protection by system design in accordance with Section XIII, Part 13 has been chosen.

(-c) A User's Design Requirements Form or other document with equivalent information shall be provided when the user of an existing Code pressure vessel is specifying replacement or repair parts to be built by a parts Manufacturer that performs no design function. The user shall identify on the form the parts as "User-Specified Parts."

(-d) Sample User's Design Requirements Forms and guidance on their preparation are found in Nonmandatory Appendix KK. This sample form might not be applicable to all pressure vessels that may be constructed in accordance with this Division. The user is cautioned that input from the Manufacturer may be necessary for completion of this form.

(b) Responsibilities[4]

(1) The Manufacturer is responsible for the structural and pressure-retaining integrity of a vessel or part thereof, as established by conformance with the requirements of the rules of this Division and any additional requirements specified in the User's Design Requirements Form when provided. The Manufacturer's Data Report shall include the design requirements of (a)(2)(-a) and and (a)(2)(-b)when specified.

(2) The Manufacturer of any vessel or part to be marked with the Certification Mark has the responsibility of complying with all of the applicable requirements of this Division and, through proper certification, of assuring that all work done by others also complies. The vessel Manufacturer or, when applicable, the part Manufacturer is responsible for the preparation and accuracy of design calculations to show compliance with the rules of this Division, and the vessel or part Manufacturer's signature on the Manufacturer's Data Report Form shall be considered as certification that this has been done. The vessel or part Manufacturer shall have available for the Inspector's review the applicable design calculations and, when provided, the User's Design Requirements Form. See Mandatory Appendix 10, 10-5 and 10-15(d).

(3) The Manufacturer has the responsibility of ensuring all personnel performing design activities are qualified in the applicable area(s) of design. See Mandatory Appendix 10 and Mandatory Appendix 47.

(4) The Manufacturer has the responsibility to report methods of design used that are not covered by the rules of this Division [see (g)], and shall be described in the "Remarks" of the Manufacturer's Data Report.

(5) Some types of work, such as forming, nondestructive examination, and heat treating, may be performed by others (for welding, see UW-26 and UW-31). It is the vessel or part Manufacturer's responsibility to ensure that all work so performed complies with all the applicable requirements of this Division. After ensuring Code compliance, the vessel or part may be stamped with the Certification Mark and Designator by the appropriate Certificate holder after acceptance by the Inspector.

(c) A vessel may be designed and constructed using any combination of the methods of fabrication and the classes of materials covered by this Division, provided the rules applying to each method and material are complied with and the vessel is marked as required by UG-116.

(d) When the strength of any part cannot be computed with a satisfactory assurance of safety, the rules provide procedures for establishing its maximum allowable working pressure.

(e) It is the duty of the Inspector to make all of the inspections specified by the rules of this Division, and to monitor the quality control and the examinations made by the Manufacturer. The Inspector shall make such other inspections deemed necessary by the Inspector to permit certification that the vessel has been designed and constructed in accordance with the minimum requirements of this Division. The Inspector has the duty of verifying that the applicable design calculations have been made and are on file at Manufacturer's plant at the time the Data Report is signed. Any questions concerning the calculations raised by the Inspector must be resolved. See UG-90.3.

NOTE: The term "applicable design calculations" means that all pressure-retaining components covered by the Certification Mark stamping are supported by calculations and/or proof tests that comply with the requirements of this Division. The method of verifying that applicable design calculations have been made will vary with the individual Inspector and depend largely on the Manufacturer's procedures for producing the design calculations and any subsequent quality checks performed by the Manufacturer.

(f) The rules of this Division shall serve as the basis for the Inspector to:

(1) perform the required duties;

(2) authorize the application of the Certification Mark;

(3) sign the Certificate of Shop (or Field Assembly) Inspection.

(g) This Division of Section VIII does not contain rules to cover all details of construction. Where complete details of construction are not given, the Manufacturer, subject to the acceptance of the Authorized Inspector, shall provide the appropriate details to be used.

(1) Where design rules do not exist in this Division, one of the following three methods shall be used:

(-a) Mandatory Appendix 46.

(-b) proof test in accordance with UG-101.

(-c) other recognized and generally accepted methods, such as those found in other ASME, EN, ISO, national, and industry standards or codes. This option shall provide details of design consistent with the allowable stress criteria provided in UG-23.

(2) The provisions of this paragraph shall not be used to justify the use of materials, joining processes (fabrication), examination, inspection, testing, certification, and overpressure protection methods other than those allowed by this Division.

(h) Field assembly of vessels constructed to this Division may be performed as follows.

(1) The Manufacturer of the vessel completes the vessel in the field; completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P within Nonmandatory Appendix W, and stamps the vessel.

(2) The Manufacturer of parts of a vessel to be completed in the field by some other party stamps these parts in accordance with Code rules and supplies the Manufacturer's Partial Data Report Form U-2 or Form U-2A to the other party. The other party, who must hold a valid U Certificate of Authorization, makes the final assembly, required NDE, and final pressure test; completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P, and stamps the vessel.

(3) The field portion of the work is completed by a holder of a valid U Certificate of Authorization other than the vessel Manufacturer. The Certificate Holder performing the field work is required to supply the Manufacturer's Partial Data Report Form U-2 or Form U-2A covering the organization's portion of the work completed (including data on the pressure test if conducted by the Certificate Holder performing the field work) to the Manufacturer responsible for the Code vessel. The vessel Manufacturer applies the Certification Mark with the U Designator in the presence of a representative from the Inspection Agency and completes the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P with the Inspector.

In all three alternatives, the party completing and signing the Manufacturer's Data Report Form U-1, Form U-1A, or Form U-1P assumes full Code responsibility for the vessel. In all three cases, each Manufacturer's Quality Control System shall describe the controls to assure compliance for each Certificate Holder.

(i) For some design analyses, both a chart or curve and a equation or tabular data are given. Use of the equation or tabular data may result in answers which are slightly different from the values obtained from the chart or curve. However, the difference, if any, is within practical accuracy and either method is acceptable.

(j) The Manufacturer of the completed vessel shall establish the construction requirements for subcontracted parts [see Mandatory Appendix 43, 43-2(a)(2)] requiring inspection under this Division. The Manufacturer shall give consideration to the compatibility of the parts with the completed vessel. Such consideration shall include, but not be limited to, the following:

(1) the design requirements established by the user or the user's designated agent [see (a)]

(2) the Certificate Holder responsible for design [see UG-120(c)(1)(-b)]

(3) the need for pressure testing by the Manufacturer of the part, including the required test pressure

(4) impact testing requirements for materials and/or welding procedure qualifications

(5) compliance with special requirements for vessels intended for special services [see UG-120(d)]

(6) the need for preheat or postweld heat treatment

(7) the extent and method of nondestructive examination (see UW-12)

(8) the units of measurement (see U-4)

(9) the mandated Edition of the Code to be used for construction (see Mandatory Appendix 43)

U-3 STANDARDS REFERENCED BY THIS DIVISION

(a) Throughout this Division references are made to various standards, such as ASME standards, which cover pressure–temperature rating, dimensional, or procedural standards for pressure vessel parts. These standards, with the year of the acceptable edition, are listed in Table U-3.

(b) Rules for the use of these standards are stated elsewhere in this Division.

U-4 UNITS OF MEASUREMENT[5]

(a) U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with requirements of this edition related to materials, fabrication, examination, inspection, testing, certification, and overpressure protection.

(b) A single system of units shall be used for all aspects of design except where otherwise permitted by this Division. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component, subject to the limitations given in (c). Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component, subject to the limitations given in (c).

(c) For any single equation, all variables shall be expressed in a single system of units. Calculations using any material data published in this Division or Section II, Part D (e.g., allowable stresses, physical properties, external pressure design factor *B*) shall be carried out in one of the standard units given in Table U-4-1. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations or any other calculations carried out in either U.S. Customary or SI units may be converted to other units.

(d) Production, measurement and test equipment, drawings, Welding Procedure Specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents, or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

(1) Conversion factors shall be accurate to at least four significant figures.

(2) The results of conversions of units shall be expressed to a minimum of three significant figures.

(e) Conversion of units, using the precision specified above, shall be performed to assure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Nonmandatory Appendix GG, Guidance for the Use of U.S. Customary and SI Units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the Manufacturer shall provide the source of the conversion factors which shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

(f) Dimensions shown in the text, tables, and figures, whether given as decimals or fractions, may be taken as decimals or fractions and do not imply any manufacturing precision or tolerance on the dimensions.

(g) Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary units or SI units may be used regardless of the units system used in design.

(h) All entries on a Manufacturer's Data Report and data for Code-required nameplate marking shall be in units consistent with the fabrication drawings for the component using U.S. Customary, SI, or local customary units. Units (either primary or alternative) may be shown parenthetically. Users of this Code are cautioned that the receiving jurisdiction should be contacted to ensure the units are acceptable.

U-5 TOLERANCES

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

U-6 CROSS-REFERENCES TO SECTION VIII, DIVISION 2 (25)

In some instances, this Division references Section VIII, Division 2 for design rules. If a cross-referenced Division 2 requirement then refers to another Division 2 element (e.g., a paragraph, figure, or table), the designer using this Division shall use the applicable element of this Division. Refer to the relevant tables located at the beginning of each Part or Appendix that references Division 2 design rules.

For example, see Part UEJ, Table UEJ-1-2, which lists the Division 1 elements that are used in lieu of Division 2 elements referenced in the Division 2 design rules.

(25)

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division

Title	Number	Year
Pipe Threads, General Purpose (Inch)	ANSI/ASME B1.20.1	Latest edition
Marking and Labeling Systems	ANSI/UL-969	Latest edition
Seat Tightness of Pressure Relief Valves	API Std. 527	2020
Minimum Design Loads and Associated Criteria for Buildings and Other Structures	ASCE/SEI 7	2022
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	Latest edition
Gray Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250	ASME B16.1	2020
Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard	ASME B16.5	2025 [Note (1)], [Note (4)]
Factory-Made Wrought Buttwelding Fittings	ASME B16.9	Latest edition
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	Latest edition
Cast Copper Alloy Threaded Fittings, Classes 125 and 250	ASME B16.15	Latest edition
Metallic Gaskets for Pipe Flanges	ASME B16.20	Latest edition
Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves, Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24	2021
Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300	ASME B16.42	2021
Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47	2025 [Note (4)]
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2	Latest edition
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	Latest edition
Conformity Assessment Requirements	ASME CA-1	Latest edition
Pressure Boundary Bolted Flange Joint Assembly	ASME PCC-1	2022
Repair of Pressure Equipment and Piping	ASME PCC-2	2022
Standard Test Method for Measurement of Fracture Toughness	ASTM E1820	2024
Section VIII - Division 1 Example Problem Manual	ASME PTB-4	Latest edition
Criteria for Shell-and-Tube Heat Exchangers According to Part UHX of ASME Section VIII-Division 1	ASME PTB-7	2014
Safety Standard for Pressure Vessels for Human Occupancy	ASME PVHO-1	2016
Qualifications for Authorized Inspection	ASME QAI-1	Latest edition [Note (2)]
Standard Practice for Quantitative Measurement and Reporting of Hypoeutectoid Carbon and Low-Alloy Steel Phase Transformations	ASTM A1033	Latest edition
Standard Test Method for Flash Point by Tag Closed Tester	ASTM D56	Latest edition
Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester	ASTM D93	Latest edition
Standard Guide for Preparation of Metallographic Specimens	ASTM E3	2017
Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings	ASTM E125	1963 (R2023) [Note (3)]
Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness	ASTM E140	Latest edition
Standard Reference Radiographs for Heavy-Walled [2 to 4$^1/_2$ in. (50.8 to 114 mm)] Steel Castings	ASTM E186	2020
Standard Test Method for Conducting Drop-Weight Test to Determine Nil– Ductility Transition Temperature of Ferritic Steels	ASTM E208	Latest edition
Standard Reference Radiographs for Heavy-Walled [4$^1/_2$ to 12 in. (114 to 305 mm)] Steel Castings	ASTM E280	2021
Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness	ASTM E446	2020
Metallic Materials — Charpy Pendulum Impact Test Part 1: Test Method	ISO 148-1	Latest edition
Metallic Materials — Charpy Pendulum Impact Test Part 2: Verification of Testing Machines	ISO 148-2	Latest edition
Metallic Materials — Charpy Pendulum Impact Test Part 3: Preparation and Characterization of Charpy V-Notch Test Pieces for Indirect Verification of Pendulum Impact Machines	ISO 148-3	Latest edition
Metric Standards		
Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal	AWS A4.2M	Latest edition
Metric Screw Thread — M Profile	ASME B1.13M	Latest edition

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division (Cont'd)

Title	Number	Year
Metric Screw Thread — MJ Profile	ASME B1.21M	Latest edition
Metric Heavy Hex Screws	ASME B18.2.3.3M	Latest edition
Metric Fasteners for Use in Structural Applications	ASME B18.2.6M	Latest edition
Standard Test Method for Compressive Strength of Carbon and Graphite	ASTM C695	2021
Standard Practices for Force Verification of Testing Machines	ASTM E4	2021
Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods	ASTM E177	2020
Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method	ASTM E691	2023

NOTES:
(1) See UG-11(a)(2).
(2) See UG-91 and UG-117(a).
(3) R — Reaffirmed.
(4) The use of a flange or flanged fitting that relies on and meets the requirements of a B16 Case is not permitted.

Table U-4-1
Standard Units for Use in Equations

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches (in.^{2})	square millimeters (mm^2)
Volume	cubic inches (in.^{3})	cubic millimeters (mm^3)
Section modulus	cubic inches (in.^{3})	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 (in.^{4})	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{\text{in.}}$)	MPa square root meters (MPa$\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

SUBSECTION A
GENERAL REQUIREMENTS

PART UG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

(25) UG-1 SCOPE

The requirements of Part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B, C, and D and the Mandatory Appendices that pertain to the method of fabrication and the material used.

MATERIALS

(25) UG-4 GENERAL

(a) Material subject to stress due to pressure shall conform to one of the specifications given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and shall be limited to those that are permitted in the applicable Part of Subsection C, except as otherwise permitted in UG-9; UG-10; UG-11; UG-15; Part UCS; Subsection D, Part UIG; and the Mandatory Appendices. Material may be identified as meeting more than one material specification and/or grade, provided the material meets all requirements of the identified material specification(s) and/or grade(s) [see UG-23(a)].

(b) Material for nonpressure parts, such as skirts, supports, baffles, lugs, clips, and extended heat transfer surfaces, need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Division, but if attached to the vessel by welding shall be of weldable quality [see UW-5(b)]. The allowable stress values for material not identified in accordance with UG-93 shall not exceed 80% of the maximum allowable stress value permitted for similar material in Subsection C.

(c) Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and so long as the product complies with the requirements of the specification. (See UG-85.)

(d) Materials other than those allowed by the rules of this Division shall not be used. Data for new materials shall be submitted to and approved by the ASME Boiler and Pressure Vessel Committee on Materials in accordance with Section II, Part D, Mandatory Appendix 5.

(e) Materials outside the limits of size and/or thickness given in the title or scope clause of the specifications given in Section II, and permitted by the applicable Part of Subsection C, may be used if the material is in compliance with the other requirements of the specification,[6] and no size or thickness limitation is given in the stress tables. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(f) It is recommended that the user or the user's designated agent ensure that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life. See also informative and nonmandatory guidance regarding metallurgical phenomena in Section II, Part D, Nonmandatory Appendix A.

(g) When specifications, grades, classes, and types are referenced, and the material specification in Section II, Part A or Part B is a dual-unit specification (e.g., SA-516/SA-516M), the design values and rules shall be applicable to either the U.S. Customary version of the material specification or the SI unit version of the material specification. For example, when SA-516M Grade 485 is used in construction, the design values listed for its equivalent, SA-516 Grade 70, in either the U.S. Customary or metric Section II, Part D (as appropriate) shall be used.

(h) When the rules of this Division require the use of material physical properties, these properties shall be taken from the applicable tables in Section II, Part D,

Subpart 2. If the applicable tables in Section II, Part D, Subpart 2 do not contain these properties for a permitted material or do not list them within the required temperature range, the Manufacturer may use other authoritative sources for the needed information. The Manufacturer's Data Report shall note under "Remarks" the property values obtained and their source.

NOTE: If material physical properties are not listed, the Manufacturer is encouraged to bring the information to the attention of the ASME Committee on Materials (BPV Section II) so that the data can be added in Section II, Part D, Subpart 2.

UG-5 PLATE[7]

Plate used in the construction of pressure parts of pressure vessels shall conform to one of the specifications in Section II for which allowable stress values are given in the tables referenced in UG-23, except as otherwise provided in UG-4, UG-10, UG-11, and UG-15.

(25) UG-6 FORGINGS

(a) Specifications and maximum allowable stress values for acceptable forging materials are given in the tables referenced in UG-23. (See Part UF for forged vessels.)

(b) Bar [as defined in UG-14(a)] that is forged independent of the material specification to which it is certified may be used only within the limitations of UG-14.

(c) Forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 may be used as tubesheets and hollow cylindrical forgings for pressure vessel shells that otherwise meet all the rules of this Division, provided the following additional requirements are met:

(1) Forgings certified to SA-105 or SA-181 shall be subject to one of the austenitizing heat treatments permitted by these specifications.

(2) One tension test specimen shall be taken from each forging weighing more than 5,000 lb (2 250 kg). The largest obtainable tension test specimen as specified by the test methods referenced in the applicable specification shall be used. Except for upset-disk forgings, the longitudinal axis of the test specimen shall be taken parallel to the direction of major working of the forging. For upset-disk forgings, the longitudinal axis of the test specimen shall be taken in the tangential direction. When agreed to by the Manufacturer, and when not prohibited by the material specification, test specimens may be machined from specially forged test blocks meeting the provisions provided in SA-266 or other similar specifications for large forgings.

(3) For quenched and tempered forgings weighing more than 10,000 lb (4 500 kg) at the time of heat treatment, two tension test specimens shall be taken from each forging. These shall be offset 180 deg from each other, except that if the length of the forging, excluding test prolongations, exceeds 12 ft (3.7 m), then one specimen shall be taken from each end of the forging.

UG-7 CASTINGS

Cast material may be used in the construction of pressure vessels and vessel parts. Specifications and maximum allowable stress values for acceptable casting materials are given in the tables referenced in UG-23. These allowable stress values shall be multiplied by the applicable casting quality factor given in UG-24 for all materials except cast iron.

UG-8 PIPE AND TUBES

(a) Pipe and tubes of seamless or welded[8] construction conforming to one of the specifications given in Section II may be used for shells and other parts of pressure vessels. Allowable stress values for the materials used in pipe and tubes are given in the tables referenced in UG-23.

(b) Integrally finned tubes may be made from tubes that conform in every respect with one of the specifications given in Section II. The requirements of (1), (2), (3), and (5) do not apply to tubes produced in accordance with a Section II integrally-finned material specification. These tubes may be used under the following conditions:

(1) The tubes, after finning, shall have a temper or condition that conforms to one of those provided in the governing specifications, or, when specified, they may be furnished in the "as-fabricated condition" where the finned portions of the tube are in the cold worked temper (as-finned) resulting from the finning operation, and the unfinned portions in the temper of the tube prior to finning.

(2) The maximum allowable stress value for the finned tube shall be that given in the tables referenced in UG-23 for the tube before finning except as permitted in (3) below.

(3) The maximum allowable stress value for a temper or condition that has a higher stress value than that of the tube before finning may be used, provided that qualifying mechanical property tests demonstrate that such a temper or condition is obtained and conforms to one of those provided in the governing specifications in Section II, and provided that allowable stress values have been established in the tables referenced in UG-23 for the tube material used. The qualifying mechanical property tests shall be made on specimens of finned tube from which the fins have been removed by machining. The frequency of tests shall be as required in the unfinned tube specification.

(4) The maximum allowable internal or external working pressure of the tube shall be based on the root diameter and the minimum wall of the finned section, or the outside diameter and wall of the unfinned section together with appropriate stress values, whichever results in the lower maximum allowable working pressure. Alternatively, the maximum allowable external pressure for tubes with integral fins may be established under the rules of Mandatory Appendix 23.

(5) In addition to the tests required by the governing specifications, each tube after finning shall be subjected to a pneumatic test or a hydrostatic test as indicated below. UG-90.3(a)(10) requirement for a visual inspection by the Inspector does not apply to either of these tests.

(-a) an internal pneumatic test of not less than 250 psi (1.7 MPa) for 5 sec without evidence of leakage. The test method shall permit easy visual detection of any leakage such as immersion of the tube under water or a pressure differential method.[9]

(-b) an individual tube hydrostatic test in accordance with UG-99 that permits complete examination of the tube for leakage.

(25) UG-9 WELDING MATERIALS

UG-9.1 Production Welding Materials. Welding materials used for production shall meet the requirements of this Division, Section IX, and the applicable qualified Welding Procedure Specification.

UG-9.2 Identification of Welding Materials. The vessel or part Manufacturer may accept one or more of the following for identification of welding materials:

(a) the marking or tagging of the welding material, containers, or packages as required by the Section II, Part C specification to which the material conforms

(b) the marking or tagging of the materials in the Welding Procedure Specification if the material does not conform to a Section II, Part C specification

(c) the Test Report

(d) the Certificate of Compliance

(25) UG-10 RECERTIFICATION OF MATERIAL TO A SPECIFICATION PERMITTED BY THIS DIVISION

UG-10.1 Recertification Procedural Requirements.

(a) Only a Certificate Holder (vessel or part Manufacturer) shall recertify material.

(b) The Certificate Holder shall only recertify a material to a specification permitted by this Division that is any of the following (see also Mandatory Appendix 43):

(1) an ASME material specification published in the current Edition of Section II, Part A or Part B

(2) a material specification otherwise explicitly permitted by the current Edition of Section II, Part A, Mandatory Appendix II or Section II, Part B, Mandatory Appendix II

(3) a Code Case material specification

UG-10.2 Recertification of Identified Material. A Certificate Holder shall recertify per UG-10.2.1 or UG-10.2.2 a material meeting the following criteria:

(a) The material is identified with a specification not permitted by this Division.

(b) The material is identified to a single lot as required by a specification permitted by this Division.

(c) The material has marking acceptable to the Inspector that identifies the material to the documentation.

See UG-10.3 for recertification of material that does not meet the criteria of (a), (b), and (c).

UG-10.2.1 Recertification When Documentation Is Available.

(a) The material manufacturer shall provide to the Certificate Holder documentation that the material meets all the requirements of a specification permitted by this Division.

(b) After establishing the material's conformance to the permitted specification, the Certificate Holder shall mark the material as required by the permitted specification identified in (a).

UG-10.2.2 Recertification When Complete Documentation Is Unavailable. If the complete documentation described in UG-10.2.1(a) is unavailable, the Certificate Holder shall meet the requirements in 10.2.2.1 through 10.2.2.5.

UG-10.2.2.1 Missing Chemical Requirements Documentation. If documentation demonstrating complete conformance to the chemical requirements is not available, the Certificate Holder shall perform chemical analyses as described in (a) through (d).

(a) The Certificate Holder shall select a sample of random pieces from the lot of material for chemical analysis. The number of pieces in the sample shall be at least

$$\min\left[\max(0.10n, 3), n\right]$$

where

n = number of pieces in the lot

(b) The Certificate Holder shall analyze each piece in the sample per the chemical analyses described in the permitted specification.

(c) The Certificate Holder shall analyze those elements for which the permitted specification (including its general requirements specification) requires analysis and for which documentation is unavailable.

(d) To qualify for recertification, the material shall satisfy the following criteria:

(1) Each individual analysis for an element shall conform to the product analysis limits of the permitted specification.

(2) The average of each element shall conform to the heat analysis limits of the permitted specification.

UG-10.2.2.2 Missing Mechanical Requirements Documentation.

(a) The Certificate Holder shall test all mechanical properties for which required documentation is unavailable.

(b) The Certificate Holder shall perform the tests per the requirements of the permitted specification.

(c) The results of the mechanical properties tests shall conform to the requirements of the permitted specification.

UG-10.2.2.3 Missing Heat Treatment Requirements Documentation. If documentation demonstrating complete conformance to the heat treatment requirements is not available, the Certificate Holder shall heat treat the material per the requirements of the permitted specification. The heat treatment may be done before or during fabrication (see also UG-85).

UG-10.2.2.4 Other Requirements. The Certificate Holder shall demonstrate that the material meets all other applicable requirements of the permitted specification.

UG-10.2.2.5 Marking and Acceptance. After establishing per UG-10.2.2.1 through UG-10.2.2.4 the material's conformance to the permitted specification, the Certificate Holder shall mark the material as required by the permitted specification.

UG-10.3 Recertification of Material Not Fully Identified. A Certificate Holder may recertify per UG-10.3.1 and UG-10.3.2 a material that cannot be recertified per UG-10.2. UG-10.3.1 and UG-10.3.2 apply to material meeting either of the following criteria:

(a) The material is not fully identified as required by a specification permitted by this Division.

(b) The material is unidentified.

UG-10.3.1 Recertification Requirements. The Certificate Holder shall perform the following steps:

(a) Test each piece of material to show that it meets the chemical composition for heat analysis of the permitted specification. Chemical analyses shall be made for those elements required by the permitted specification (including its general requirements specification).

(b) Test each piece of material to show that it meets the mechanical properties requirements of the permitted specification.

(c) When the direction of final rolling or major work (as required by the material specification) is not known, the Certificate Holder shall do the following:

(1) Take tension test specimens in each appropriate direction from each sampling location designated in the permitted specification.

(2) Ensure that all test results conform to the minimum requirements of the specification.

(3) Show that the tensile strength of at least one specimen conforms to the maximum requirement.

(d) Heat treat if required per UG-10.2.2.3.

(e) Demonstrate that the material meets all other applicable requirements of the permitted specification.

UG-10.3.2 Recertification Acceptance.

(a) After identifying the material per UG-10.3.1, the Certificate Holder shall mark the material with the following information:

(1) the number of the permitted specification and grade, type, or class, as applicable, of the material

(2) a serial number identifying the lot of material

(b) The Certificate Holder shall complete and certify a material report clearly labeled "Report on Tests of Nonidentified Material."

(c) The Inspector shall review the "Report on Tests of Nonidentified Material" [see (b)]. If accepted by the Inspector, the report shall constitute authority to use the material in lieu of material procured to the requirements of the permitted specification.

UG-11 PREFABRICATED OR PREFORMED PRESSURE PARTS

(a) Prefabricated or preformed pressure parts for pressure vessels that are subject to stresses due to pressure and that are furnished by others or by the Manufacturer of the completed vessel shall conform to all applicable requirements of this Division except as permitted in (b), (c), (d), (e), and (f) below. When the prefabricated or preformed parts are furnished with a nameplate that contains product identifying marks and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Authorized Inspector, may remove the nameplate. The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report. The nameplate shall be destroyed. The rules of (b), (c), (d), and (e) below shall not be applied to welded shells or heads or to quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively).

Parts furnished under the provisions of (b), (c), (d), and (f) need not be manufactured by a Certificate Holder. However, the Manufacturer of the completed vessel or Certification Mark–stamped part shall ensure that parts furnished under the provisions of (b) through (f) meet all of the applicable Code requirements such as UCS-79(d), UNF-79(a), UHA-44(a), and UHT-79(a). Prefabricated or preformed pressure parts may be supplied as follows:

(1) cast, forged, rolled, or die formed non-standard pressure parts

(2) cast, forged, rolled, or die formed standard pressure parts that comply with an ASME product standard, either welded or nonwelded

(3) cast, forged, rolled, or die formed standard pressure parts that comply with a standard other than an ASME product standard, either welded or nonwelded

(4) cast cylindrical acrylic shells meeting the requirements of Part UAS.

(b) Cast, Forged, Rolled, or Die Formed Non-standard Pressure Parts. Pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division, and the manufacturer of the part shall furnish identification in accordance with UG-93. Such parts shall be marked with the name or trademark of the parts manufacturer and

with such other markings as will serve to identify the particular parts with accompanying material identification. The Manufacturer of the completed vessel shall be satisfied that the part is suitable for the design conditions specified for the completed vessel in accordance with the rules of this Division.

(c) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With an ASME Product Standard, Either Welded or Nonwelded

(1) These are pressure parts that comply with an ASME product standard accepted by reference in UG-44(a). The ASME product standard establishes the basis for the pressure–temperature rating and marking unless modified in UG-44(a).

(2) Flanges and flanged fittings may be used at the pressure–temperature ratings specified in the appropriate standard listed in this Division.

(3) Materials for standard pressure parts shall be as follows:

(-a) as permitted by this Division or

(-b) as specifically listed in the ASME product standard

(4) When welding is performed it shall meet the following:

(-a) the requirements of UW-26(a), UW-26(b), and UW-26(c) and UW-27 through UW-40, or;

(-b) the welding requirements of ASME specification SA-234.

(5) Standard pressure parts as identified in UG-11(c) do not require inspection, identification in accordance with UG-93.1 or UG-93.2, or Partial Data Reports, provided the requirements of UG-11(c) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the vessel to be marked with the Certification Mark.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the pressure parts manufacturer

(8) Parts made to an ASME product standard shall be marked as required by the ASME product standard.

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts that comply with an ASME product standard:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer shall fulfill these responsibilities by obtaining, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested. The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(d) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With a Standard Other Than an ASME Product Standard, Either Welded or Nonwelded

(1) Standard pressure parts that are either welded or nonwelded and comply with a manufacturer's proprietary standard or a standard other than an ASME product standard may be supplied by

(-a) a Certificate Holder

(-b) a pressure parts manufacturer

(2) Parts of small size falling within this category for which it is impossible to obtain identified material or that may be stocked and for which identification in accordance with UG-93 cannot be obtained and are not customarily furnished, may be used for parts as described in UG-4(b).

(3) Materials for these parts shall be as permitted by this Division only.

(4) Requirements for welding and brazing are as follows:

(-a) When welding is performed, it shall meet the requirements of UW-26(a), UW-26(b), UW-26(c), and UW-27 through UW-40.

(-b) When brazing is performed, it shall meet the requirements of Part UB.

(5) Standard pressure parts as identified in (d) do not require inspection, identification in accordance with UG-93.1 or UG-93.2, or Partial Data Reports, provided the requirements of (d) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the completed vessel.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the parts Manufacturer

(-c) the location of the pressure parts manufacturer

(8) Marking for these parts shall be as follows:

(-a) with the name or trademark of the Certificate Holder or the pressure part manufacturer and any other markings as required by the proprietary standard or other standard used for the pressure part

(-b) with a permanent or temporary marking that will serve to identify the part with the Certificate Holder or the pressure parts manufacturer's written documentation of the particular items, and that defines the pressure–temperature rating of the part

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer of the completed vessel shall fulfill these responsibilities by one of the following methods:

(-a) Obtain, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested, or;

(-b) Perform an analysis of the pressure part in accordance with the rules of this Division. [See also U-2(g).] This analysis shall be included in the documentation and shall be made available for examination by the Inspector when requested.

(11) The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(-d) a written certification by the pressure parts manufacturer that all welding and brazing complies with Code requirements

(**25**) *(e)* The Code recognizes that a Certificate Holder may fabricate parts in accordance with UG-11(d), and that are marked in accordance with UG-11(d)(8). In lieu of the requirement in UG-11(d)(4), the Certificate Holder may subcontract to an individual or organization not holding an ASME Certificate standard pressure parts that are fabricated to a standard other than an ASME product standard provided all the following conditions are met:

(1) The activities to be performed by the subcontractor are included within the Certificate Holder's Quality Control System.

(2) The Certificate Holder's Quality Control System provides for the following activities associated with subcontracting of joining operations, and these provisions shall be acceptable to the Manufacturer's Authorized Inspection Agency:

(-a) the joining processes permitted by this Division that are permitted to be subcontracted

(-b) joining operations

(-c) Authorized Inspection activities

(-d) placement of the Certificate Holder's marking in accordance with UG-11(d)(8)

(3) The Certificate Holder's Quality Control System provides for the requirements of UG-92 to be met at the subcontractor's facility.

(4) The Certificate Holder shall be responsible for reviewing and accepting the Quality Control Programs of the subcontractor.

(5) The Certificate Holder shall ensure that the subcontractor uses written procedures and joining operations that have been qualified as required by this Division.

(6) The Certificate Holder shall ensure that the subcontractor uses personnel that have been qualified as required by this Division.

(7) The Certificate Holder and the subcontractor shall describe in their Quality Control Systems the operational control of procedure and personnel qualifications of the subcontracted joining operations.

(8) The Certificate Holder shall be responsible for controlling the quality and ensuring that all materials and parts that are joined by subcontractors and submitted to the Inspector for acceptance, conform to all applicable requirements of this Division.

(9) The Certificate Holder shall describe in their Quality Control Systems the operational control for maintaining traceability of materials received from the subcontractor.

(10) The Certificate Holder shall receive approval for subcontracting from the Authorized Inspection Agency prior to commencing of activities.

(f) Cast Acrylic Shells

(1) Cast acrylic cylindrical shells meeting the requirements of Part UAS may be supplied as material.

(2) The acrylic cylindrical shell manufacturer shall provide certification that the acrylic shell has been constructed in accordance with all the requirements of Part UAS. The certification package shall include all certification documentation required by Part UAS, UAS-8 and ASME PVHO-1 Forms VP-1 through VP-4.

(3) The certification package shall be verified by the Authorized Inspector prior to the acrylic shell being installed into any part of the vessel.

(4) The Certificate Holder shall include the acrylic certification package and PVHO-1 Form VP-5 with Form U-1 or Form U-1A.

UG-12 BOLTS AND STUDS

(a) Bolts and studs may be used for the attachment of removable parts. Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in the tables referenced in UG-23.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1^1/_2$ diameters in length.

Studs greater than eight diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1^1/_2$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion;

(3) a suitable transition shall be provided between the root diameter and the unthreaded portion; and

(4) particular consideration shall be given to any dynamic loadings.

UG-13 NUTS AND WASHERS

(a) Nuts shall conform to the requirements in the applicable Part of Subsection C (see UCS-11 and UNF-13). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

(25) UG-14 BARS

(a) General

(1) Bar materials shall conform to the requirements for bars or bolting in the applicable Part of Subsection C.

(2) A bar is defined as a solid section whose axial length is greater than its maximum cross-sectional dimension, with a nominally constant cross section throughout its length.

(3) A rod is defined as a bar with other than a square or rectangular cross section; the general term "bar" is used in this paragraph.

(b) Bars Used in Tension or Longitudinal Bending. Bars may be used in pressure vessel construction for pressure parts whose primary stresses are parallel to the axis of the bar, such as flange rings [see Mandatory Appendix 2, 2-2(d)], stiffening rings, frames for reinforced openings, stays and staybolts, and similar parts.

(c) Other Parts Machined From Bar. Pressure parts other than those in (b), such as hollow cylindrically shaped parts, heads, caps, tubesheets, flanges, elbows, return bends, tees, and header tees, may be machined directly from bar as provided below. (See Table UG-14-1.)

(1) Using a Reduction in Design Stresses. Parts may be machined from bar provided all the following requirements are met:

(-a) The minimum required thickness of the component is calculated using 50% of the following values, as appropriate:

(-1) the specified allowable stress

(-2) the "B" value for external pressure or compressive stress design

(-3) the yield and tensile strengths for rules using such criteria

(-b) The following surfaces shall be examined by the magnetic particle or liquid penetrant method in accordance with the requirements of Mandatory Appendix 6 or Mandatory Appendix 8, respectively (see Figure UG-14-1):

(-1) any surface that has a slope greater than 1:3 from the axis of the bar following final machining, except where accessibility prevents meaningful interpretation and characterization of imperfections

(-2) the cut surfaces of the weld preparations prior to welding

(-c) Bar having a minimum cross-sectional dimension greater than 8.00 in. (205 mm) shall also conform to the ultrasonic requirements of (2)(-b) and (2)(-c).

(2) Using Transverse Tension Testing and Ultrasonic Examination. As an alternative to (1), parts may be machined from bar without a reduction in design stresses provided all the following requirements are met:

(-a) Transverse Test Specimens

(-1) In addition to the tension test specimens required by the material specification, tension test specimens shall meet the following requirements:

(+a) They shall be taken transverse to the axis of the bar per the requirements of (-2).

(+b) They shall be sampled from each lot (as defined in the material specification) of bar material.

(+c) In addition to the per-lot requirement of (+b), bars in the same lot shall be sampled from each diameter in the lot.

(-2) Specimens shall be removed from the bar as shown in Figure UG-14-2.

(+a) Hollow Parts, Such as Hollow, Cylindrically Shaped Parts, and Ring, Slip-On, or Weld Neck Flanges. The axis of the two outer tension test specimens shall be located, as nearly as practicable, midway between the minimum inner and maximum outer surfaces of the finished part, as measured from the bar axis, and 90 deg around the perimeter from each other.

(+b) Solid Parts, Such as Heads, Caps, Tubesheets, Blind Flanges, Elbows, Return Bends, Tees, and Header Tees

(+1) The axis of the two outer tension test specimens shall be located as nearly as practicable to the outer surface of the finished part, as measured from the bar axis, and 90 deg around the perimeter from each other.

(+2) The axis and mid-gage length of the third specimen shall be located approximately at the centerline of the bar; its orientation need not be aligned with either of the two other specimens.

(-3) All specimens shall meet all the mechanical tension test property requirements of the material specification.

(-b) Ultrasonic Examination. Each bar, before machining, shall be 100% ultrasonically examined perpendicular to the longitudinal axis by the straight beam

technique in accordance with Section V, SA-388 or SA-745, as applicable. The bar shall be unacceptable if either of the following occurs:

(-1) The examination results show one or more indications accompanied by loss of back reflection larger than 60% of the reference back reflection.

(-2) The examination results show indications larger than 40% of the reference back reflection when accompanied by a 40% loss of back reflection.

(-c) Longitudinal Ultrasonic Examination. For machined features of components for which it is practicable, such as heads, tubesheets and the flat portion of caps, the ultrasonic examination perpendicular to the longitudinal axis of (-b) shall also be performed in the axial direction. If the axial ultrasonic examination is qualified for the bar prior to machining, this ultrasonic examination may be done in lieu of the examination perpendicular to the longitudinal axis per (-b).

(-d) Surface Examination. Each part shall be surface examined per (1)(-b).

(3) Exemptions. The following are exemptions to the requirements of (c):

(-a) ASME Standard Parts. The requirements of (1) and (2) do not apply to parts conforming to an ASME standard per UG-11(c).

(-b) Proof-Tested Parts. The requirements of (1)(-a) and (2) do not apply to parts that use the provisions of UG-101. Only the requirements of (1)(-b) and (1)(-c) apply.

(25) **UG-15 PRODUCT SPECIFICATION**

When a material specification is not listed in this Division covering a particular wrought or hot isostatically pressed material product of a grade (i.e., desired material), but there is an approved specification listed in this Division covering some other wrought or hot isostatically pressed material product of that grade (i.e., approved material), the desired material may be used provided the following conditions are met:

(a) The chemical, mechanical, heat treating, deoxidation, and grain size requirements shall conform to the approved material.

(b) Hot isostatically pressed material shall also meet the requirements of Section II, Part D, Mandatory Appendix 5, Table 5-100 and 5-600 and shall be limited to the classes of material itemized in the title of Section II, Part D, Mandatory Appendix 5, Table 5-100.

(c) The desired material shall be covered in a Section II specification.

(d) The stress values for the approved material given in the tables referenced in UG-23 shall be used.

(e) For the case of welded product forms without the addition of filler metal, the allowable stresses of the desired material shall be the appropriate approved material stress values multiplied by a factor of 0.85.

(f) The product shall not be pipe or tube fabricated by fusion welding with the addition of filler metal unless it is constructed as a pressure part in accordance with the rules of this Division.

(g) The material test reports shall reference the specifications used in producing the material and reference this paragraph.

DESIGN

UG-16 GENERAL (25)

The design of pressure vessels and vessel parts shall conform to the general design requirements in UG-16.1 through UG-16.4. In addition, design of pressure vessels and vessel parts shall conform to the specific requirements for *Design* given in the applicable Parts of Subsections B, C, and D.

(a) If the design rules for a component reside in this Division, without reference to Section VIII, Division 2, then the design rules of this Division apply, except that Mandatory Appendix 46 may be used as an alternative.

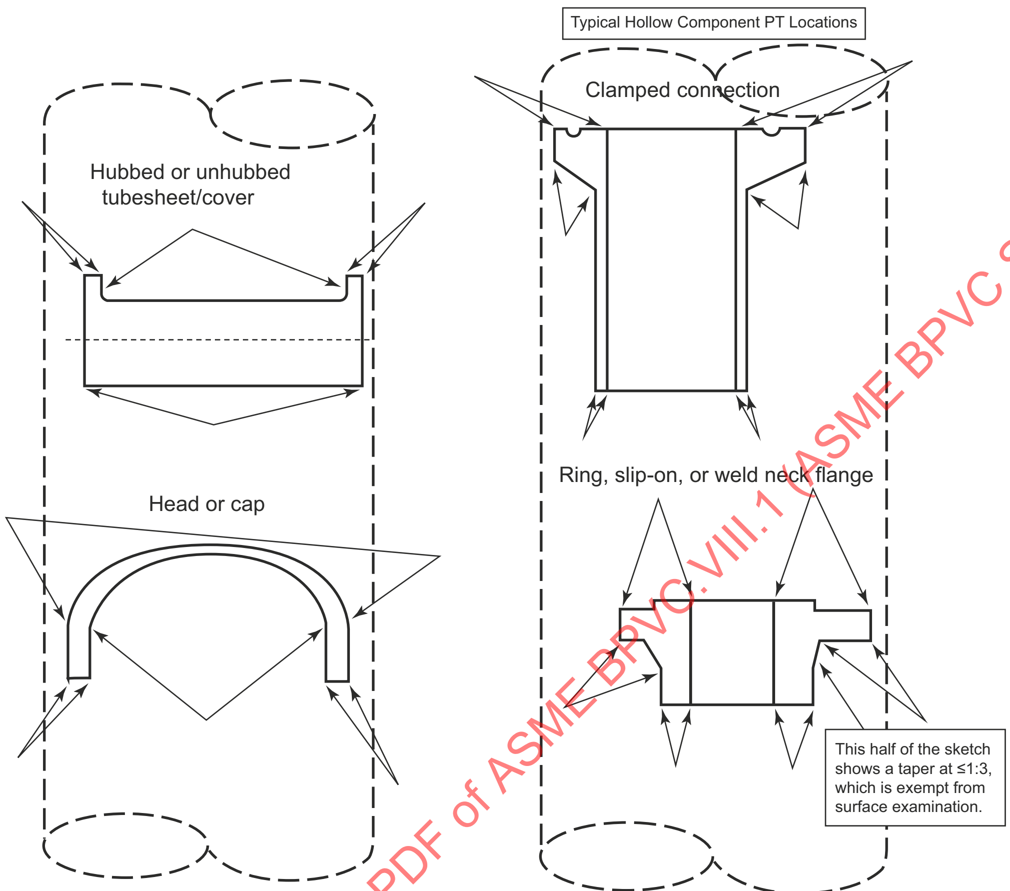
(b) If the design rules for a component refer to the design procedures in Section VIII, Division 2, then those design procedures shall be used subject to the conditions

Table UG-14-1 Criteria and Requirements for Bar per UG-14(c) (25)

Direction of Primary Stresses Relative to the Bar Axis: Parallel	Not Parallel	Bar Nominal Size, in. (mm)	Design Stress Penalty Required per UG-14(c)(1)(-a), %	Volumetric Ultrasonic Examination Required per UG-14(c)(2)(-b) and UG-14(c)(2)(-c)	Transverse Tension Testing Required per UG-14(c)(2)(-a)	Surface Examination Required per UG-14(c)(1)(-b)
X	...	Any	None	None	None	None
...	X	≤8.00 (≤205)	50	None	None	X
...	X	>8.00 (>205)	50	X	None	X
...	X	Any	None	X	X	X

(25)

Figure UG-14-1
Typical Component Surface Examination Locations and Machined Features Requiring Axial Ultrasonic Examination



GENERAL NOTES:
(a) The areas between the arrows shall be surface examined.
(b) The features delineated between the arrows indicate examples of parts for which axial ultrasonic examination would be required, when practicable, in the machined part or in the bar prior to machining.

specified in the applicable appendix or paragraph in this Division. Requirements other than design shall be in accordance with this Division.

(c) For examples applying the design rules in this Division, see ASME PTB-4.

UG-16.1 Corrosion Allowance. Unless otherwise specified, all dimensions represented by dimensional symbols used in design equations throughout this Division are taken in the corroded condition.

UG-16.2 Minimum Thickness Requirements. The minimum thickness of the following components, after forming, regardless of product form or material, and exclusive of any corrosion allowance, shall be as follows:

(a) 0.25 in. (6 mm) for shells and heads of unfired steam boilers

(b) 0.0938 in. (2.5 mm) for shells and heads constructed from Table UCS-23 materials and used in compressed air service, steam service, or water service

(c) 0.022 in. (0.5 mm) for tubes used in air-cooled or cooling tower heat exchangers provided the tubes

(1) are not used in lethal service applications [see UW-2(a)]

(2) are protected by fins or other mechanical means, and

(3) have an outside diameter of 0.375 in. to 1.5 in. (10 mm to 38 mm), inclusive

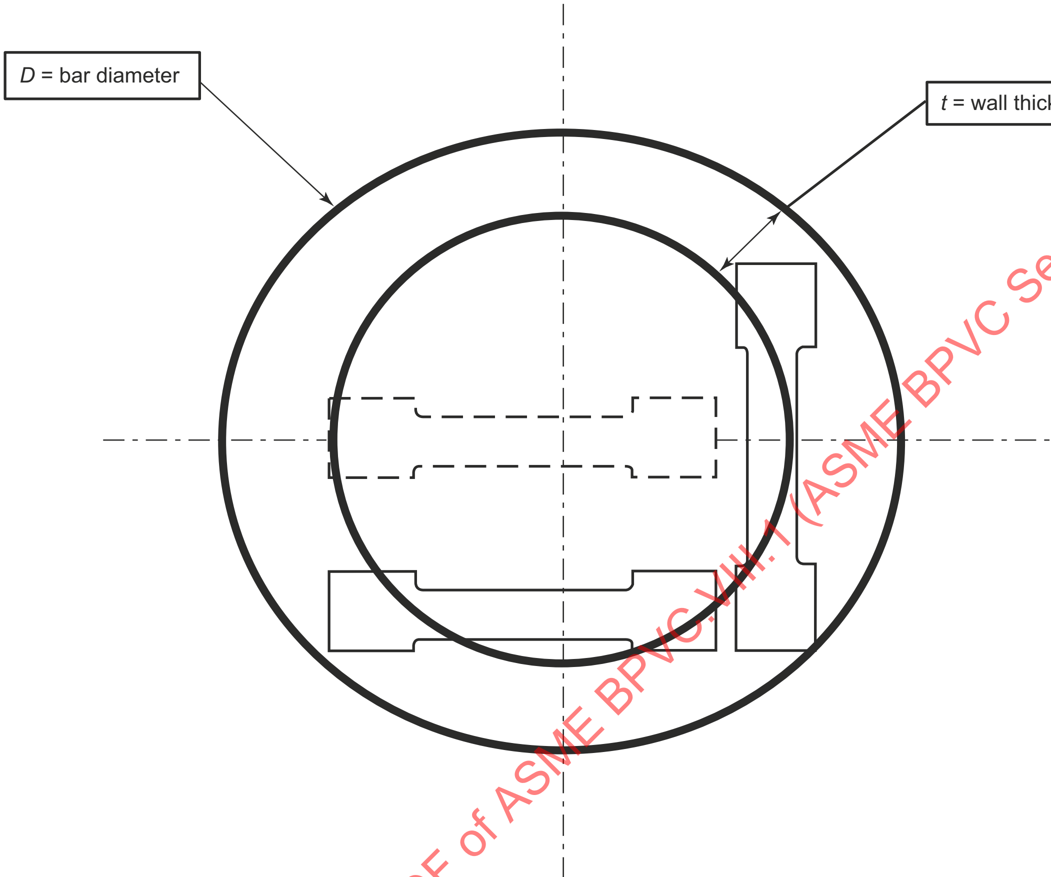
(d) 0.0625 in. (1.5 mm) for all other components, unless otherwise specified in this Division

UG-16.3 Minimum Thickness Exemptions. Minimum thickness requirements do not apply to the following components:

(a) heat transfer plates of plate-type heat exchangers

(25)

Figure UG-14-2
Transverse Tension Test Specimen Locations and Orientations



GENERAL NOTES:
(a) The thick solid outlines are illustrative of a finished part geometry.
(b) The thin solid specimens are the two mandatory locations.
(c) The thin dashed specimen is the third specimen when the centerline material remains in the finished part.

(b) the inner pipe of double-pipe heat exchangers and pipes and tubes NPS 6 (DN 150) or smaller shielded from mechanical damage by an outer protective element (such as a shell, casing, or duct), with the following provisions:

(1) This exemption applies regardless of whether the protective element is constructed to Code rules.

(2) The Manufacturer shall note on the Manufacturer's Data Report when the protective element is not provided as part of the vessel. The user or the user's designated agent shall ensure installation of the protective element prior to operation.

(3) Pressure buildup within the protective element due to a pipe or tube leak should be avoided and shall be accounted for in the design.

UG-16.4 Material Thickness Requirements. Material thickness shall be selected using the following criteria:

(a) Plate Undertolerance

(1) Plate material shall be ordered with a nominal thickness greater than or equal to the design thickness.

(2) Plate material shall not have a measured thickness less than the design thickness unless the difference in thickness is less than the minimum of 0.01 in. (0.3 mm) and 6% of the design thickness [see UG-90(b)(6)].

(3) A suitably larger nominal thickness shall be ordered if the material specification allows a manufacturing undertolerance greater than the minimum thickness difference in (2).

(b) Pipe Undertolerance

(1) Pipe and tube material ordered by nominal wall thickness shall have a nominal thickness greater than or equal to the design thickness plus the manufacturing undertolerance allowed by the applicable material specification.

(2) The requirement in (1) does not apply to the nozzle wall thickness defined in UG-37(a).

(c) Fabrication Allowance. The forming, heat treatment, and other fabrication processes shall not reduce the material thickness at any point below the required thickness.

UG-17 METHODS OF FABRICATION IN COMBINATION

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Division, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements (see UG-116).

UG-18 MATERIALS IN COMBINATION

Except as specifically prohibited by other rules of this Division, a vessel may be designed and constructed of any combination of materials permitted in Subsection C, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

The requirements for the base metals, HAZs, and weld metal(s) of a weldment between metals having different impact testing requirements and acceptance criteria shall each be applied in accordance with the rules of this Division.

NOTE: Because of the different thermal coefficients of expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration and also because of metallurgical changes occurring at elevated temperatures. [See also *Galvanic Corrosion* in Section II, Part D, Nonmandatory Appendix A, A-440(c).]

(25) UG-19 SPECIAL CONSTRUCTIONS

(a) Combination Units. A combination unit is a pressure vessel that consists of more than one independent or dependent pressure chamber, operating at the same or different pressures and temperatures. The parts separating each pressure chamber are the common elements. Each element, including the common elements, shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation (see Mandatory Appendix 3, 3-2). This includes consideration of loads from chambers that are otherwise exempt from Code requirements per U-1(c)(2)(-f) and U-1(c)(2)(-g). Only the chambers that come within the scope of this Division (see U-1) need be constructed in compliance with its provisions. Also, see UJV-1(d) for jacketed vessels, and UG-99(e) or UG-100(d) for pressure tests of combination units.

(1) Common Element Design. It is permitted to design each common element for a differential pressure less than the maximum of the design pressures of its adjacent chambers (differential pressure design) or a mean metal temperature less than the maximum of the design temperatures of its adjacent chambers (mean metal temperature design), or both, only when the vessel is to be installed in a system that controls the common element design conditions.

(2) Differential Pressure Design (Dependent Pressure Chamber). When differential pressure design is permitted, the common element design pressure shall be the maximum differential design pressure expected between the adjacent chambers. The common element and its corresponding differential pressure shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(1) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-a) and UHX-19.2.1(a)]. The differential pressure shall be controlled to ensure the common element design pressure is not exceeded.

(3) Mean Metal Temperature Design. When mean metal temperature design is used, the maximum common element design temperature determined in accordance with UG-20(a) may be less than the greater of the maximum design temperatures of its adjacent chambers; however, it shall not be less than the lower of the maximum design temperatures of its adjacent chambers. The common element and its corresponding design temperature shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(2) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-b) and UHX-19.2.1(b)]. The fluid temperature, flow, and pressure, as required, shall be controlled to ensure the common element design temperature is not exceeded.

(b) Special Shapes. Vessels other than cylindrical and spherical and those for which no design rules are provided in this Division may be designed under the conditions set forth in U-2.

(c) When no design rules are given and the strength of a pressure vessel or vessel part cannot be calculated with a satisfactory assurance of accuracy, the maximum allowable working pressure of the completed vessel shall be established in accordance with the provisions of UG-101.

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see Mandatory Appendix 3, 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions. See also U-2(a).

NOTE: The user and Manufacturer are cautioned that certain fabrication details allowed by this Division may result in cracking at welds and associated heat-affected zones (HAZ) for vessels designed for use at elevated temperature. WRC Bulletin 470, "Recommendations for Design of Vessels for Elevated Temperature Service" has information that may prove helpful to the vessel designer. WRC Bulletin 470 contains recommended design details for use at elevated temperature service, which is for the purposes of this Division, when the allowable stresses in Section II, Part D are based on time-dependent properties. The use of these details does not relieve the Manufacturer of design responsibility with regard to consideration of stresses associated with both steady state conditions and transient events, such as startup, shutdown, intermittent operation, thermal cycling, etc., as defined by the user.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division[10] (see UG-116, UCS-66, and UCS-A-3). The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below for vessels meeting the requirements of (f) below]. The MDMT marked on the nameplate shall correspond to a coincident pressure equal to the MAWP. When there are multiple MAWP's, the largest value shall be used to establish the MDMT marked on the nameplate. Additional MDMT's corresponding with other MAWP's may also be marked on the nameplate.[10]

(c) Design temperatures that exceed the temperature limit in the applicability column shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Nonmandatory Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials that satisfy all of the following:

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a) [see also Note (1) in Figure UCS-66.2], shall not exceed that given in (-a) or (-b) below:

(-a) $^1/_2$ in. (13 mm) for materials listed in Curve A of Figure UCS-66 (Figure UCS-66M);

(-b) 1 in. (25 mm) for materials listed in Curve B, C, or D of Figure UCS-66 (Figure UCS-66M).

(2) The completed vessel shall be hydrostatically tested per UG-99(b) or UG-99(c) or UGL-4. Alternatively, the completed vessel may be pneumatically tested in accordance with 35-6.

(3) Design temperature is no warmer than 650°F (345°C) nor colder than −20°F (−29°C). Occasional operating temperatures colder than −20°F (−29°C) are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[11]

Each element of a pressure vessel shall be designed for at least the most severe condition of coincident pressure (including coincident static head in the operating position) and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered [see UG-98 and Mandatory Appendix 3, 3-2]. See also U-2(a).

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions;

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Nonmandatory Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Nonmandatory Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion;

(i) abnormal pressures, such as those caused by deflagration;

(j) test pressure and coincident static head acting during the test (see UG-99).

UG-23 MAXIMUM ALLOWABLE STRESS VALUES[12] (25)

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Section II, Part D, Subpart 1. Section II, Part D is published as two separate publications. One publication contains values only in the U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction. A listing of these materials is given in the following tables, which are included in Subsection C. For material identified as meeting more than one material specification and/or grade, the maximum allowable tensile stress value for either material specification and/or grade may be used provided all

requirements and limitations for the material specification and grade are met for the maximum allowable tensile stress value chosen.

Table	Title
UCS-23	Carbon and Low Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other carbon steels)
UNF-23.1 through UNF-23.5	Nonferrous Metals (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1B for other nonferrous metals)
UHA-23	High Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A or Table 1B for other high alloy steels)
UCI-23	Maximum Allowable Stress Values in Tension for Cast Iron
UCD-23	Maximum Allowable Stress Values in Tension for Cast Ductile Iron
UHT-23	Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Subpart 1, Table 1A)
ULT-23	Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

The methods for determining maximum allowable stress values for impervious graphite (Certified Material) are given in UIG-23.

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined by the following procedure where

E = modulus of elasticity of material at design temperature. The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.)
R_o = outside radius of cylindrical shell or tube
t = the minimum required thickness of the cylindrical shell or tube

The joint efficiency for butt-welded joints shall be taken as unity.

The value of B shall be determined as follows.

Step 1. Using the selected values of t and R_o, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of t and R_o used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 5. Compare the value of B determined in Step 3 or Step 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. If the value of B is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of B is obtained that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combination of loadings listed in UG-22 that induce primary stress and are expected to occur simultaneously during normal operation[13] of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension (see UG-23), except as provided in (d) below. Except where limited by special rules, such as those for cast iron in flanged joints, the above loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness that exceeds $1^1/_2$ times[14] the maximum allowable stress value in tension (see UG-23). It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature that is expected to be maintained in the metal under the conditions of loading being considered. Maximum stress values may be interpolated for intermediate temperatures.

(d) For the combination of earthquake loading, or wind loading with other loadings in UG-22, the wall thickness of a vessel computed by these rules shall be determined such that the general primary membrane stress shall not exceed 1.2 times the maximum allowable stress permitted in (a), (b), or (c) above. This rule is applicable to stresses caused by internal pressure, external pressure, and axial compressive load on a cylinder.[15]

Earthquake loading and wind loading need not be considered to act simultaneously.

(e) Localized discontinuity stresses [see (c) above] are calculated in Mandatory Appendix 1, 1-5(g) and 1-8(e), Part UHX, and Part UEJ. The primary plus secondary stresses[14] at these discontinuities shall be limited to S_{PS}, where S_{PS} = 3S, and S is the maximum allowable stress of the material at temperature [see (a) above].

In lieu of using S_{PS} = 3S, a value of S_{PS} = 2S_Y may be used, where S_Y is the yield strength at temperature, provided the following are met:

(1) the allowable stress of material S is not governed by time-dependent properties as provided in Section II, Part D, Subpart 1, Table 1A or Table 1B;

(2) the room temperature ratio of the specified minimum yield strength to specified minimum tensile strength for the material does not exceed 0.7;

(f) Values for yield strength, S_Y, as a function of temperature are provided in Section II, Part D, Subpart 1, Table Y-1. If the material being used is not listed in Table Y-1, while being listed in other tables of Section II, Part D, Subpart 1, or the specified temperature exceeds the highest temperature for which a value is provided, the yield strength may be determined as described below for use in the design equations in this Division. S is the maximum allowable stress at the temperature specified [see (a)] and f is the factor (e.g., weld factor) used to determine the allowable stress as indicated in the notes for the stress line. If the value of f is not provided, set f equal to 1.

(1) If allowable stress is established based on the 66$^2/_3$% yield criterion, then yield strength, S_Y, shall be taken as 1.5S/f.

(2) If the allowable stress is established based on yield criterion between 66$^2/_3$% and 90%, then the yield strength, S_Y, shall be taken as 1.1S/f.

NOTE: For temperatures where the allowable stress, S, is based on time-dependent properties, the yield strength obtained by these formulas may be overly conservative.

(g) Maximum shear stress in restricted shear, such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without a reduction of area, shall be limited to 0.80 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

(h) Maximum bearing stress shall be limited to 1.60 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

UG-24 CASTINGS (25)

UG-24.1 General Requirements.

(a) Surface Finish for Centrifugal Castings — All Materials. Machine all surfaces after heat treatment (when applicable) to a finish not coarser than 250 μin. (6.3 μm) arithmetical average deviation.

(b) Material Specification. All castings shall meet the minimum requirements of the material specification.

(c) Mandatory Appendix 7. Radiographic, liquid penetrant, and magnetic particle examination techniques and acceptance standards are given in Mandatory Appendix 7.

UG-24.2 Casting Quality Factors.

UG-24.2.1 General.

(a) Except for castings permitted by Part UCI, apply a casting quality factor, as specified in (b), to the allowable stress values for cast materials given in Subsection C.

(b) Apply the lesser of the following values at a welded joint in a casting:

(1) the quality factor specified in UG-24.2.2, UG-24.2.3, or UG-24.3

(2) the weld joint efficiency specified in UW-12

UG-24.2.2 Default Quality Factors — All Materials. Unless the additional requirements of UG-24.2.3 are met or UG-24.3 is required for lethal service, the following quality factors shall be used based on casting process:

(a) Static Castings. The quality factor shall not exceed 80%.

(b) Centrifugal Castings. The quality factor shall not exceed 85%.

UG-24.2.3 Quality Factors — Specific Materials.

UG-24.2.3.1 Nonferrous and Ductile Cast Iron Materials (See Part UNF or Part UCD, as Applicable). The quality factor shall not exceed 90% when castings of nonferrous and ductile cast iron material comply with UG-24.2.3.1 or UG-24.2.3.2.

UG-24.2.3.1.1 Multiple Castings.

(a) Visually examine all surfaces of each casting, particularly those surfaces exposed by machining or drilling.

(b) Dissect at all critical sections[16] or examine according to UG-24.2.3.1.2 at least three pilot castings[17] representing the first lot of five castings made from a new or altered design.

(c) Section or radiograph, at all critical sections, one more casting taken at random from every next lot of five.

(d) Examine all castings other than those that have been radiographed at all critical sections by the magnetic particle or liquid penetrant technique.

(e) The examination of samples in (b) and (c) shall not reveal any defects.

UG-24.2.3.1.2 Single Casting. A single casting shall meet one of the following requirements:

(a) The user or user's designated agent shall radiograph the casting at all critical sections.

(b) Machine a casting to the extent that all critical sections are exposed for examination as applicable for the full wall thickness, such as in tubesheets drilled with holes spaced no farther apart than the wall thickness of the casting.

UG-24.2.3.2 Carbon, Low Alloy, or High Alloy Steel Materials (See Part UCS, Part UHT, or Part UHA, as Applicable). Higher quality factors may be applied for these materials if the additional examinations of UG-24.2.3.2.1 or UG-24.2.3.2.2 are made.

UG-24.2.3.2.1 Static Castings. The quality factor shall not exceed 100% if the castings are radiographed and examined by the magnetic particle or liquid penetrant technique.

UG-24.2.3.2.2 Centrifugal Castings.

(a) The quality factor shall not exceed 90% if the castings are examined by the magnetic particle or liquid penetrant technique.

(b) The quality factor shall not exceed 100% if the castings are radiographed and examined by the magnetic particle or liquid penetrant technique.

UG-24.3 Lethal Service. The additional requirements of UG-24.3.1 through UG-24.3.3 apply when castings (including those permitted in UG-11) are to be used in vessels containing lethal substances (see UW-2).

UG-24.3.1 Cast Iron and Cast Ductile Iron. Cast iron (see UCI-2) and cast ductile iron castings (see UCD-2) shall not be used in lethal service.

UG-24.3.2 Nonferrous Castings. The quality factor shall not exceed 90% if nonferrous castings are radiographed at all critical sections.

UG-24.3.3 Steel Castings. The quality factor shall not exceed 100% for steel castings that have been examined for severe service applications [see Mandatory Appendix 7, 7-3(b)].

UG-24.4 Defects. Castings with defects shall be rejected or repaired by welding. Defects are imperfections defined as unacceptable by the more restrictive of the following:

(a) the material specification

(b) Mandatory Appendix 7, 7-3

UG-24.4.1 Defects Repaired by Welding.

(a) The completed repair shall be subject to reexamination in accordance with the applicable requirements of UG-24.2 or UG-24.3 and Mandatory Appendix 7, 7-4.

(b) The completed repair shall be subject to postweld heat treatment if required by any of the following:

(1) the rules of this Division

(2) the casting specification

(3) to obtain a 90% or 100% quality factor following UG-24.2.3.1, UG-24.2.3.2, UG-24.3.2, or UG-24.3.3

UG-24.5 Identification and Marking. Use the following identifications and markings in addition to those required by the material specification when a quality factor greater than 80% is applied:

(a) the manufacturer's identification, name, trademark, or other traceable identification

(b) the casting identification, including the quality factor and the material designation

UG-25 CORROSION (25)

(a) The user or the user's designated agent (see U-2) shall specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.

(b) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. (See Nonmandatory Appendix E.)

NOTE: When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

(c) Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts.

(d) No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

(e) Telltale Holes. Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. Telltale holes shall not be used in vessels that are to contain lethal substances [see UW-2(a)], except as permitted by ULW-76 for vent holes in layered construction. When telltale holes are provided, they shall have a diameter of $^1/_{16}$ in. to $^3/_{16}$ in. (1.5 mm to 5 mm)and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the opposite surface to that where deterioration is expected. [For telltale holes in clad or lined vessels, see UCL-25(b).]

(f) Openings for Drain. Vessels subject to internal corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within $^1/_4$ in. (6 mm) of the lowest point.

UG-26 LININGS

Corrosion resistant or abrasion resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall except as permitted in Part UCL (see Nonmandatory Appendix F).

UG-27 THICKNESS OF SHELLS UNDER INTERNAL PRESSURE

(a) The minimum required thickness of shells under internal pressure shall not be less than that computed by the following formulas,[18] except as permitted by Mandatory Appendix 1 or Mandatory Appendix 32. In addition, provision shall be made for any of the loadings listed in UG-22, when such loadings are expected. The provided thickness of the shells shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

(b) The symbols defined below are used in the formulas of this paragraph.

E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or the efficiency of ligaments between openings, whichever is less.

For welded vessels, use the efficiency specified in UW-12.

For ligaments between openings, use the efficiency calculated by the rules given in UG-53.

P = internal design pressure (see UG-21)

R = inside radius of the shell course under consideration[19]

S = maximum allowable stress value (see UG-23 and the stress limitations specified in UG-24)

t = minimum required thickness of shell

(c) Cylindrical Shells. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385SE$, the following formulas shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t} \tag{1}$$

(2) Longitudinal Stress (Circumferential Joints).[20] When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t} \tag{2}$$

(d) Spherical Shells. When the thickness of the shell of a wholly spherical vessel does not exceed $0.356R$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t} \tag{3}$$

(e) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(f) A stayed jacket shell that extends completely around a cylindrical or spherical vessel shall also meet the requirements of UG-47(c).

(g) Any reduction in thickness within a shell course or spherical shell shall be in accordance with UW-9.

UG-28 THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE (25)

(a) Rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Figure UG-28. Charts used in determining minimum required thicknesses of these components are given in Section II, Part D, Subpart 3.

(b) The symbols defined below are used in the procedures of this paragraph:

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/t values less than 10, see (c)(2).

B = factor determined from the applicable material chart or table in Section II, Part D, Subpart 3 for maximum design metal temperature [see UG-20(c)]

D_o = outside diameter of cylindrical shell course or tube

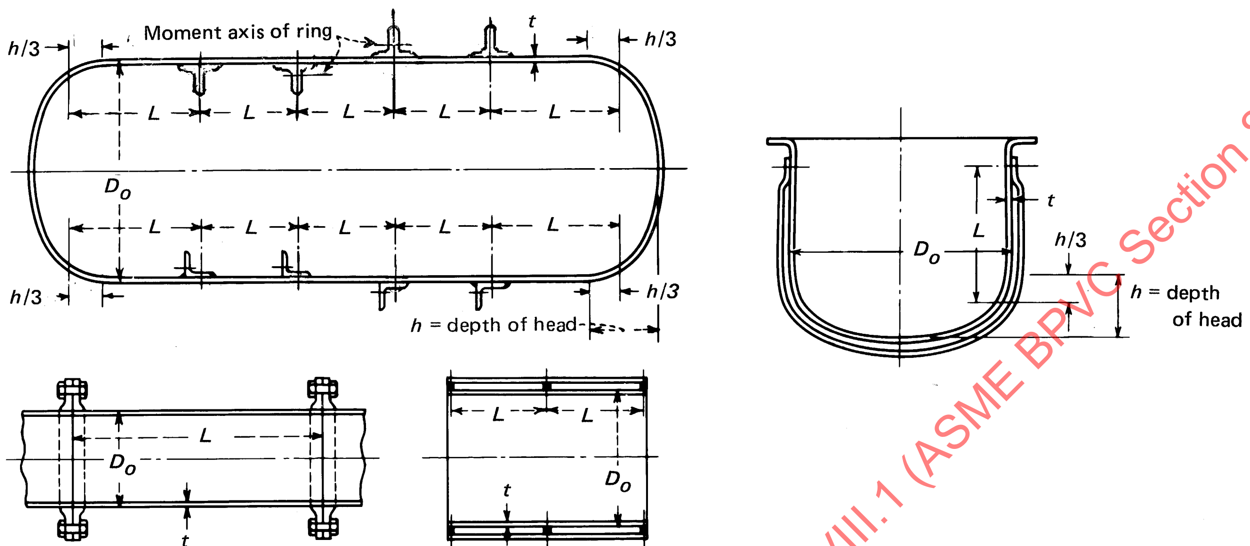
E = modulus of elasticity of material at design temperature. For external pressure design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.)

L = total length, in. (mm), of a tube between tubesheets, or design length of a vessel section between lines of support (see Figure UG-28.1). A line of support is:

(a) a circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

(b) a stiffening ring that meets the requirements of UG-29;

Figure UG-28
Diagrammatic Representation of Variables for Design of Cylindrical Vessels Subjected to External Pressure



(c) a jacket closure of a jacketed vessel that meets the requirements of Mandatory Appendix 9, 9-5;

(d) a cone-to-cylinder junction or a knuckle-to-cylinder junction of a toriconical head or section that satisfies the moment of inertia requirement of Mandatory Appendix 1, 1-8.

P = external design pressure [see Note in (f)]

P_a = calculated value of maximum allowable external working pressure for the assumed value of t, [see Note in (f) below]

R_o = outside radius of spherical shell

t = minimum required thickness of cylindrical shell or tube, or spherical shell, in. (mm)

t_s = nominal thickness of cylindrical shell or tube, in. (mm)

(c) Cylindrical Shells and Tubes. The required minimum thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure:

(1) Cylinders having D_o/t values ≥ 10:

Step 1. Assume a value for t and determine the ratios L/D_o and D_o/t.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o = 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o = 0.05.

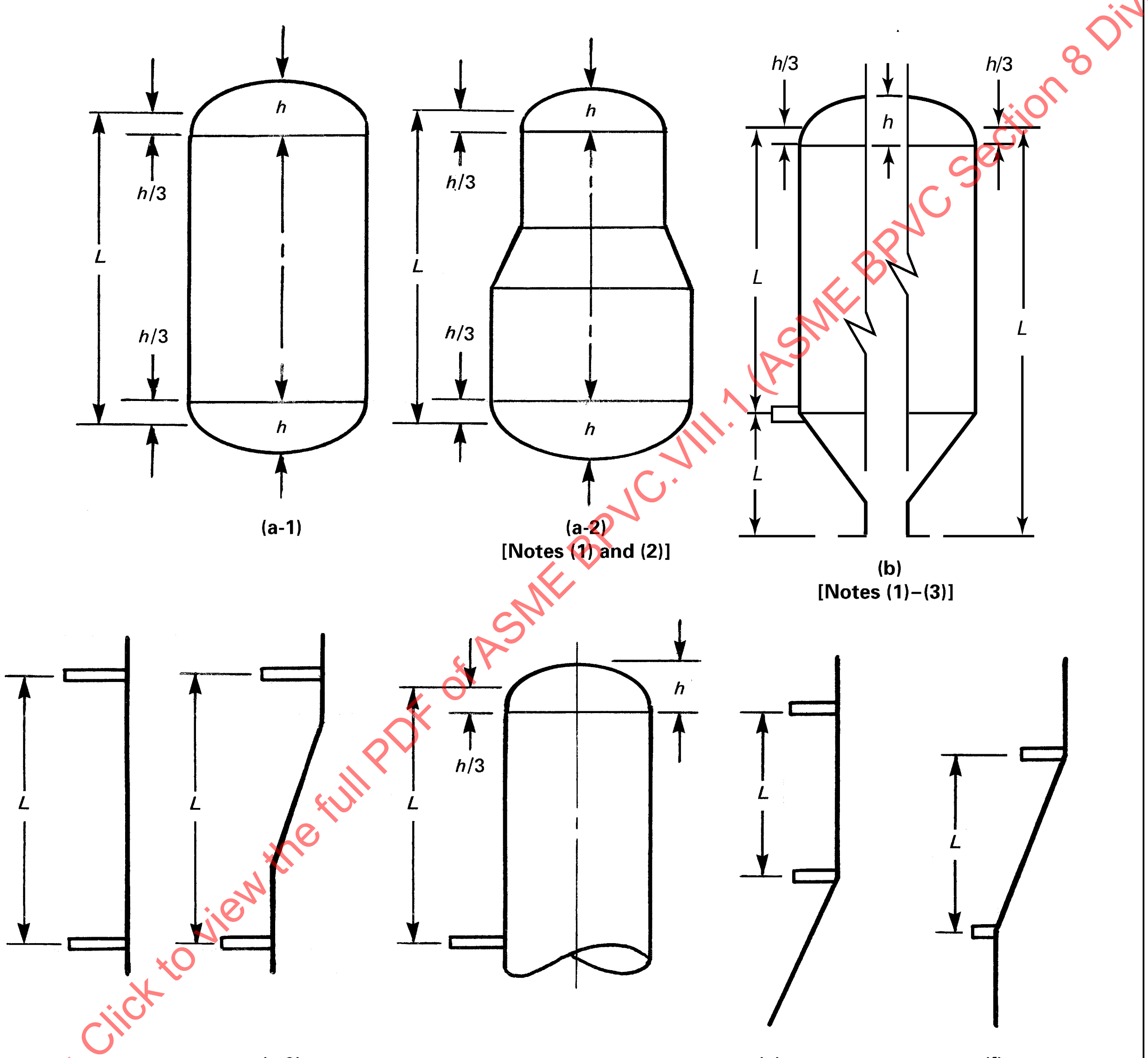
Step 3. Move horizontally to the line for the value of D_o/t determined in Step 1. Interpolation may be made for intermediate values of D_o/t; extrapolation is not permitted. From this point of intersection move vertically downward to determine the value of factor A. For values of A greater than 0.10, use a value of 0.10.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Figure UG-28.1
Diagrammatic Representation of Lines of Support for Design of Cylindrical Vessels Subjected to External Pressure



NOTES:

(1) When the cone-to-cylinder or the knuckle-to-cylinder junction is not a line of support, the required thickness of the cone, knuckle, or toriconical section shall not be less than the required thickness of the adjacent cylindrical shell. Also, the reinforcement requirement of Mandatory Appendix 1, 1-8 shall be satisfied when a knuckle is not provided at the cone-to-cylinder junction.

(2) Calculations shall be made using the diameter and corresponding thickness of each cylindrical section with dimension L as shown. Thicknesses of the transition sections are based on Note (1).

(3) When the cone-to-cylinder or the knuckle-to-cylinder junction is a line of support, the moment of inertia shall be provided in accordance with Mandatory Appendix 1, 1-8 [see UG-33(f)].

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following equation:

$$P_a = \frac{4B}{3(D_o/t)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/t)}$$

If tabular values are used, determine B as in Step 4 and apply it to the equation in Step 6.

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

(2) Cylinders having D_o/t values <10:

Step 1. Using the same procedure as given in (1), obtain the value of B. For values of D_o/t less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/t)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o/t)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S}{D_o/t}\left[1 - \frac{1}{D_o/t}\right]$$

where S is the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced in UG-23, or 0.9 times the yield strength of the material at design temperature. Values of yield strength are obtained from the applicable external pressure chart as follows:

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(d) Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the following procedure:

Step 1. Assume a value for t and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external working pressure P_a using the following equation:

$$P_a = \frac{B}{(R_o/t)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 6. Compare P_a obtained in Step 4 or Step 5 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(e) The external design pressure or maximum allowable external working pressure shall not be less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

(f) Vessels intended for service under external design pressures of 15 psi (103 kPa) and less [see U-1(c)(2)(-h)] may be stamped with the Certification Mark and Designator denoting compliance with the rules for external pressure, provided all the applicable rules of this Division are satisfied. When the Certification Mark is to be applied, the user or the user's designated agent shall specify the required maximum allowable external working pressure.[21] The vessel shall be designed and stamped with the maximum allowable external working pressure.

(g) When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(h) Circumferential joints in cylindrical shells may be of any type permitted by the Code and shall be designed for the imposed loads.

(i) Those portions of pressure chambers of vessels that are subject to a collapsing pressure and that have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels that extend over only a portion of the circumference, shall be fully staybolted in accordance with the requirements of UG-47 through UG-50 or shall be proof tested in compliance with UG-101(p).

(j) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(25) UG-29 STIFFENING RINGS FOR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE

(a) External stiffening rings shall be attached to the shell by welding or brazing [see UG-30]. Internal stiffening rings need not be attached to the shell when the rings are designed to carry the loads and adequate means of support is provided to hold the ring in place when subjected to external pressure loads. Segments of rings need not be attached when the requirements of (c) are met.

Except as exempted in (f) below, the available moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two formulas:

$$I_s = \left[D_o^2 L_s\left(t + A_s/L_s\right)A\right]/14$$

$$I_s' = \left[D_o^2 L_s\left(t + A_s/L_s\right)A\right]/10.9$$

where

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I' = available moment of inertia of combined ring-shell cross section about its neutral axis parallel to the axis of the shell. The nominal shell thickness t_s shall be used and the width of shell that is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

I_s' = required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

A = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor determined from the applicable chart or table in Section II, Part D, Subpart 3 for the material used for the stiffening ring [see UG-20(c)]

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. A line of support is:

(a) a stiffening ring that meets the requirements of this paragraph;

(b) a circumferential connection to a jacket for a jacketed section of a cylindrical shell;

(c) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

(d) a cone-to-cylinder junction.

D_o, E, P, t, and t_s are as defined in UG-28(b).

The adequacy of the moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. See below.

(a) If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine an A value that lies between two adjacent tabular values for a specific temperature. Linear interpolation may also be used to determine an A value at an intermediate temperature that lies between two sets of tabular values, after first determining A values for each set of tabular values. The value of A so determined is then applied in the equation for I_s or I_s' in Step 6(a) or Step 6(b).

(b) If material charts in Section II, Part D, Subpart 3 are used, enter the right-hand side of the applicable material chart for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E$.

Step 6. See below.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

(b) In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I_s' given above.

Step 7. See below.

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6(a) and Step 7(a) are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, Step 6(b) and Step 7(b) are considered.

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

(b) Stiffening rings shall extend completely around the circumference of the cylinder except as permitted in (c) below. Any joints between the ends or sections of such rings, such as shown in Figure UG-29.1 (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Figure UG-29.1 (C) shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

(c) Stiffening rings placed on the inside of a vessel may be arranged as shown in Figure UG-29.1 (E) and (F), provided that the required moment of inertia of the ring in (E) or of the combined ring-shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

Any gap in that portion of a stiffening ring supporting the shell, such as shown in Figure UG-29.1 (D) and (E), shall not exceed the length of are given in Figure UG-29.2 unless additional reinforcement is provided as shown in Figure UG-29.1 (C) or unless the following conditions are met:

(1) only one unsupported shell arc is permitted per ring; and

(2) the length of the unsupported shell arc does not exceed 90 deg; and

Figure UG-29.1
Various Arrangements of Stiffening Rings for Cylindrical Vessels Subjected to External Pressure

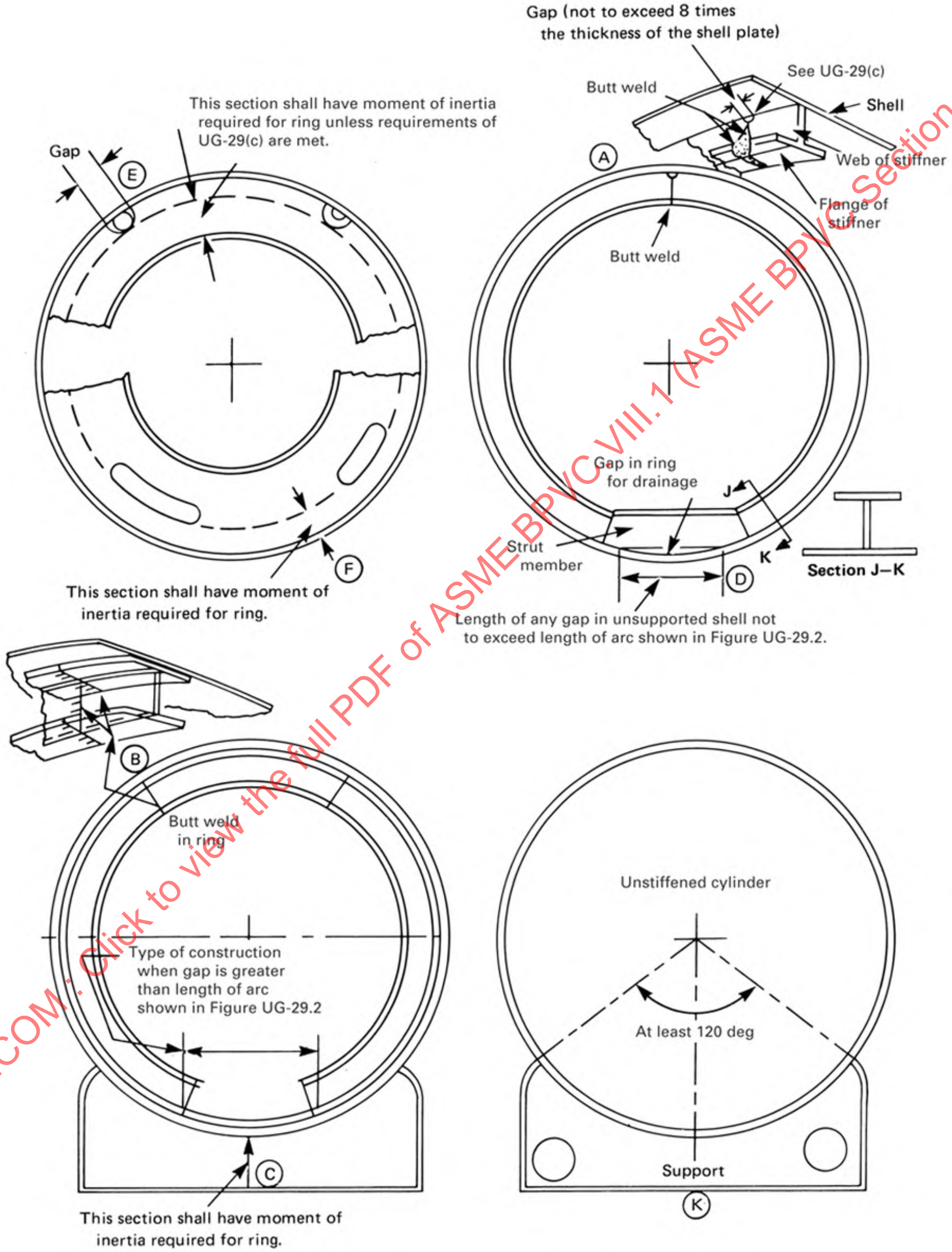
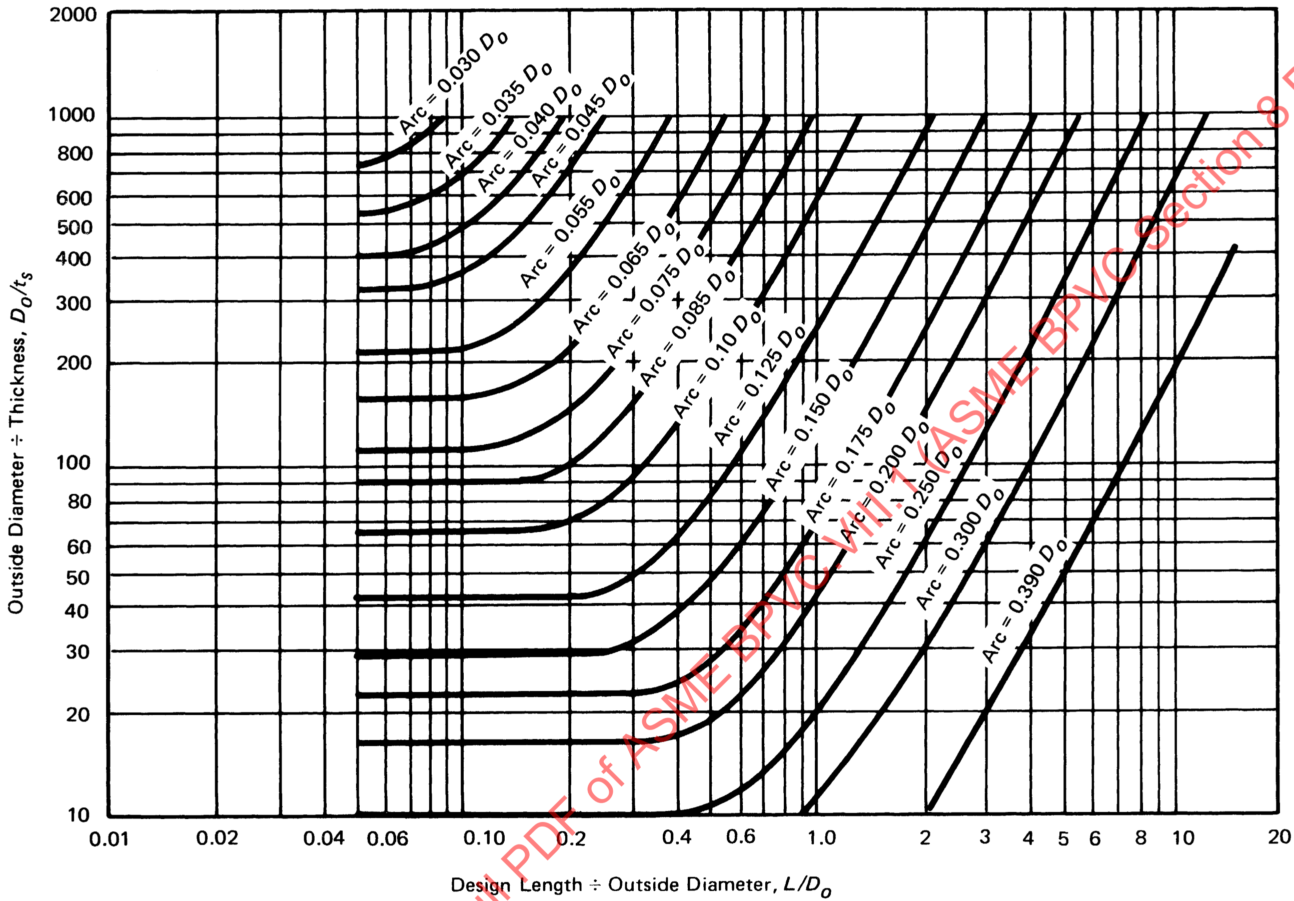


Figure UG-29.2
Maximum Arc of Shell Left Unsupported Because of Gap in Stiffening Ring of Cylindrical Shell Under External Pressure



(3) the unsupported arcs in adjacent stiffening rings are staggered 180 deg; and

(4) the dimension L defined in UG-28(b) is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder (such as bubble trays or baffle plates) are used in a vessel, they may also be considered to act as stiffening rings, provided they are designed to function as such.

(e) Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see Nonmandatory Appendix G, G-3). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at (K) in Figure UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Nonmandatory Appendix G.)

(f) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30 ATTACHMENT OF STIFFENING RINGS

(a) Stiffening rings may be placed on the inside or outside of a vessel, and except for the configurations permitted by UG-29, shall be attached to the shell by welding or brazing. Brazing may be used if the vessel is not to be later stress relieved. The ring shall be essentially

in contact with the shell and meet the rules in UG-29(b) and UG-29(c). Welding of stiffening rings shall comply with the requirements of this Division for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds or brazes. Some acceptable methods of attaching stiffening rings are illustrated in Figure UG-30.

(c) Intermittent welding shall be placed on both sides of the stiffener and may be either staggered or in-line. Length of individual fillet weld segments shall not be less than 2 in. (50 mm) and shall have a maximum clear spacing between toes of adjacent weld segments of $8t$ for external rings and $12t$ for internal rings where t is the shell thickness at the attachment. The total length of weld on each side of the stiffening ring shall be:

(1) not less than one-half the outside circumference of the vessel for rings on the outside; and

(2) not less than one-third the circumference of the vessel for rings on the inside.

(d) A continuous full penetration weld is permitted as shown in sketch (e) of Figure UG-30. Continuous fillet welding or brazing on one side of the stiffener with intermittent welding or brazing on the other side is permitted for sketches (a), (b), (c), and (d) of Figure UG-30 when the thickness t_w of the outstanding stiffening element [sketches (a) and (c)] or width w of the stiffening element mating to the shell [sketches (b) and (d)] is not more than 1 in. (25 mm). The weld segments shall be not less than 2 in. (50 mm) long and shall have a maximum clear spacing between toes of adjacent weld segments of $24t$.

(e) Strength of Attachment Welds. Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load.

(1) The radial pressure load from shell, lb/in., is equal to PL_s.

(2) The radial shear load is equal to $0.01PL_sD_O$.

(3) P, L_s, and D_O are defined in UG-29.

(f) Minimum Size of Attachment Welds. The fillet weld leg size shall be not less than the smallest of the following:

(1) $^1/_4$ in. (6 mm);

(2) vessel thickness at the weld location;

(3) stiffener thickness at weld location.

UG-31 TUBES, AND PIPE WHEN USED AS TUBES OR SHELLS

(a) Internal Pressure. The required wall thickness for tubes and pipe under internal pressure shall be determined in accordance with the rules for shells in UG-27.

(b) External Pressure. The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with the rules in UG-28.

(c) The thickness as determined under (a) or (b) above shall be increased when necessary to meet the following requirements:

(1) Additional wall thickness should be provided when corrosion, erosion, or wear due to cleaning operations is expected.

(2) Where ends are threaded, additional wall thickness is to be provided in the amount of $0.8/n$ in. ($20/n$ mm) [where n equals the number of threads per inch (25.4 mm)].

NOTE: The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

UG-32 FORMED HEADS, AND SECTIONS, PRESSURE ON CONCAVE SIDE

(a) The minimum required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, conical, and toriconical heads under pressure on the concave side (plus heads) shall be computed by the appropriate formulas in this paragraph,[23] except as permitted by Mandatory Appendix 32. Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provision shall be made for any of the loadings listed in UG-22. The provided thickness of the heads shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

(b) The symbols defined below are used in the formulas of this paragraph:

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis

D_i = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone
= $D - 2r(1 - \cos\alpha)$

E = lowest efficiency of any joint in the head; for hemispherical heads this includes head-to-shell joint; for welded vessels, use the efficiency specified in UW-12

L = inside spherical or crown radius. The value of L for ellipsoidal heads shall be obtained from Table UG-37.

P = internal design pressure (see UG-21)

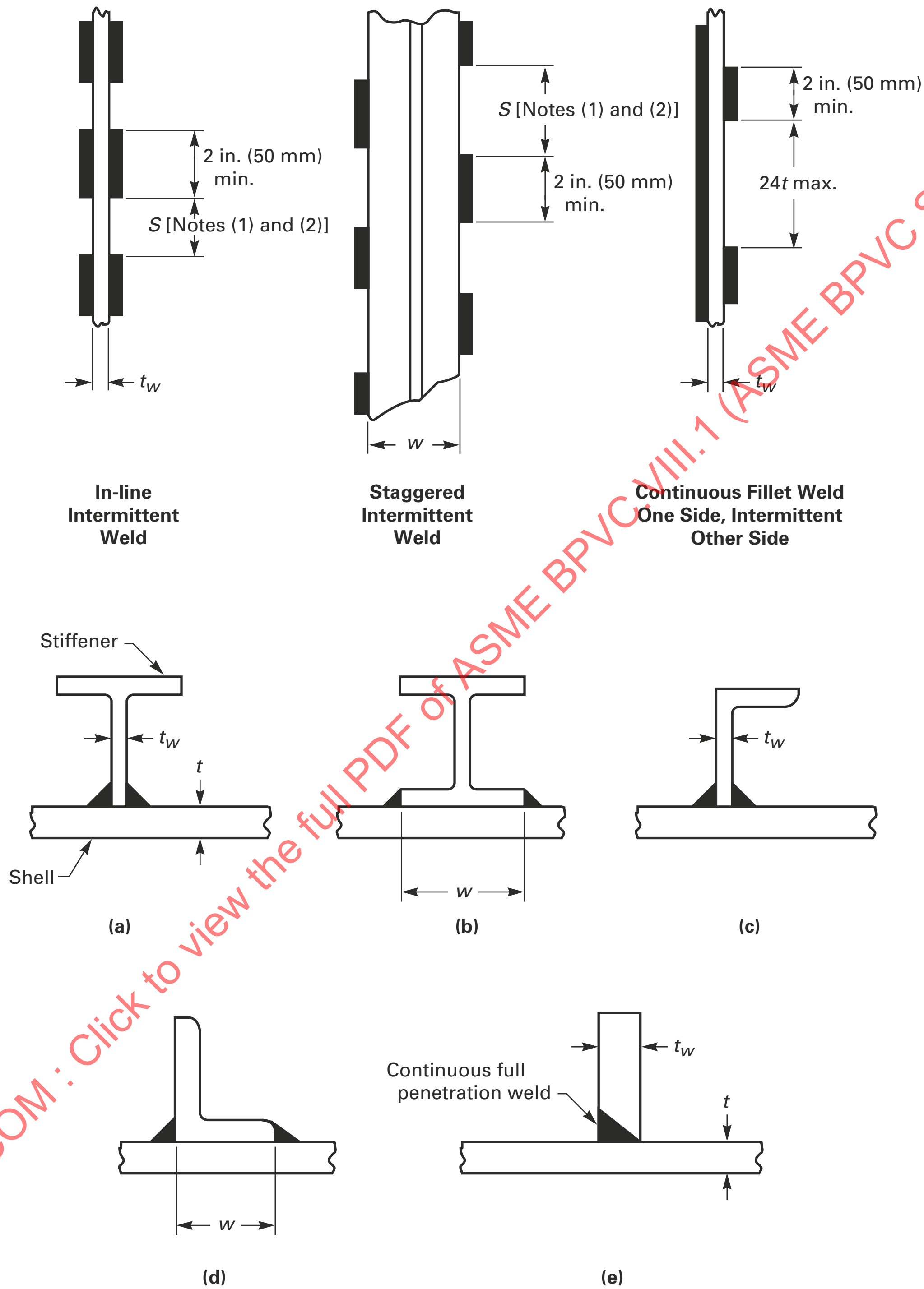
r = inside knuckle radius

S = maximum allowable stress value in tension as given in the tables referenced in UG-23, except as limited in UG-24 and (d) below.

t = minimum required thickness of head after forming

t_s = minimum specified thickness of head after forming, in. (mm). t_s shall be $\geq t$

Figure UG-30
Some Acceptable Methods of Attaching Stiffening Rings



NOTES:
(1) For external stiffeners, $S \le 8t$.
(2) For internal stiffeners, $S \le 12t$.

α = one-half of the included (apex) angle of the cone at the centerline of the head (see Mandatory Appendix 1, Figure 1-4)

(c) Ellipsoidal Heads With $t_s/L \geq 0.002$. The required thickness of a dished head of semiellipsoidal form, in which half the minor axis (inside depth of the head minus the skirt) equals one-fourth of the inside diameter of the head skirt, shall be determined by

$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t} \tag{1}$$

NOTE: For ellipsoidal heads with $t_s/L < 0.002$, the rules of Mandatory Appendix 1, 1-4(f) shall also be met.

An acceptable approximation of a 2:1 ellipsoidal head is one with a knuckle radius of $0.17D$ and a spherical radius of $0.90D$.

(d) Torispherical Heads With $t_s/L \geq 0.002$. The required thickness of a torispherical head for the case in which the knuckle radius is 6% of the inside crown radius and the inside crown radius equals the outside diameter of the skirt [see (i)] shall be determined by

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t} \tag{2}$$

NOTE: For torispherical heads with $t_s/L < 0.002$, the rules of Mandatory Appendix 1, 1-4(f) shall also be met.

Torispherical heads made of materials having a specified minimum tensile strength exceeding 70,000 psi (485 MPa) shall be designed using a value of S equal to 20,000 psi (138 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material (see UG-23).

(e) Hemispherical Heads. When the thickness of a hemispherical head does not exceed $0.356L$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t} \tag{3}$$

(f) Conical Heads and Sections (Without Transition Knuckle). The required thickness of conical heads or conical shell sections that have a half apex-angle α not greater than 30 deg shall be determined by

$$t = \frac{PD}{2\cos\alpha(SE - 0.6P)} \quad \text{or} \quad P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha} \tag{4}$$

A reinforcing ring shall be provided when required by the rule in Mandatory Appendix 1, 1-5(d) and 1-5(e).

Conical heads or sections having a half apex-angle α greater than 30 deg without a transition knuckle shall comply with eq. (4) and Mandatory Appendix 1, 1-5(g).

(g) Toriconical Heads and Sections. The required thickness of the conical portion of a toriconical head or section, in which the knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness, shall be determined by eq. (f)(4) in (f) above, using D_i in place of D.

The required thickness of the knuckle shall be determined by Mandatory Appendix 1, eq. 1-4(d)(3) in which

$$L = \frac{D_i}{2\cos\alpha}$$

Toriconical heads or sections may be used when the angle $\alpha \leq 30$ deg and are mandatory for conical head designs when the angle α exceeds 30 deg, unless the design complies with Mandatory Appendix 1, 1-5(g).

(h) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of UG-47 for braced and stayed flat plates.

(i) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than 3 times the head thickness.

(j) A dished head with a reversed skirt may be used in a pressure vessel, provided the maximum allowable working pressure for the head is established in accordance with the requirements of UG-101.

(k) All formed heads, thicker than the shell and concave to pressure, intended for butt-welded attachment, shall have a skirt length sufficient to meet the requirements of Figure UW-13.1, when a tapered transition is required. All formed heads concave to pressure and intended for butt-welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same inside diameter.

(l) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints in Part UB.

(m) Any taper at a welded joint within a formed head shall be in accordance with UW-9. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of UW-13 for the respective type of joint shown therein.

(n) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by eq. UG-34(c)(2)(1), using $C = 0.25$.

(o) Openings in formed heads under internal pressure shall comply with the requirements of UG-36 through UG-46.

(p) A stayed jacket that completely covers a formed inner head or any of the types included in this paragraph shall also meet the requirements of UG-47(c).

(25) UG-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

(a) General. The required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, toriconical, and conical heads and conical segments under pressure on the convex side (minus heads) shall be computed by the appropriate formulas given in this paragraph (see UG-16). Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provisions shall be made for any other loading given in UG-22. The required thickness for heads due to pressure on the convex side shall be determined as follows.

(1) For ellipsoidal and torispherical heads, the required thickness shall be computed by the appropriate procedure given in (d) or (e) below.

(2) For hemispherical heads, the required thickness shall be determined by the rules given in (c) below.

(3) For conical and toriconical heads and conical sections, the required thickness shall be determined by the rules given in (f) below.

(b) Nomenclature. The nomenclature defined below is used in this paragraph. Mandatory Appendix 1, Figure 1-4 shows principal dimensions of typical heads.

A, B, E, and P are as defined in UG-28(b)

D_o = outside diameter of the head skirt

$D_o/2h_o$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table UG-33.1)

D_L = outside diameter at large end of conical section under consideration

D_s = outside diameter at small end of conical section under consideration

D_{ss} = outside diameter at small end of conical section under consideration

h_o = one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line)

K_o = factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table UG-33.1)

L_c = axial length of cone or conical section between lines of support (see Figure UG-33.1).

L_e = equivalent length of conical head or Section between lines of support [see (g)]

R_o = for hemispherical heads, the outside radius

= for ellipsoidal heads, the equivalent outside spherical radius taken as K_oD_o

= for torispherical heads, the outside radius of the crown portion of the head

t = minimum required thickness of head after forming, in. (mm)

t_e = effective thickness of conical section

= t cos α

α = one-half the apex angle in conical heads and sections, deg

(c) Hemispherical Heads. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in UG-28(d) for determining the thickness for a spherical shell.

(d) Ellipsoidal Heads. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1. Assume a value for t and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R_o/t}$$

Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in UG-28(d), Steps 2 through 6.

(e) Torispherical Heads. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R_o.

(f) Conical Heads and Sections. When the cone-to-cylinder junction is not a line-of-support, the required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints shall not be less than the required thickness of the adjacent cylindrical shell and, when a knuckle is not provided, the reinforcement requirement of Mandatory Appendix 1, 1-8 shall be satisfied (see Figure UG-28.1). When the cone-to-cylinder junction is a line-of-support, the required thickness shall be determined in accordance with the following subparagraphs. This procedure shall also apply to cone sections between lines of support as shown in Figure UG-33.1, sketch (b).

(1) When α is equal to or less than 60 deg:

(-a) cones having D_L/t_e values ≥10:

Step 1. Assume a value for t_e and determine the ratios L_e/D_L and D_L/t_e.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at a value of L/D_o equivalent to the value of L_e/D_L determined in Step 1. For values of L_e/D_L greater than 50, enter the chart at a value of L_e/D_L = 50.

Step 3. Move horizontally to the line for the value of D_o/t equivalent to the value of D_L/t_e determined in Step 1. Interpolation may be made for intermediate values of D_L/t_e; extrapolation is not permitted. From this point of intersection move vertically downwards to determine the value of factor A.

Table UG-33.1
Values of Spherical Radius Factor K_o for Ellipsoidal Head With Pressure on Convex Side

$D_o/2h_o$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_o	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

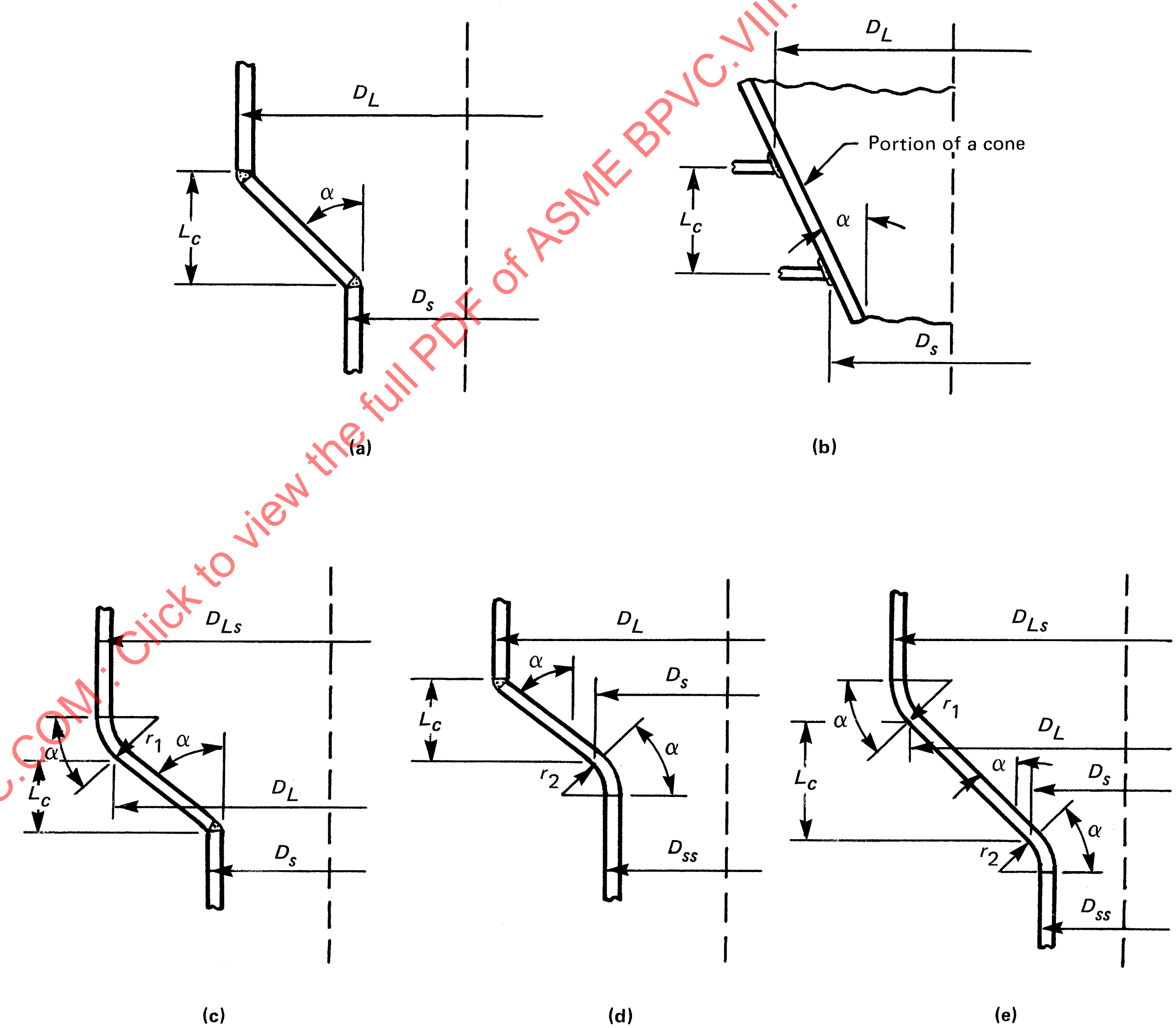
GENERAL NOTE: Interpolation permitted for intermediate values.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Figure UG-33.1 (25)
Length L_c of Some Typical Conical Sections for External Pressure



Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L/t_e)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_L/t_e)}$$

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

Step 9. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with Mandatory Appendix 1, 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(-b) cones having D_L/t_e values <10:

Step 1. Using the same procedure as given in (-a) above, obtain the value of B. For values of D_L/t_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L/t_e)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_L/t_e)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_L/t_e}\left[1 - \frac{1}{D_L/t_e}\right]$$

where

S = the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced by UG-23, or 0.9 times the yield strength of the material at design temperature

Values of yield strength are obtained from the applicable external pressure chart as follows.

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

Step 5. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with Mandatory Appendix 1, 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(2) When α of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone (see UG-34).

(3) The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

(g) The required thickness of a conical part of a toriconical head or conical section having pressure on the convex side, either seamless or of built-up construction with butt joints within the conical part of a toriconical head or conical section, shall not be less than that determined from (f) above with the exception that L_e shall be determined as follows:

(1) For sketches (a) and (b) in Figure UG-33.1,

$$L_e = (L_c/2)(1 + D_s/D_L)$$

(2) For sketch (c) in Figure UG-33.1,

$$L_e = r_1 \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_{Ls}}\right)$$

(3) For sketch (d) in Figure UG-33.1,

$$L_e = r_2 \frac{D_{ss}}{D_L}\sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_L}\right)$$

(4) For sketch (e) in Figure UG-33.1,

$$L_e = \left(r_1 + r_2 \frac{D_{ss}}{D_{Ls}}\right)\sin\alpha + \frac{L_c}{2}\frac{(D_L + D_s)}{D_{Ls}}$$

(h) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(i) The required length of skirt on heads convex to pressure shall comply with the provisions of UG-32(k) and UG-32(l) for heads concave to pressure.

(j) Openings in heads convex to pressure shall comply with the requirements of UG-36 through UG-46.

(25) UG-34 UNSTAYED FLAT HEADS AND COVERS

(a) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[24] heads and covers. Some acceptable types of flat heads and covers are shown in Figure UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(b) The symbols used in this paragraph and in Figure UG-34 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, dimensionless

D = long span of noncircular heads or covers measured perpendicular to short span

d = diameter, or short span, measured as indicated in Figure UG-34

E = joint efficiency, from Table UW-12, of any Category A weld as defined in UW-3(a)

h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Mandatory Appendix 2, Table 2-5.2

K = influence coefficient
= 0.2 in. for Customary units
= 5 mm for SI units

L = perimeter of noncircular bolted head measured along the centers of the bolt holes

m = the ratio t_r/t_s, dimensionless

P = internal design pressure (see UG-21)

r = inside corner radius on a head formed by flanging or forging

S = maximum allowable stress value in tension from applicable table of stress values referenced by UG-23

t = minimum required thickness of flat head or cover

t_1 = throat dimension of the closure weld, as indicated in Figure UG-34, sketch (r)

t_f = nominal thickness of the flange on a forged head, at the large end, as indicated in Figure UG-34, sketch (b)

t_h = nominal thickness of flat head or cover

t_r = required thickness of seamless shell, for pressure

t_s = nominal thickness of shell

t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Figure UG-34, sketch (g)

W = design bolt load for the operating condition and the gasket seating condition for circular heads for Mandatory Appendix 2

Y = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure UG-34, sketches (a) and (c), in. (mm)

Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c) below, dimensionless

(c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements.[25]

(1) Circular blind flanges conforming to any of the flange standards listed in Table U-3 and further limited in UG-44(a) shall be acceptable for the diameters and pressure–temperature ratings in the respective standard when the blind flange is of the types shown in Figure UG-34, sketches (j) and (k).

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \quad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \quad (2)$$

When using eq. (2), the thickness t shall be calculated for both operating conditions and gasket seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from Mandatory Appendix 2, eq. 2-5(e)(4) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Mandatory Appendix 2, eq. 2-5(e)(5) shall be used.

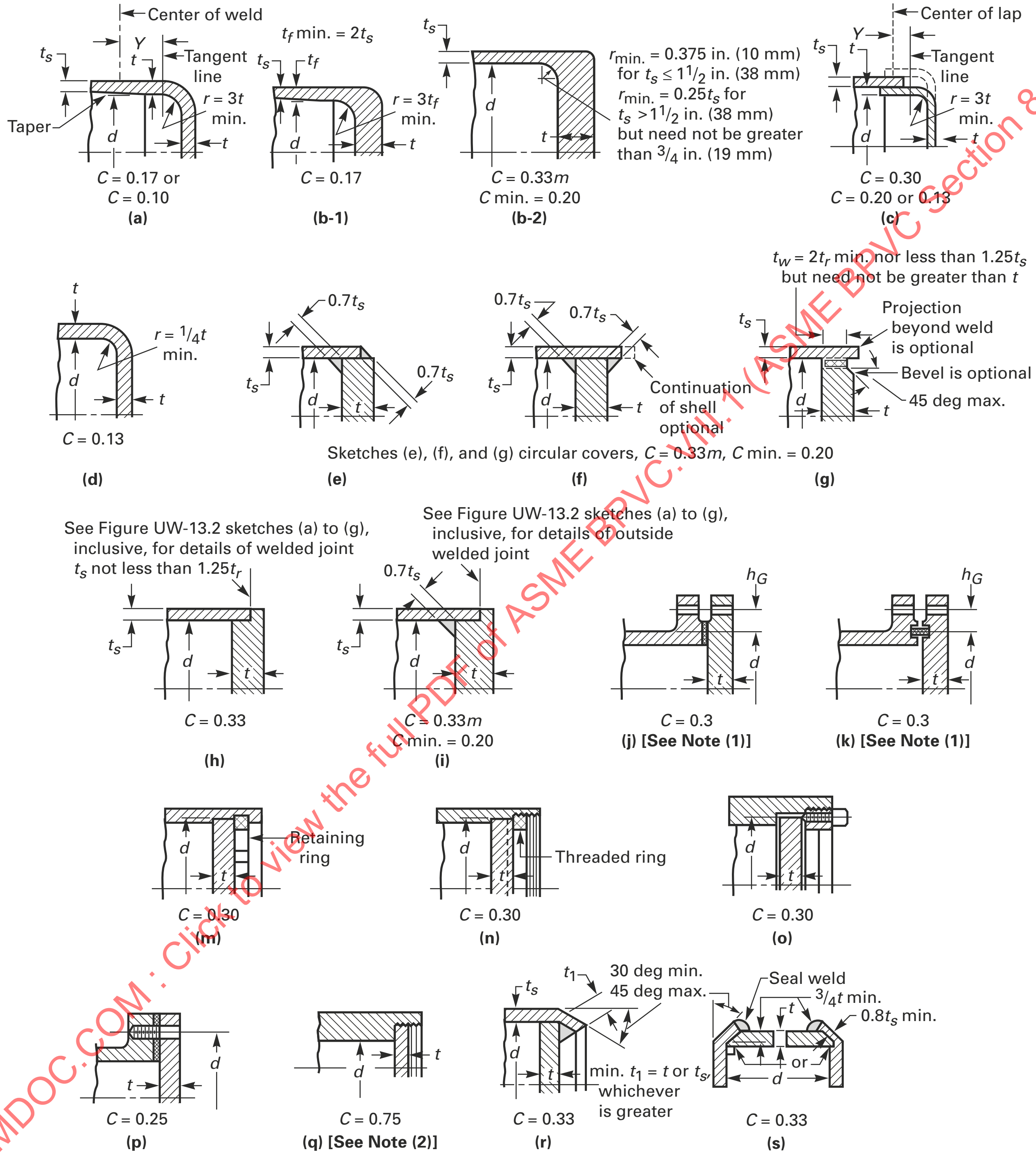
(3) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE} \quad (3)$$

where

$$Z = 3.4 - \frac{2.4d}{D} \quad (4)$$

Figure UG-34
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: The above sketches are diagrammatic only. Other designs that meet the requirements of UG-34 are acceptable.

NOTES:
(1) Use UG-34(c)(2) eq. (2) or UG-34(c)(3) eq. (5).
(2) When pipe threads are used, see Table UG-43.

with the limitation that Z need not be greater than two and one-half (2.5).

Equation (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [see Figure UG-34, sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE + 6Wh_G/SELd^2} \quad (5)$$

When using eq. (5), the thickness t shall be calculated in the same way as specified above for eq. (2)(2).

(d) For the types of construction shown in Figure UG-34, the minimum values of C to be used in eqs. (c)(2)(1), (c)(2)(2), (c)(3)(3), and (c)(3)(5) are:

(1) Sketch (a). C = 0.17 for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all the requirements for circumferential joints given in Part UW.

C = 0.10 for circular heads, when the flange length for heads of the above design is not less than

$$Y = \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \quad (6)$$

C = 0.10 for circular heads, when the flange length Y is less than the requirements in eq. (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - Y/\sqrt{dt_h}} \quad (7)$$

for a length of at least $2\sqrt{dt_s}$.

When C = 0.10 is used, the taper shall be at least 1:3.

(2) Sketch (b-1). C = 0.17 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part UW.

(3) Sketch (b-2). C = 0.33m but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than the following:

$$r_{min} = 0.375 \text{ in. } (10 \text{ mm}) \text{ for } t_s \le 1\tfrac{1}{2} \text{ in. } (38 \text{ mm})$$

$$r_{min} = 0.25\, t_s \text{ for } t_s > 1\tfrac{1}{2} \text{ in. } (38 \text{ mm}) \text{ but need not be greater than } \tfrac{3}{4} \text{ in. } (19 \text{ mm})$$

The welding shall meet all the requirements for circumferential joints given in Part UW.

(4) Sketch (c). C = 0.13 for circular heads lap welded or brazed to the shell with corner radius not less than $3t$ and Y not less than required by eq. (1)(6) and the requirements of UW-13 are met.

C = 0.20 for circular and noncircular lap welded or brazed construction as above, but with no special requirement with regard to Y.

C = 0.30 for circular flanged plates screwed over the end of the vessel, with inside corner radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on the allowable stress values in UG-23 and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(5) Sketch (d). C = 0.13 for integral flat circular heads when the dimension d does not exceed 24 in. (600 mm), the ratio of thickness of the head to the dimension d is not less than 0.05 or greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than 0.25t, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(6) Sketches (e), (f), and (g). C = 0.33m but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least 0.7t_s. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

C = 0.33 for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least 0.7t_s. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

(7) Sketch (h). C = 0.33 for circular plates welded to the end of the shell when t_s is at least 1.25t_r and the weld details conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive. See also UG-93.4.

(8) Sketch (i). $C = 0.33m$ but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b. See also UG-93.4.

(9) Sketches (j) and (k). $C = 0.3$ for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that eq. (c)(2)(2) or (c)(3)(5) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.9Wh_G/Sd^3}$$

for circular heads and covers, nor less than

$$d\sqrt{6Wh_G/SLd^2}$$

for noncircular heads and covers.

(10) Sketches (m), (n), and (o). $C = 0.3$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are designed using the allowable stress values in UG-23. Seal welding may be used, if desired.

(11) Sketch (p). $C = 0.25$ for circular and noncircular covers bolted with a full-face gasket, to shells, flanges or side plates.

(12) Sketch (q). $C = 0.75$ for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on the allowable stress values in UG-23. If a tapered pipe thread is used, the requirements of Table UG-43 shall also be met. Seal welding may be used, if desired.

(13) Sketch (r). $C = 0.33$ for circular plates having a dimension d not exceeding 18 in. (450 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

(14) Sketch (s). $C = 0.33$ for circular beveled plates having a diameter d not exceeding 18 in. (450 mm), inserted into a vessel, the end of which is crimped over at least 30 deg, but not more than 45 deg, and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = KS/d$.

This construction is not permissible if machined from rolled plate.

UG-35 OTHER TYPES OF CLOSURES

UG-35.1 Dished Covers

Requirements for design of dished heads with bolting flanges are given in 1-6.

UG-35.2 Quick-Actuating Closures (25)

(a) Quick-actuating closures are closures that are operated by an action that releases all holding elements.

(b) Design requirements, additional definitions, and recommendations for quick-actuating closures can be found in Section VIII, Division 2, 4.8 and shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(c) Table UG-35.2-1 lists the new locations for all requirements formerly located in this Division.

UG-35.3 Quick-Opening Closures (25)

(a) Quick-opening closures are closures other than

(1) bolted flange joints as described in UG-44(a)

(2) bolted flange joints meeting the requirements of Mandatory Appendix 2

(3) bolted head joints meeting the requirements of Mandatory Appendix 1, 1-6

(4) quick-actuating closures as described in UG-35.2

Table UG-35.2-1 (25)
Paragraph Cross-Reference List

2023 Division 1 Designator, Topic	Division 2
UG-35.2(a), Definitions	4.8.2
UG-35.2(b), General	4.8.3, 4.8.5
UG-35.2(c), Specific design requirements	4.8.5
UG-35.2(d), Alternative designs for manually operated closures	4.8.5(g), 4.8.5(h)
UG-35.3(a), Definitions	4.8.2
UG-35.3(b), General	4.8.3, 4.8.4
UG-35.3(c), Specific design requirements	4.8.4
Nonmandatory Appendix FF	Annex 4-B

(5) clamp connections meeting the requirements of Mandatory Appendix 24

(6) closures with multiple, manually operated swing bolts

(b) Additional definitions, rules, and recommendations for quick-opening closures can be found in Section VIII, Division 2, 4.8 and shall be used in accordance with UG-16(a) and Mandatory Appendix 46.

(c) Table UG-35.2-1 lists the new locations for all requirements formerly located in this Division.

OPENINGS AND REINFORCEMENTS[26]

UG-36 OPENINGS IN PRESSURE VESSELS

(a) Shape of Opening [27]

(1) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround.[28] When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(2) Openings may be of other shapes than those given in (1) above, and all corners shall be provided with a suitable radius. These openings shall be designed in accordance with U-2(g).

(b) Size of Openings

(1) Properly reinforced openings in cylindrical and conical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1 520 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (510 mm); for vessels over 60 in. (1 520 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1 020 mm). (For conical shells, the inside shell diameter as used above is the cone diameter at the center of the opening.) For openings exceeding these limits, supplemental rules of Mandatory Appendix 1, 1-7 shall be satisfied in addition to the rules of this paragraph.

(2) Properly reinforced openings in formed heads and spherical shells are not limited in size. For an opening in an end closure, which is larger than one-half the inside diameter of the shell, one of the following alternatives to reinforcement may also be used:

(-a) a conical section as shown in Figure UG-36, sketch (a);

(-b) a cone with a knuckle radius at the large end as shown in Figure UG-36, sketch (b);

(-c) a reverse curve section as shown in Figure UG-36, sketches (c) and (d); or

(-d) using a flare radius at the small end as shown in Figure UG-33.1, sketch (d).

The design shall comply with all the requirements of the rules for reducer sections [see (e) below] insofar as these rules are applicable.

(c) Strength and Design of Finished Openings

(1) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement. The finished opening diameter is the diameter d as defined in UG-37 and in Figure UG-40.

(2) See below.

(-a) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in UG-37 except as given in (3) below.

(-b) Openings in flat heads shall be reinforced as required by UG-39.

(3) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(-a) welded, brazed, and flued connections meeting the applicable rules and with a finished opening not larger than:

(-1) $3\frac{1}{2}$ in. (89 mm) diameter — in vessel shells or heads with a required minimum thickness of $\frac{3}{8}$ in. (10 mm) or less;

(-2) $2\frac{3}{8}$ in. (60 mm) diameter — in vessel shells or heads over a required minimum thickness of $\frac{3}{8}$ in. (10 mm);

(-b) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than $2\frac{3}{8}$ in. (60 mm) diameter;

(-c) no two isolated unreinforced openings, in accordance with (-a) or (-b) above, shall have their centers closer to each other than the sum of their diameters;

(-d) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with (-a) or (-b) above, shall have their centers closer to each other than the following:

for cylindrical or conical shells,

$$\left(1 + 1.5\cos\theta\right)\left(d_1 + d_2\right);$$

for doubly curved shells and formed or flat heads,

$$2.5\left(d_1 + d_2\right)$$

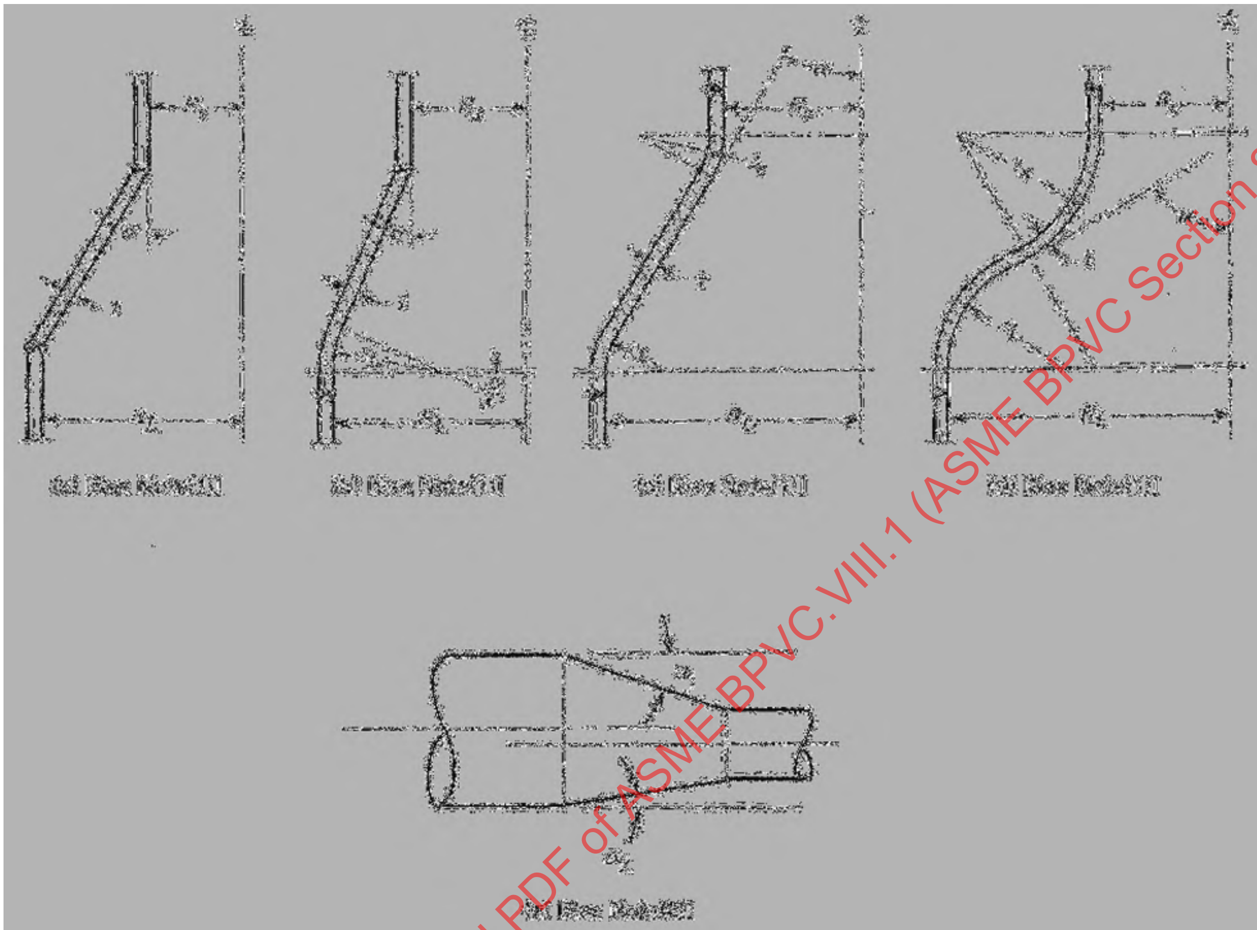
where

d_1, d_2 = the finished diameter of the two adjacent openings

θ = the angle between the line connecting the center of the openings and the longitudinal axis of the shell

The centerline of an unreinforced opening as defined in (-a) and (-b) above shall not be closer than its finished diameter to any material used for reinforcement of an adjacent reinforced opening.

Figure UG-36
Large Head Openings — Reverse-Curve and Conical Shell-Reducer Sections



NOTES:
(1) r_L shall not be less than the greater of $0.12(R_L + t)$ or $3t$: r_s has no dimensional requirement.
(2) $\alpha_1 > \alpha_2$; therefore, use α_1 in design equations.

(d) Openings Through Welded Joints. Additional provisions governing openings through welded joints are given in UW-14.

(e) Reducer Sections Under Internal Pressure

(1) The equations and rules of this paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

(2) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in UG-22, where such loadings are expected.

(3) The symbols defined in either UG-32(b) or below are used in this paragraph (see Figure UG-36).

t = minimum required thickness of the considered element of a reducer after forming
R_L = inside radius of larger cylinder
R_s = inside radius of smaller cylinder
r_L = inside radius of knuckle at larger cylinder
r_s = radius to the inside surface of flare at the small end
α = one-half of the included (apex) angle of a conical element

(4) Elements of a Reducer. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of this paragraph are met.

(-a) Conical Shell Section. The required thickness of a conical shell section, or the allowable working pressure for such a section of given thickness, shall be determined by the equations given in UG-32(f).

(-b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of the appropriate equations and provisions of UG-32.

(5) Combination of Elements to Form a Reducer. When elements of (4) above, having different thicknesses are combined to form a reducer, the joints including the plate taper required by UW-9(c) shall lie entirely within the limits of the thinner element being joined.

(-a) A reducer may be a simple conical shell section, Figure UG-36, sketch (a), without knuckle, provided the half-apex angle α is not greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g). A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of Mandatory Appendix 1, 1-5.

(-b) A toriconical reducer, Figure UG-36, sketch (b), may be shaped as a portion of a toriconical head, UG-32(g), a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle α is not greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g). A reinforcement ring shall be provided at the small end of the conical reducer element when required by the rules in Mandatory Appendix 1, 1-5.

(-c) Reverse curve reducers, Figure UG-36, sketches (c) and (d), may be shaped of elements other than those of (4) above. See U-2(g).

(f) Reducers Under External Pressure. The rules of UG-33(f) shall be followed, where applicable, in the design of reducers under external pressure.

(g) Oblique Conical Shell Sections Under Internal Pressure. A transition section reducer consisting of an oblique conical shell section may be used to join two cylindrical shell sections of different diameters and axes, provided the following requirements are used:

(1) The required thickness shall be determined by the equations given in UG-32(f).

(2) The angle α to be used shall be the largest included angle between the oblique cone and the attached cylindrical section [see Figure UG-36, sketch (e)] and shall not be greater than 30 deg, except as provided for in Mandatory Appendix 1, 1-5(g)

(3) Diametrical dimensions to be used in the design equations shall be measured perpendicular to the axis of the cylinder to which the cone is attached.

(4) A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of Mandatory Appendix 1, 1-5.

UG-37 REINFORCEMENT REQUIRED FOR OPENINGS IN SHELLS AND FORMED HEADS

(a) Nomenclature. The symbols used in this paragraph are defined as follows:

A = total cross-sectional area of reinforcement required in the plane under consideration (see Figure UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v < 1.0$)

A_1 = area in excess thickness in the vessel wall available for reinforcement (see Figure UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v < 1.0$)

A_2 = area in excess thickness in the nozzle wall available for reinforcement (see Figure UG-37.1)

A_3 = area available for reinforcement when the nozzle extends inside the vessel wall (see Figure UG-37.1)

A_5 = cross-sectional area of material added as reinforcement (see Figure UG-37.1)

A_{41}, A_{42}, A_{43} = cross-sectional area of various welds available for reinforcement (see Figure UG-37.1)

c = corrosion allowance

D = inside shell diameter

D_p = outside diameter of reinforcing element (actual size of reinforcing element may exceed the limits of reinforcement established by UG-40; however, credit cannot be taken for any material outside these limits)

d = finished diameter of circular opening or finished dimension (chord length at midsurface of thickness excluding excess thickness available for reinforcement) of nonradial opening in the plane under consideration, in. (mm) [see Figures UG-37.1 and UG-40]

E = 1 (see definitions for t_r and t_{rn})

E_1 = 1 when an opening is in the solid plate or in a Category B butt joint; or

= 0.85 when an opening is located in an ERW or autogenously welded pipe or tube. If the ERW or autogenously welded joint is clearly identifiable and it can be shown that the opening does not pass through this weld joint, then E_1 may be determined using the other rules of this paragraph; or

= joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint

F = correction factor that compensates for the variation in internal pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure UG-37 may be used for integrally reinforced openings in cylindrical shells and cones. [See UW-16(c)(1).]

f_r = strength reduction factor, not greater than 1.0 [see UG-41(a)]

f_{r1} = S_n/S_v for nozzle wall inserted through the vessel wall

= 1.0 for nozzle wall abutting the vessel wall and for nozzles shown in Figure UG-40, sketch (j), (k), (n), and (o).

f_{r2} = S_n/S_v

f_{r3} = (lesser of S_n or S_p)/S_v

f_{r4} = S_p/S_v

h = distance nozzle projects beyond the inner surface of the vessel wall. (Extension of the nozzle beyond the inside surface of the vessel wall is not limited; however, for reinforcement calculations, credit shall not be taken for material outside the limits of reinforcement established by UG-40.)

K_1 = spherical radius factor (see definition of t_r and Table UG-37)

L = length of projection defining the thickened portion of integral reinforcement of a nozzle neck beyond the outside surface of the vessel wall [see Figure UG-40, sketch (e)]

P = internal design pressure (see UG-21), psi (MPa)

R = inside radius of the shell course under consideration

R_n = inside radius of the nozzle under consideration

S = allowable stress value in tension (see UG-23), psi (MPa). For welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

S_n = allowable stress in nozzle, psi (MPa) (see S above)

S_p = allowable stress in reinforcing element (plate), psi (MPa) (see S above)

S_v = allowable stress in vessel, psi (MPa) (see S above)

t = specified vessel wall thickness,[29] (not including forming allowances). For pipe it is the nominal thickness less manufacturing undertolerance allowed in the pipe specification.

t_e = thickness or height of reinforcing element (see Figure UG-40)

t_i = nominal thickness of internal projection of nozzle wall

t_n = nozzle wall thickness.[29] Except for pipe, this is the wall thickness not including forming allowances. For pipe, use the nominal thickness [see UG-16.4(b)].

t_r = required thickness of a seamless shell based on the circumferential stress, or of a formed head, computed by the rules of this Division for the designated pressure, using E = 1, and, for shells fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85, except that

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by Mandatory Appendix 1, 1-4(d), using M = 1;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table UG-37.

t_{rn} = required thickness of a seamless nozzle wall, using E = 1, and, for nozzles fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

W = total load to be carried by attachment welds (see UG-41)

(b) *General*. The rules in this paragraph apply to all openings other than:

(1) small openings covered by UG-36(c)(3);

(2) openings in flat heads covered by UG-39;

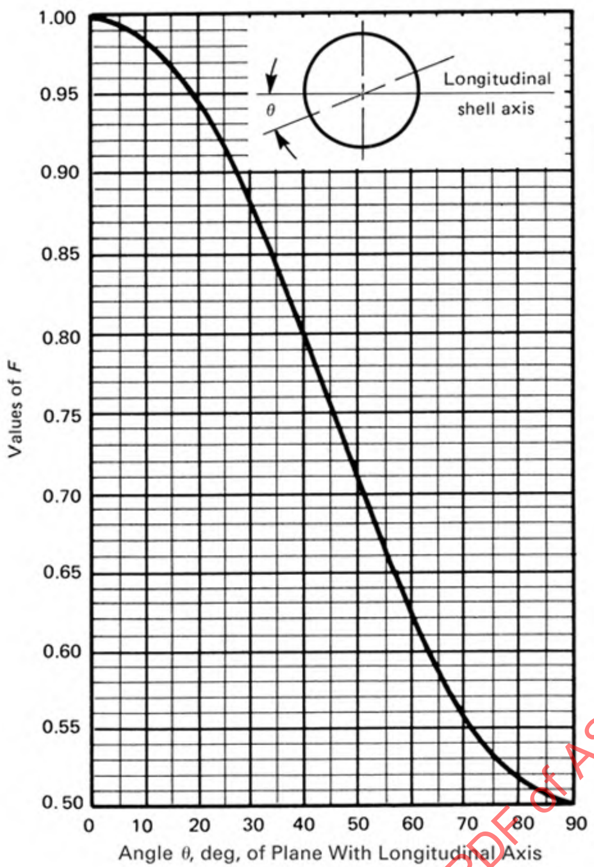
(3) openings designed as reducer sections covered by UG-36(e);

(4) large head openings covered by UG-36(b)(2);

(5) tube holes with ligaments between them conforming to the rules of UG-53.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the

Figure UG-37
Chart for Determining Value of *F*, as Required in UG-37



axis of the shell is the plane of greatest loading due to pressure. Not less than half the required reinforcement shall be on each side of the centerline of single openings.

(c) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane through the opening for a shell or formed head under internal pressure shall be not less than

$$A = dt_rF + 2t_nt_rF\left(1 - f_{r1}\right)$$

(d) Design for External Pressure

(1) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50% of that required in (c) above, where t_r is the wall thickness required by the rules for vessels under external pressure and the value of F shall be 1.0 in all external pressure reinforcement calculations.

(2) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (1) above when the shell is subject to external pressure, and with (c) above when the shell is subject to internal pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

(e) Design for Alternate Internal and External Pressure. Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of (c) above for internal pressure and of (d) above for external pressure.

(f) Details and equations for required area and available area are given in Figure UG-37.1.

(g) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one vent hole [maximum diameter $^7/_{16}$ in. (11 mm)] that may be tapped with straight or tapered threads. These vent holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

(h) Segmental reinforcing elements are allowed, provided the individual segments are joined by full penetration butt welds. These butt welds shall comply with all the applicable requirements of Part UW. Each segment of the reinforcing element shall have a vent hole as required by (g). Unless the provisions given below are satisfied, the area A_5 as defined in Figure UG-37.1 shall be multiplied by 0.75. The area A_5 does not require any reduction if one of the following is satisfied:

(1) Each butt weld is radiographed or ultrasonically examined to confirm full penetration, or

(2) For openings in cylinders, the weld is oriented at least 45 deg from the longitudinal axis of the cylinder.

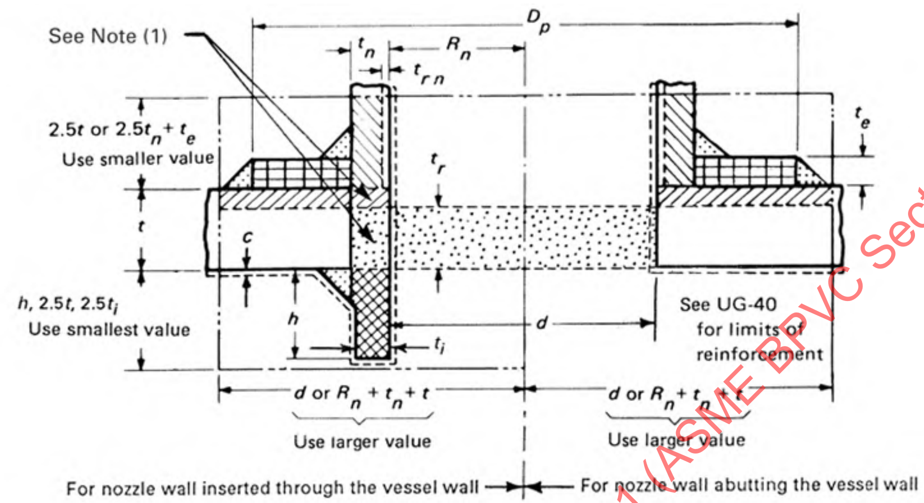
(i) The reinforcement rules in this Division are applicable for internal or external pressure and do not address the requirements for openings under the action of externally applied loadings (such as pipe reactions). When externally applied loadings are to be considered, see U-2(g).

UG-38 FLUED OPENINGS IN SHELLS AND FORMED HEADS

(a) Flued openings in shells and formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in UG-37. The thickness of the flued flange shall also meet the requirements of UG-27 and/or UG-28, as applicable, where L as used in UG-28 is the minimum depth of flange as shown in Figure UG-38. The minimum thickness of the flued flange on a vessel subject to both internal and external pressure shall be the larger of the two thicknesses as determined above.

(b) The minimum depth of flange of a flued in opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or (t_r + 3 in.) (for SI units, t_r + 75 mm), whichever is less, where t_r is the required shell or head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straightedge to the edge of the flanged opening (see Figure UG-38).

Figure UG-37.1
Nomenclature and Formulas for Reinforced Openings



Without Reinforcing Element

$= A$	$= d\,t_r\,F + 2t_n\,t_r\,F(1 - f_{r1})$	Area required
$= A_1$	$= d(E_1\,t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1})$ $= 2\,(t + t_n)\,(E_1 t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1})$	Area available in shell; use larger value
$= A_2$	$= 5(t_n - t_{rn})\,f_{r2}\,t$ $= 5(t_n - t_{rn})\,f_{r2}\,t_n$	Area available in nozzle projecting outward; use smaller value
$= A_3$	$= 5\,t\,t_i\,f_{r2}$ $= 5\,t_i\,t_i\,f_{r2}$ $= 2\,h\,t_i\,f_{r2}$	Area available in inward nozzle; use smallest value
$= A_{41}$	= outward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in outward weld
$= A_{43}$	= inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld

If $A_1 + A_2 + A_3 + A_{41} + A_{43} \geq A$ — Opening is adequately reinforced

If $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$ — Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

With Reinforcing Element Added

A	= same as A, above	Area required
A_1	= same as A_1, above	Area available
A_2	$= 5(t_n - t_{rn})f_{r2}t$ $= 2(t_n - t_{rn})\,(2.5t_n + t_e)\,f_{r2}$	Area available in nozzle projecting outward; use smaller area
A_3	= same as A_3, above	Area available in inward nozzle
$= A_{41}$	= outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
$= A_{42}$	= outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
$= A_{43}$	= inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
$= A_5$	$= (D_p - d - 2t_n)\,t_e\,f_{r4}$ [Note (2)]	Area available in element

If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A$ — Opening is adequately reinforced

GENERAL NOTE: This figure illustrates a common nozzle configuration and is not intended to prohibit other configurations permitted by the Code.

NOTES:
(1) Includes consideration of these areas if S_n/S_v < 1.0 (both sides of centerline).
(2) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

Table UG-37
Values of Spherical Radius Factor K_1

$D/2h$	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

GENERAL NOTES:
(a) Equivalent spherical radius = K_1D; $D/2h$ = axis ratio.
(b) For definitions, see Mandatory Appendix 1, 1-4(b).
(c) Interpolation permitted for intermediate values.

(c) There is no minimum depth of flange requirement for flued out openings.

(d) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with UG-46(j).

(25) UG-39 REINFORCEMENT REQUIRED FOR OPENINGS IN FLAT HEADS AND COVERS

(a) General. The rules in this paragraph apply to all openings in flat heads except opening(s) that do not exceed the size and spacing limits in UG-36(c)(3) and do not exceed one-fourth the head diameter or shortest span. Electric immersion heater support plates (see Mandatory Appendix 41, 41-3) may be designed in accordance with the rules of this paragraph or Mandatory Appendix 41.

(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\left(1 - f_{r1}\right)$$

where d, t_n, and f_{r1} are defined in UG-37 and t in UG-34.

(2) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced individually as required by (1) above when the spacing between any pair of adjacent openings is equal to or greater than twice the average diameter of the pair.

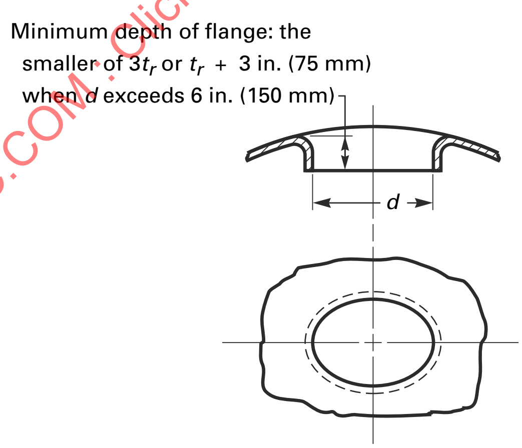
When spacing between adjacent openings is less than twice but equal to or more than $1^1/_4$ the average diameter of the pair, the required reinforcement for each opening in the pair, as determined by (1) above, shall be summed together and then distributed such that 50% of the sum is located between the two openings. Spacings of less than $1^1/_4$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(3) Referencing Figure UG-39, sketch (a), the ligament between two adjacent openings (U_1, U_2, or U_3) shall not be less than one-quarter of the diameter of the smaller of the two openings in the pair. The radial distance between the inner edge of the opening (U_4, U_5, U_6, or U_7) and the dimension d as shown in Figure UG-34 and Figure UG-39, sketch (a) shall not be less than one-quarter of the diameter of that one opening.

(c) Flat heads that have an opening with a diameter that exceeds one-half the head diameter or shortest span, as defined in UG-34, shall be designed as follows:

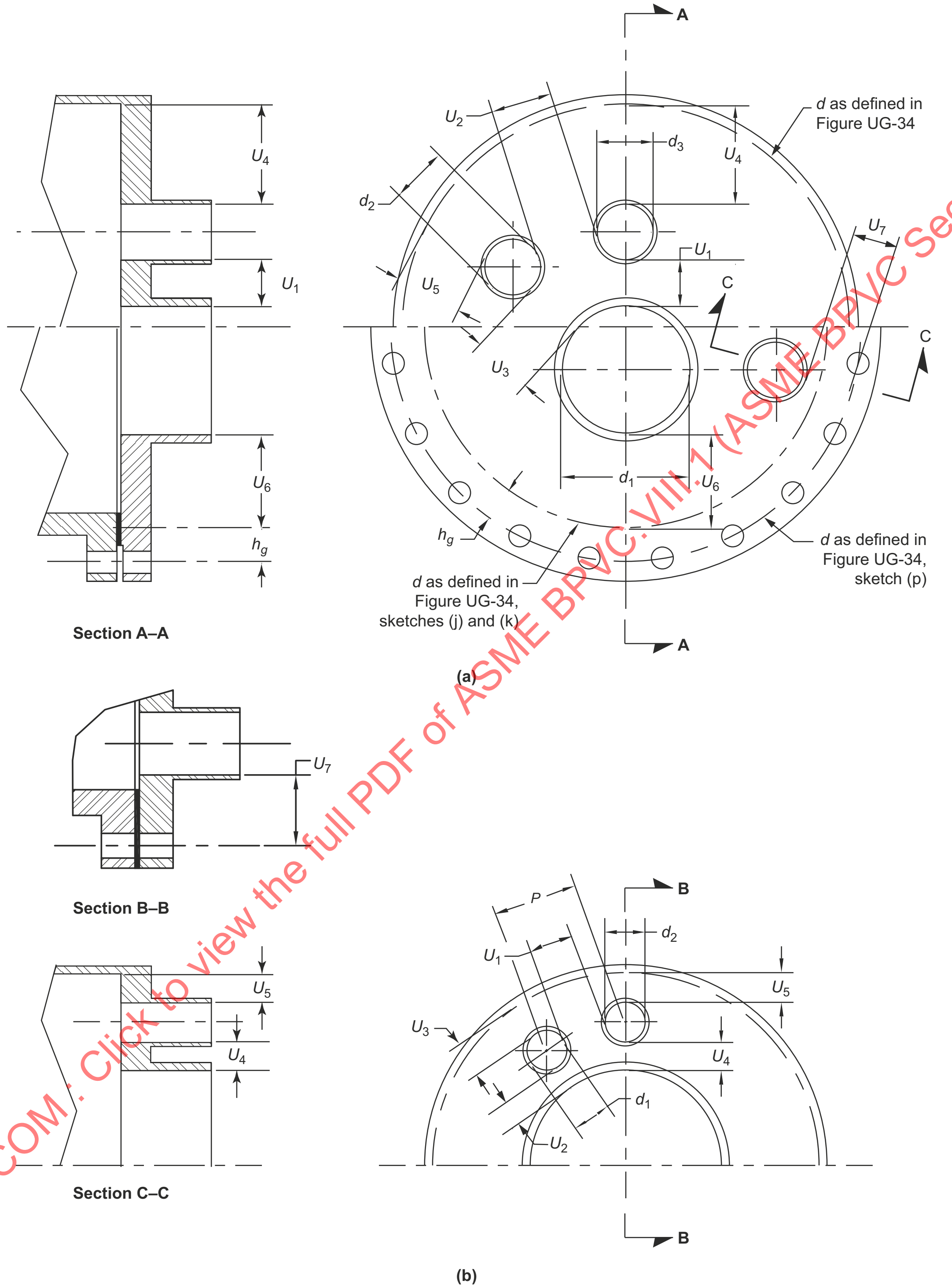
(1) When the opening is a single, circular centrally located opening in a circular flat head, the head shall be designed according to Mandatory Appendix 14 and related factors in Mandatory Appendix 2. The head-to-shell junction may be integral, as shown in Figure UG-34, sketches (a), (b-1), (b-2), (d), and (g). The head may also be attached by a butt weld or a full-penetration corner weld similar to the joints shown in Figure UW-13.2, sketches (a), (b), (c), (d), (e), or (f). The large centrally located opening may have a nozzle that is integrally formed or integrally attached by a full penetration weld or may be plain without an attached nozzle or hub. The head thickness does not have to be calculated by UG-34 rules. The thickness that satisfies all the requirements of Mandatory Appendix 14 meets the requirements of the Code.

Figure UG-38
Minimum Depth for Flange of Flued-In Openings



(25)

Figure UG-39
Openings in Flat Heads and Covers



Legend:

p = spacing, center-to-center, between openings
$U_1, U_2, \ldots$ = ligament width
$(d_1 + d_2)/2$ = average diameter of pair of openings

(2) Opening(s) may be located in the rim space surrounding the central opening. See Figure UG-39, sketch (b). Such openings may be reinforced by area replacement in accordance with the formula in (b)(1) above using as a required head thickness the thickness that satisfies rules of Mandatory Appendix 14. Multiple rim openings shall meet spacing rules of (b)(2) and (b)(3) above. Alternatively, the head thickness that meets the rules of Mandatory Appendix 14 may be increased by multiplying it by the square root of two (1.414) if only a single opening is placed in the rim space or if spacing p between two such openings is twice or more than their average diameter. For spacing less than twice their average diameter, the thickness that satisfies Mandatory Appendix 14 shall be divided by the square root of efficiency factor e, where e is defined in (e)(2) below.

The rim opening(s) shall not be larger in diameter than one-quarter the differences in head diameter less central opening diameter. The minimum ligament width U shall not be less than one-quarter the diameter of the smaller of the two openings in the pair. A minimum ligament width of one-quarter the diameter of the rim opening applies to ligaments designated as U_2, U_4, U_3, and U_5 in Figure UG-39, sketch (b).

(3) When the large opening is any other type than that described in (1) above, there are no specific rules given. Consequently, the requirements of U-2(g) shall be met.

(d) As an alternative to (b)(1) above, the thickness of flat heads and covers with a single opening with a diameter that does not exceed one-half the head diameter may be increased to provide the necessary reinforcement as follows:

(1) In eq. UG-34(c)(2)(1) or eq. UG-34(c)(3)(3), use $2C$ or 0.75 in place of C, whichever is the lesser; except that, for sketches (b-1), (b-2), (e), (f), (g), and (i) of Figure UG-34, use $2C$ or 0.50, whichever is the lesser.

(2) In eq. UG-34(c)(2)(2) or eq. UG-34(c)(3)(5), double the quantity under the square root sign.

(e) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced as follows:

(1) When the spacing between a pair of adjacent openings is equal to or greater than twice the average diameter of the pair, and this is so for all opening pairs, the head thickness may be determined by rules in (d) above.

(2) When the spacing between adjacent openings in a pair is less than twice but equal to or greater than $1\frac{1}{4}$ the average diameter of the pair, the required head thickness shall be that determined by (d) above multiplied by a factor h, where

$$h = \sqrt{0.5 / e}$$

$$e = [(p - d_{ave})/p]_{smallest}$$

where

d_{ave} = average diameter of the same two adjacent openings

e = smallest ligament efficiency of adjacent opening pairs in the head

p = center-to-center spacing of two adjacent openings

(3) Spacings of less than $1\frac{1}{4}$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(4) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair.

(5) The width of ligament between the edge of any one opening and the edge of the flat head (such as U_3 or U_5 in Figure UG-39) shall not be less than one-quarter the diameter of that one opening.

UG-40 LIMITS OF REINFORCEMENT

(a) The boundaries of the cross sectional area in any plane normal to the vessel wall and passing through the center 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 UG-37.1). Figure UG-40 depicts thicknesses t, t_e, and t_n, or t_i and diameter d used in establishing the limits of reinforcement. All dimensions are in the corroded condition; for nomenclature, see UG-37(a).

(b) 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 the following:

(1) the diameter d of the finished opening;

(2) the inside radius, R_n, of the nozzle plus the vessel wall thickness t, plus the nozzle wall thickness t_n.

(c) 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 the following:

(1) $2\frac{1}{2}$ times the vessel wall thickness t;

(2) $2\frac{1}{2}$ times the nozzle wall thickness t_n plus the thickness t_e as defined in Figure UG-40.

(d) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(1) 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 in Figure UG-37.1.

(2) 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

Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d

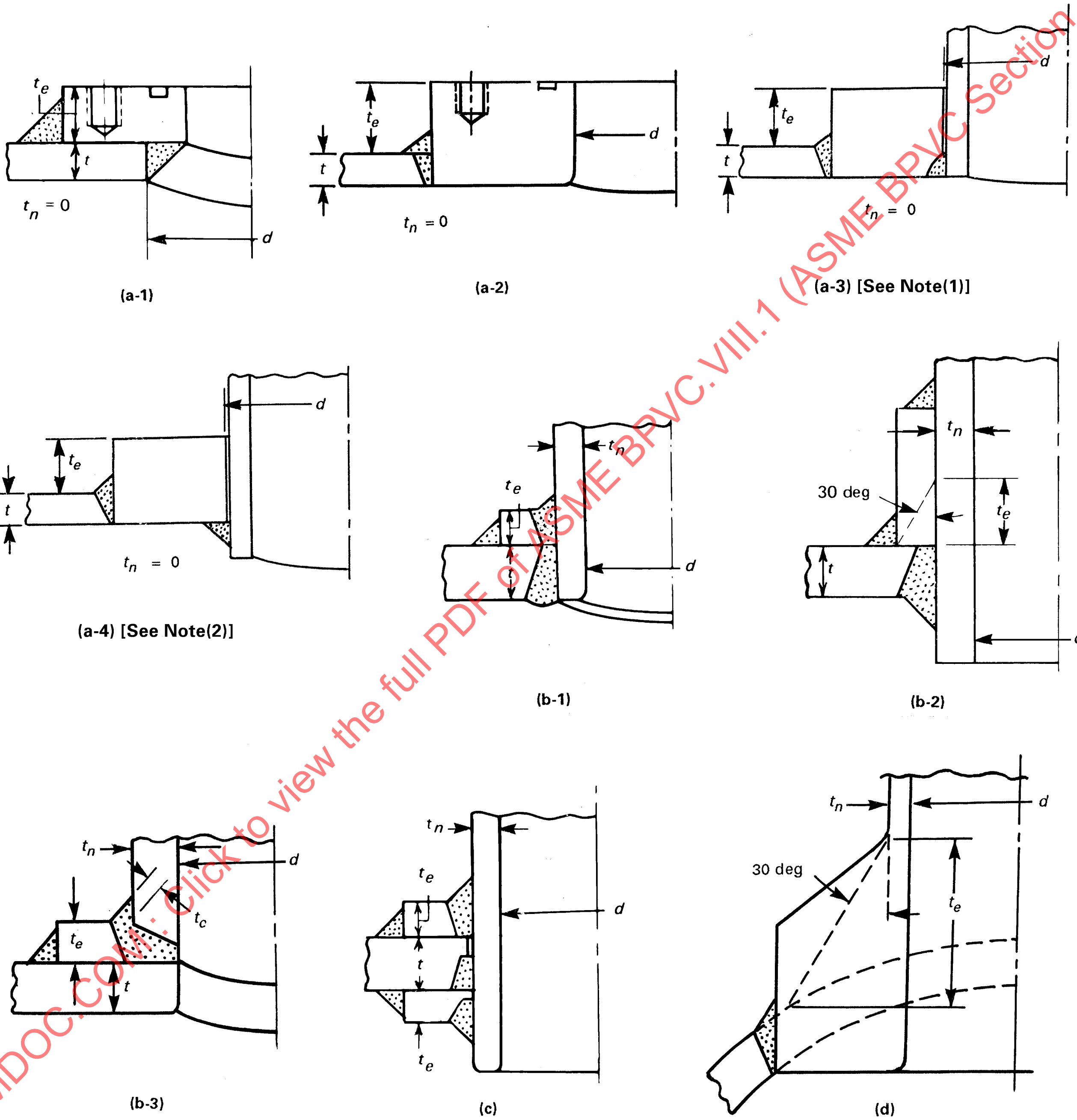
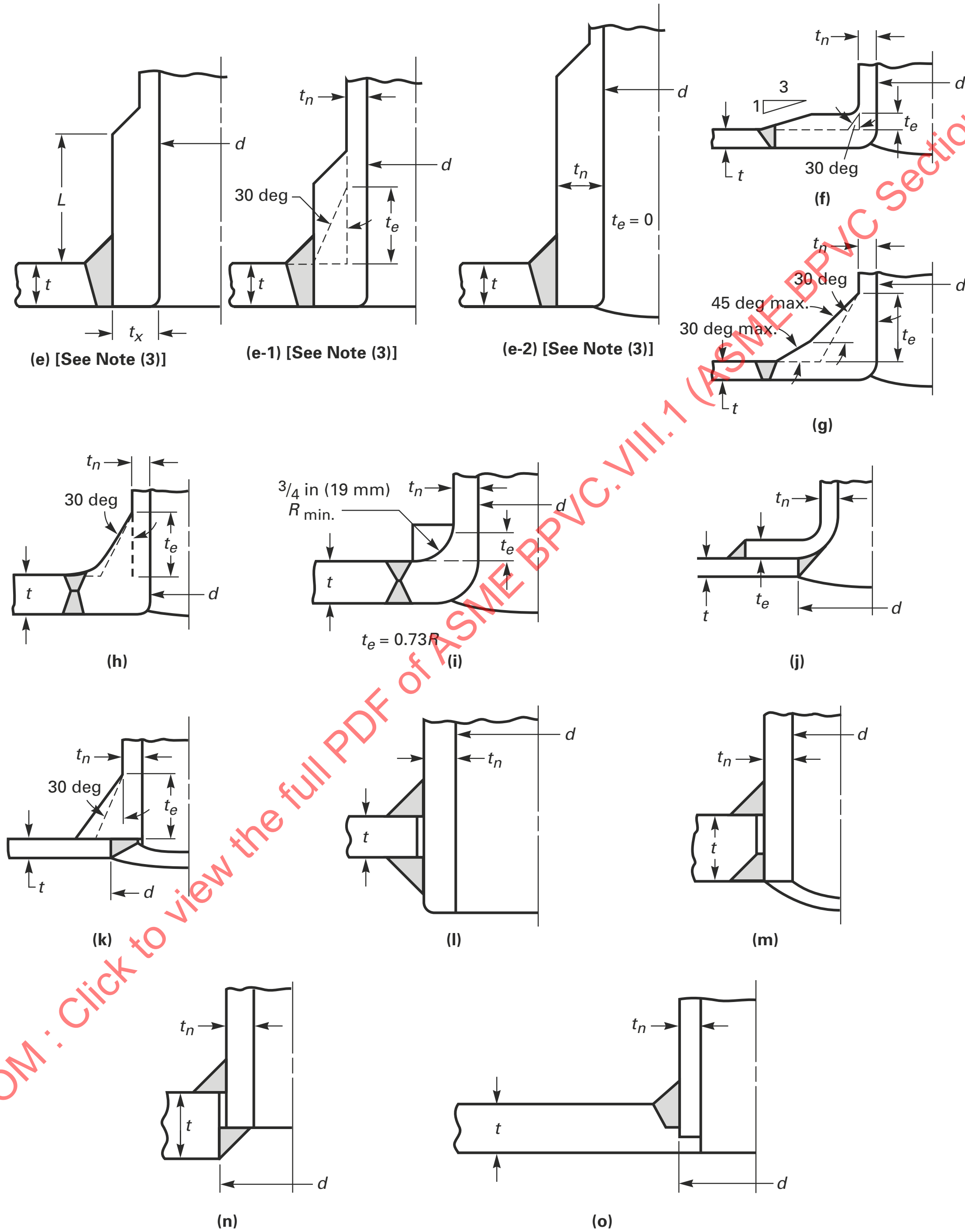


Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d (Cont'd)



NOTES:
(1) See Figure UW-16.1, sketch (v-2) for limitations.
(2) See Figure UW-16.1, sketch (w-2) for limitations.
(3) If $L < 2.5t_x$, use sketch (e-1); if $L \geq 2.5t_x$, use sketch (e-2).

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 in Figure UG-37.1.

All metal in the nozzle wall extending inside the vessel wall A_3 may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

(3) metal in attachment welds A_4 and metal added as reinforcement A_5.

(e) With the exception of studding outlet type flanges and the straight hubs of forged nozzle flanges [see UG-44(a)(10)], bolted flange material within the limits of reinforcement shall not be considered to have reinforcing value. With the exception of material within an integral hub, no material in a tubesheet or flat head shall be credited as reinforcement for an opening in an adjacent shell or head.

UG-41 STRENGTH OF REINFORCEMENT

(a) Material used for reinforcement shall have an allowable stress value 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, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

(b) On each side of the plane defined in UG-40(a), the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the smaller of:

(1) the strength in tension of the cross section of the element or elements of reinforcement being considered (see $W_{1\text{-}1}$, $W_{2\text{-}2}$, and $W_{3\text{-}3}$ of Figure UG-41.1 for examples);

(2) the strength in tension of the area defined in UG-37 less the strength in tension of the reinforcing area that is integral in the vessel wall as permitted by UG-40(d)(1) (see W of Figure UG-41.1 for examples);

(3) for welded attachments, see UW-15 for exemptions to strength calculations.

(c) 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 UG-40. 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 that passes through the center of the semicircular end of the opening.

(d) For detailed requirements for welded and brazed reinforcement see the appropriate paragraphs in the Parts devoted to these subjects (see UW-15 and UB-19).

UG-42 REINFORCEMENT OF MULTIPLE OPENINGS

(See UG-39 for multiple openings in flat heads.)

(a) When any two openings are spaced such that their limits of reinforcement overlap [see Figure UG-42, sketch (a)], the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of UG-37, UG-38, UG-40, and UG-41 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.

(1) The available area of the head or shell between openings having an overlap area shall be proportioned between the two openings by the ratio of their diameters.

(2) For cylinders and cones, if the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of Mandatory Appendix 1, 1-7(a) and 1-7(c) shall be used.

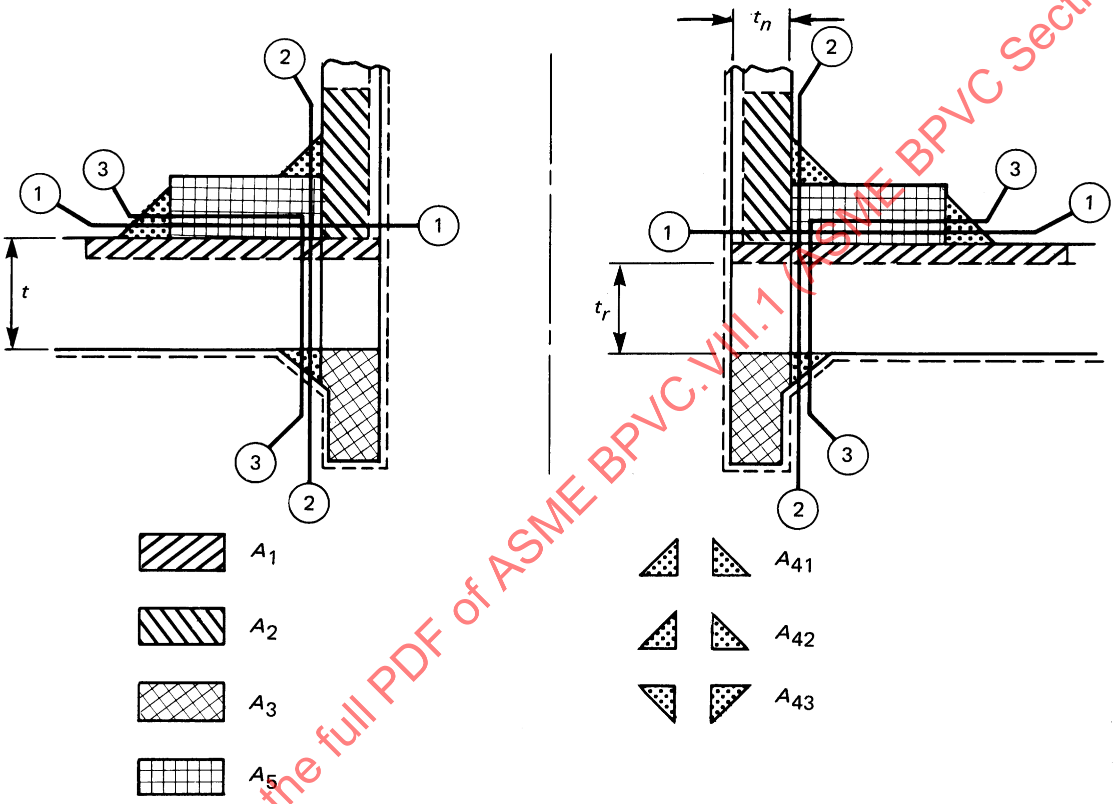
(3) A series of openings all on the same centerline shall be treated as successive pairs of openings.

(b) When more than two openings are spaced as in (a) above [see Figure UG-42, sketch (b)], and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be $1^1/_3$ times their average diameter, and the area of reinforcement between any two openings shall be at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than $1^1/_3$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings. Such openings must be reinforced as described in (c) below.

(c) Alternatively, any number of adjacent openings, in any arrangement, may be reinforced by using an assumed opening enclosing all such openings. The limits for reinforcement of the assumed opening shall be those given in UG-40(b)(1) and UG-40(c)(1). The nozzle walls of the actual openings shall not be considered to have reinforcing value. For cylinders and cones, when the diameter of the assumed opening exceeds the limits in UG-36(b)(1), the supplemental rules of Mandatory Appendix 1, 1-7(a) and 1-7(c) shall also be used.

(d) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in UW-9(c).

Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered



W = total weld load [UG-41(b)(2)]
= $[A - A_1 + 2t_n f_{r1}(E_1 t - F t_r)]S_v$

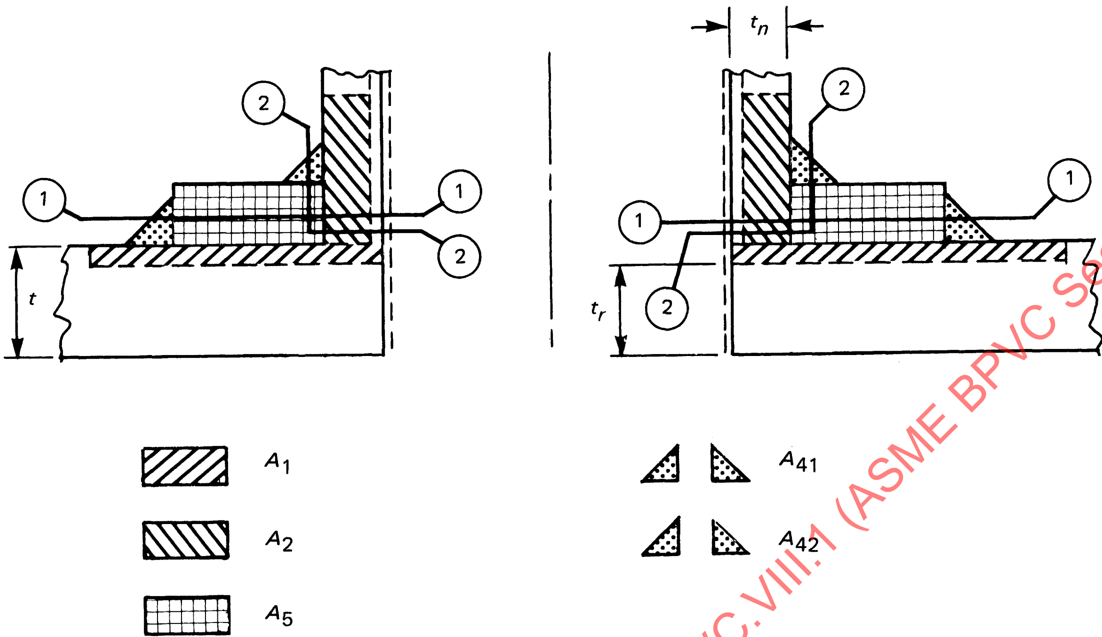
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$

$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_3 + A_{41} + A_{43} + 2t_n t f_{r1})S_v$

$W_{3\text{-}3}$ = weld load for strength path 3-3 [UG-41(b)(1)]
= $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2t_n t f_{r1})S_v$

(a) Depicts Typical Nozzle Detail With Neck Inserted Through the Vessel Wall

Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered (Cont'd)



W = total weld load [UG-41(b)(2)]
$= (A - A_1)S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
$= (A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
$= (A_2 + A_{41})S_v$

(b) Depicts Typical Nozzle Detail With Neck Abutting the Vessel Wall

GENERAL NOTES:
(a) Areas A_1, A_2, A_3, A_5, and A_{4i} are modified by f_{rx} factors.
(b) Nomenclature is the same as in UG-37 and Figure UG-37.1.

(e) When a series of two or more openings in a cylindrical or conical shell are arranged in a regular pattern, reinforcement of the openings may be provided per the rules of ligaments in UG-53.

UG-43 METHODS OF ATTACHMENT OF PIPE AND NOZZLE NECKS TO VESSEL WALLS

(a) General. Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in UG-36.

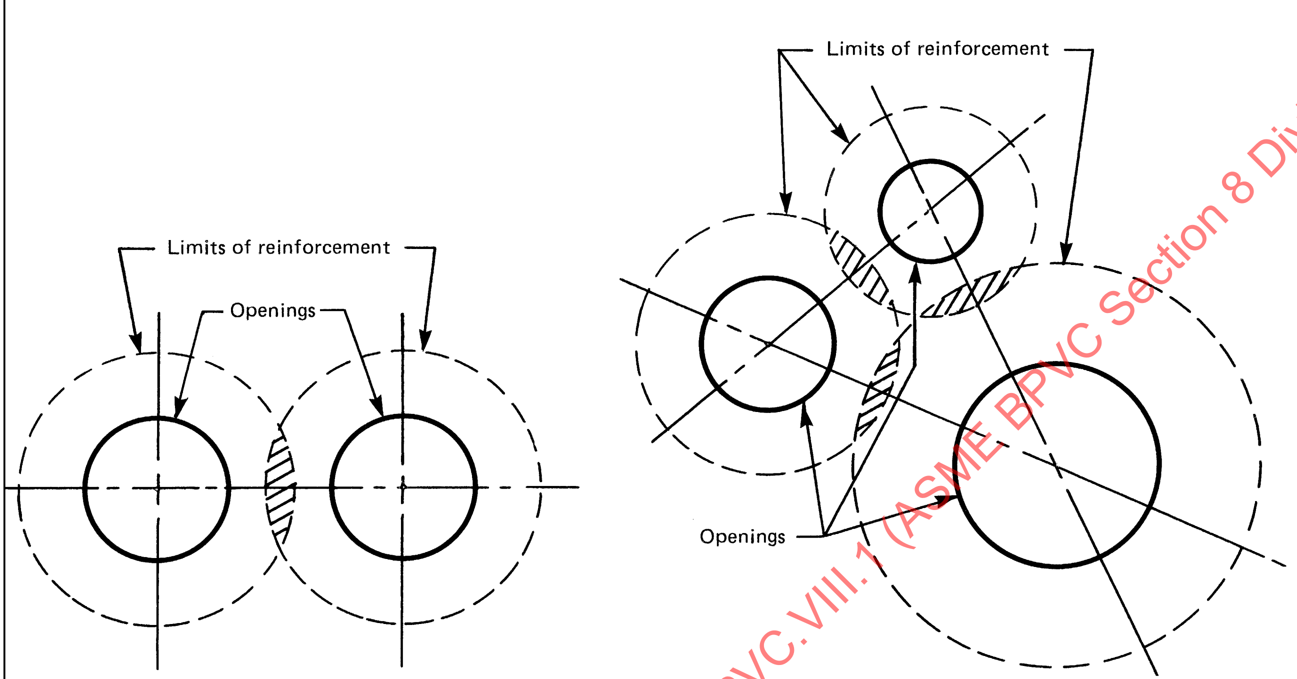
(b) Welded Connections. Attachment by welding shall be in accordance with the requirements of UW-15 and UW-16.

(c) Brazed Connections. Attachment by brazing shall be in accordance with the requirements of UB-17 through UB-19.

(d) Studded Connections. Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, or on a built-up pad, or on a properly attached plate or fitting. The distance from the inside surface of the vessel to the bottom of a drilled hole to be tapped shall not be less than the corrosion allowance plus one-fourth of the minimum required wall thickness. Weld metal may be added to the inside surface of the vessel to maintain this distance (see UW-42). The tapped holes shall also conform to the requirements of (g) below. Studded connections shall meet the requirements for reinforcement in UG-36 through UG-42.

(e) Threaded Connections. Pipes, tubes, and other threaded connections that conform to the ASME Standard for Pipe Threads, General Purpose, Inch (ASME B1.20.1) may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table UG-43 after allowance has been made

Figure UG-42
Examples of Multiple Openings



(a) Two Openings Spaced With Limits of Reinforcement Overlapping

(b) More Than Two Openings Spaced With Limits of Reinforcement Overlapping

for curvature of the vessel wall. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table UG-43, or to furnish reinforcement when required.

Threaded connections larger than 4 in. pipe size (DN 100) shall not be used in vessels that contain liquids having a flash point below 110°F (43°C), or flammable vapors, or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than 3 in. pipe size (DN 80) shall not be used when the maximum allowable working pressure exceeds 125 psi (0.8 MPa), except that this 3 in. pipe size (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes, or to integrally forged openings in vessel heads meeting the requirement of UF-43.

(f) Expanded Connections. A pipe, tube, or forging may be attached to the wall of a vessel by inserting through an unreinforced opening and expanding into the shell, provided the diameter is not greater than 2 in. pipe size (DN 50). A pipe, tube, or forging not exceeding 6 in.

Table UG-43
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, NPS (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
$^1/_2$ and $^3/_4$ (DN 15 and 20)	6	0.43 (11.0)
1, 1$^1/_4$, and 1$^1/_2$ (DN 25, 32, and 40)	7	0.61 (15)
2 (DN 50)	8	0.70 (18)
2$^1/_2$ and 3 (DN 65 and 80)	8	1.0 (25)
4–6 (DN 100–150)	10	1.25 (32)
8 (DN 200)	12	1.5 (38)
10 (DN 250)	13	1.62 (41)
12 (DN 300)	14	1.75 (45)

(150 mm) in outside diameter may be attached to the wall of a vessel by inserting through a reinforced opening and expanding into the shell.

Such connections shall be:

(1) firmly rolled in and beaded; or

(2) rolled in, beaded, and seal-welded around the edge of the bead; or

(3) expanded and flared not less than $^1/_8$ in. (3 mm) over the diameter of the hole; or

(4) rolled, flared, and welded; or

(5) rolled and welded without flaring or beading, provided:

(-a) the ends extend at least $^1/_4$ in. (6 mm), but no more than $^3/_8$ in. (10 mm), through the shell;

(-b) the throat of the weld is at least $^3/_{16}$ in. (5 mm), but no more than $^5/_{16}$ in. (8 mm).

When the tube or pipe does not exceed $1^1/_2$ in. (38 mm) in outside diameter, 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 $^3/_8$ in. (10 mm) beyond the shell.

Grooving of shell openings in which tubes and pipe are to be rolled or expanded is permissible.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable and/or noxious gases and liquids unless the connections are seal-welded.

(g) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75d_s \times \frac{\text{maximum allowable stress value of stud material at design temperature}}{\text{maximum allowable stress value of tapped material at design temperature}}$$

in which d_s is the nominal diameter of the stud, except that the thread engagement need not exceed $1^1/_2 d_s$.

UG-44 FLANGES AND PIPE FITTINGS

(a) The following standards covering flanges and pipe fittings are acceptable for use under this Division in accordance with the requirements of UG-11. Pressure–temperature ratings shall be in accordance with the appropriate standard except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including the maximum allowable stress for the material. The thickness tolerance of the ASME standards shall apply.

(1) ASME B16.1, Gray Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250. Permitted only for pressure vessel parts used on pressure vessels constructed in accordance with Part UCI.

(2) ASME B16.5, Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard

(3) ASME B16.9, Factory-Made Wrought Buttwelding Fittings

(4) ASME B16.11, Forged Fittings, Socket-Welding and Threaded

(5) ASME B16.15, Cast Copper Alloy Threaded Fittings, Classes 125 and 250

(6) ASME B16.20, Metallic Gaskets for Pipe Flanges

(7) ASME B16.24, Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves, Classes 150, 300, 600, 900, 1500, and 2500

(8) ASME B16.42, Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300

(9) ASME B16.47, Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard

(10) A forged nozzle flange may use the ASME B16.5/B16.47 pressure–temperature ratings for the flange material being used, provided all of the following are met:

(-a) For ASME B16.5 applications, the forged nozzle flange shall meet all dimensional requirements of a flanged fitting given in ASME B16.5 with the exception of the inside diameter. The inside diameter of the forged nozzle flange shall not exceed the inside diameter of the same size lap joint flange given in ASME B16.5. For ASME B16.47 applications, the inside diameter shall not exceed the weld hub diameter A given in the ASME B16.47 tables.

(-b) For ASME B16.5 applications, the outside diameter of the forged nozzle neck shall be at least equal to the hub diameter of the same size and class ASME B16.5 lap joint flange. For ASME B16.47 applications, the outside diameter of the hub shall at least equal the X diameter given in the ASME B16.47 tables. Larger hub diameters shall be limited to nut stop diameter dimensions. See Section VIII, Division 2, Figures 4.16.3 and 4.16.4.

(b) External loads (forces and bending moments) may be evaluated for flanged joints with welding neck flanges chosen in accordance with (a)(2), (a)(9), and (a)(10), using the following requirements:

(1) The vessel MAWP (corrected for the static pressure acting on the flange) at the design temperature cannot exceed the pressure–temperature rating of the flange.

(2) The actual assembly bolt load (see Nonmandatory Appendix S) shall comply with ASME PCC-1, Nonmandatory Appendix O.

(3) The bolt material shall have an allowable stress equal to or greater than SA-193 B8 Cl. 2 at the specified bolt size and temperature.

(4) The combination of vessel MAWP (corrected for the static pressure acting on the flange) with external moment and external axial force shall satisfy the following equation (the units of the variables in this equation shall be consistent with the pressure rating):

$$16M_E + 4F_EG \le \pi G^3\left[\left(P_R - P_D\right) + F_MP_R\right]$$

where

F_E = external tensile axial force
F_M = moment factor, in accordance with Table UG-44-1
G = gasket reaction diameter
M_E = external moment
P_D = vessel MAWP (corrected for static pressure acting on the flange) at design temperature
P_R = flange pressure rating at design temperature

UG-45 NOZZLE NECK THICKNESS

The minimum wall thickness of nozzle necks shall be determined as given below.

For access openings and openings used only for inspection:

$$t_{UG\text{-}45} = t_a$$

For other nozzles:

Determine t_b.

$$t_b = \min\left[t_{b3}, \max\left(t_{b1}, t_{b2}\right)\right]$$

$$t_{UG\text{-}45} = \max\left(t_a, t_b\right)$$

where

t_a = minimum neck thickness required for internal and external pressure using UG-27 and UG-28 (plus corrosion and threading allowance), as applicable. The effects of external forces and moments from supplemental loads (see UG-22) shall be considered. Shear stresses caused by UG-22 loadings shall not exceed 70% of the allowable tensile stress for the nozzle material.

t_{b1} = for vessels under internal pressure, the thickness (plus corrosion allowance) required for pressure (assuming E = 1.0) for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16.2 and UG-16.3.

t_{b2} = for vessels under external pressure, the thickness (plus corrosion allowance) obtained by using the external design pressure as an equivalent internal design pressure (assuming E = 1.0) in the formula for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16.2 and UG-16.3.

t_{b3} = the thickness given in Table UG-45 plus the thickness added for corrosion allowance.

$t_{UG\text{-}45}$ = minimum wall thickness of nozzle necks

UG-46 INSPECTION OPENINGS[30]

(a) All pressure vessels for use with compressed air and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see UG-25),

Table UG-44-1
Moment Factor, F_M (25)

Standard	Size Range	Flange Pressure Rating Class 150	300	600	900	1500	2500
ASME B16.5	≤NPS 12 (≤DN 300)	1.2	0.5	0.5	0.5	0.5	0.5
	>NPS 12 and ≤NPS 24 (>DN 300 and ≤DN 600)	1.2	0.5	0.5	0.3	0.3	...
ASME B16.47							
Series A	All	0.6	0.1	0.1	0.1	...	...
Series B	<NPS 48 (<DN1200)	[Note (1)]	[Note (1)]	0.13	0.13	...	...
	≥NPS 48 (≥DN 1200)	0.1	[Note (2)]	...	...	...	...

GENERAL NOTES:
(a) The combinations of size ranges and flange pressure classes for which this Table gives no moment factor value are outside the scope of this Table.
(b) The designer should consider reducing the moment factor if the loading is primarily sustained in nature and the bolted flange joint operates at a temperature where gasket creep/relaxation will be significant.

NOTES:
(1) F_M = 0.1 + (48 − NPS)/56.
(2) F_M = 0.1, except for NPS 60 (DN 1500), Class 300, in which case F_M = 0.03.

Table UG-45
Nozzle Minimum Thickness Requirements

	Minimum Wall Thickness [See UG-16.4(b)]	
Nominal Size	**in.**	**mm**
NPS 1/8 (DN 6)	0.060	1.51
NPS 1/4 (DN 8)	0.077	1.96
NPS 3/8 (DN 10)	0.080	2.02
NPS 1/2 (DN 15)	0.095	2.42
NPS 3/4 (DN 20)	0.099	2.51
NPS 1 (DN 25)	0.116	2.96
NPS 1 1/4 (DN 32)	0.123	3.12
NPS 1 1/2 (DN 40)	0.127	3.22
NPS 2 (DN 50)	0.135	3.42
NPS 2 1/2 (DN 65)	0.178	4.52
NPS 3 (DN 80)	0.189	4.80
NPS 3 1/2 (DN 90)	0.198	5.02
NPS 4 (DN 100)	0.207	5.27
NPS 5 (DN 125)	0.226	5.73
NPS 6 (DN 150)	0.245	6.22
NPS 8 (DN 200)	0.282	7.16
NPS 10 (DN 250)	0.319	8.11
≥ NPS 12 (DN 300)	0.328	8.34

GENERAL NOTE: For nozzles having a specified outside diameter not equal to the outside diameter of an equivalent standard NPS (DN) size, the NPS (DN) size chosen from the table shall be one having an equivalent outside diameter larger than the nozzle outside diameter.

except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

Compressed air as used in this paragraph is not intended to include air that has had moisture removed to provide an atmospheric dew point of −50°F (-46°C) or less.

Inspection openings may be omitted in vessels covered in (b), and in heat exchangers where the construction does not permit access to the shell side, such as fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers having shells integral with the tubesheets. When inspection openings are not provided, the Manufacturer's Data Report shall include one of the following notations under "Remarks":

(1) "UG-46(b)" when telltale holes are used in lieu of inspection openings;

(2) "UG-46(a)" when inspection openings are omitted in fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers having shells integral with the tubesheets;

(3) "UG-46(c)", "UG-46(d)", or "UG-46(e)" when provision for inspection is made in accordance with one of these paragraphs;

(4) the statement "for noncorrosive service."

(b) When provided with telltale holes complying with the provisions of UG-25, inspection openings as required in (a) above may be omitted in vessels not over 36 in. (900 mm) I.D. that are subject only to corrosion, provided that the holes are spaced one hole per 10 ft^2 (0.9 m^2) (or fraction thereof) of internal vessel surface area where corrosion is expected with a minimum of four uniformly spaced holes per vessel. This provision does not apply to vessels for compressed air.

(c) Vessels over 12 in. (300 mm) I.D. under air pressure that also contain, as an inherent requirement of their operation, other substances that will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently, and provided such openings are equivalent in size and number to the requirements for inspection openings in (f) below.

(d) For vessels 12 in. (300 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS 3/4 (DN 20).

(e) Vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two threaded pipe plug inspection openings of not less than NPS 1 1/2 (DN 40) except as permitted by the following: when vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. are to be installed so that inspection cannot be made without removing the vessel from the assembly, openings for inspection only may be omitted, provided there are at least two removable pipe connections of not less than NPS 1 1/2 (DN 40).

(f) Vessels that require access or inspection openings shall be equipped as follows.[31]

(1) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS 1 1/2 (DN 40).

(2) All vessels 18 in. (450 mm) to 36 in. (900 mm), inclusive, I.D. shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than NPS 2 (DN 50).

(3) All vessels over 36 in. (900 mm) I.D. shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two openings, each with a minimum area equivalent to a 4 in. × 6 in. (100 mm × 150 mm) handhole.

(4) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(5) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(6) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings, provided it is of such size and location as to afford at least an equal view of the interior.

(7) Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings, provided that:

(-a) the connections are at least equal to the size of the required openings; and

(-b) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings.

(g) When inspection or access openings are required, they shall comply at least with the following requirements:

(1) An elliptical or obround manhole shall be not less than 12 in. × 16 in. (300 mm × 400 mm). A circular manhole shall be not less than 16 in. (400 mm) I.D.

(2) A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

(h) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

(i) When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided.

(j) Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (17 mm).

BRACED AND STAYED SURFACES

(25) UG-47 BRACED AND STAYED SURFACES

(a) The minimum thickness and maximum allowable working pressure for braced and stayed flat plates and those parts that, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the following equations:

$$t = p\sqrt{\frac{P}{SC}} \qquad (1)$$

$$P = \frac{t^2 SC}{p^2} \qquad (2)$$

where

C = 2.1 for welded stays or stays screwed through plates not over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.2 for welded stays or stays screwed through plates over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers; and for stays screwed into plates as shown in Figure UG-47, sketch (b)
= 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates or made a taper fit and having the heads formed on the stays before installing them, and not riveted over, said heads being made to have a true bearing on the plate
= 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than $0.4p$ and thickness not less than t

P = internal design pressure (see UG-21)

p = maximum pitch. The maximum pitch is the greatest distance between any set of parallel straight lines passing through the centers of staybolts in adjacent rows. Each of the three parallel sets running in the horizontal, the vertical, and the inclined planes shall be considered.

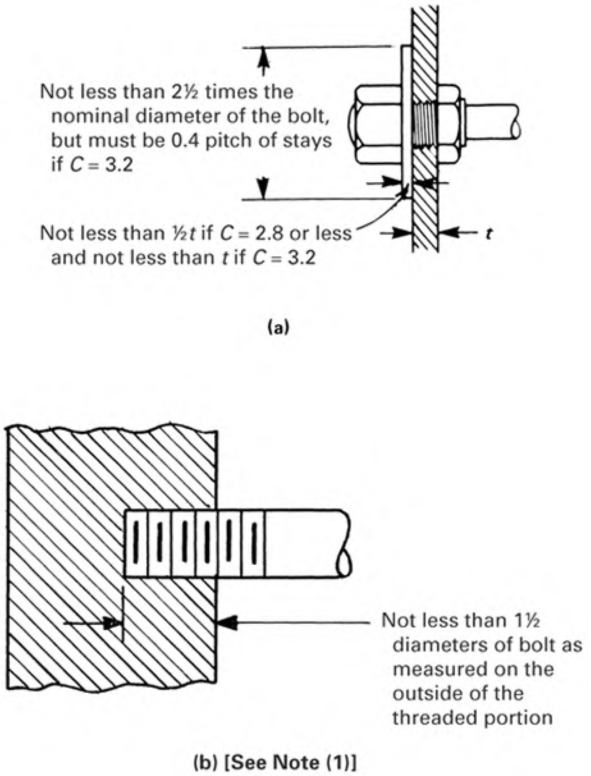
S = maximum allowable stress value in tension (see UG-23)

t = minimum thickness of plate

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $^5/_{16}$ in. (8 mm) except for welded construction covered by UW-19 or Part UDA.

(c) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above, and shall also meet the applicable requirements for shells or heads in UG-27(c) and UG-27(d) and UG-32. In addition, where any nozzle or other opening penetrates the cylindrical or spherical vessel, or completely covered head, and the jacket, the vessel or formed head shall be designed in accordance with UG-37(d)(2).

Figure UG-47
Acceptable Proportions for Ends of Stays



NOTE:
(1) See UG-83.

(d) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

(e) Acceptable proportions for the ends of through stays with washers are indicated in Figure UG-47, sketch (a). See UG-83.

(f) The maximum pitch shall be $8^1/_2$ in. (220 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt. See UW-19(a) for plate thicknesses greater than $^3/_4$ in. (19 mm).

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

UG-48 STAYBOLTS

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

(c) Requirements for welded-in staybolts are given in UW-19.

UG-49 LOCATION OF STAYBOLTS

(a) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

UG-50 DIMENSIONS OF STAYBOLTS

(a) The required area of a staybolt at its minimum cross section[32] and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt computed in accordance with (b) below by the allowable stress value for the material used, as given in Subsection C, and multiplying the result by 1.10.

(b) Load Carried by Stays. The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable working pressure.

(c) Stays made of parts joined by welding shall be checked for strength using a joint efficiency of 60% for the weld.

LIGAMENTS

UG-53 LIGAMENTS

(a) The symbols used in the equations and charts of this paragraph are defined as follows:

d = diameter of tube holes
n = number of tube holes in length p_1
p = longitudinal pitch of tube holes
p_1 = unit length of ligament
p' = diagonal pitch of tube holes
s = longitudinal dimension of diagonal pitch
= $p' \cos \theta$
θ = angle of diagonal with longitudinal line, deg

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures UG-53.1 through UG-53.3, the efficiency of the ligaments between the tube holes shall be determined as follows:

(1) When the pitch of the tube holes on every row is equal (see Figure UG-53.1), the formula is

$$\frac{p-d}{p} = \text{efficiency of ligament}$$

(2) When the pitch of tube holes on any one row is unequal (as in Figures UG-53.2 and UG-53.3), the formula is

$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

(c) When the adjacent longitudinal rows are drilled as described in (b) above, diagonal and circumferential ligaments shall also be examined. The least equivalent longitudinal efficiency shall be used to determine the minimum required thickness and the maximum allowable working pressure.

(d) When a cylindrical shell is drilled for holes so as to form diagonal ligaments, as shown in Figure UG-53.4, the efficiency of these ligaments shall be determined by Figures UG-53.5 and UG-53.6. Figure UG-53.5 is used to determine the efficiency of longitudinal and diagonal ligaments with limiting boundaries where the condition of equal efficiency of diagonal and longitudinal ligaments form one boundary and the condition of equal efficiency of diagonal and circumferential ligaments form the other boundary. Figure UG-53.6 is used for determining the equivalent longitudinal efficiency of diagonal ligaments. This efficiency is used in the equations for setting the minimum required thickness and the maximum allowable working pressure.

(e) Figure UG-53.5 is used when either or both longitudinal and circumferential ligaments exist with diagonal ligaments. To use Figure UG-53.5, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next find the vertical line in the diagram corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1. Then project this point horizontally to the left, and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The minimum shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

(f) Figure UG-53.6 is used for holes which are not in line, placed longitudinally along a cylindrical shell. The diagram may be used for pairs of holes for all planes between the longitudinal plane and the circumferential plane. To use Figure UG-53.6, determine the angle θ between the longitudinal shell axis and the line between the centers of the openings, θ, and compute the value of p'/d. Find the vertical line in the diagram corresponding to the value of θ and follow this line vertically to the line representing the value of p'/d. Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

(g) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable working pressure is based.

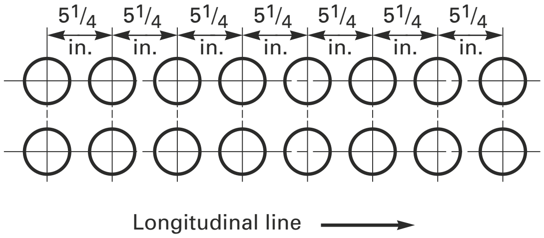
(h) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both:[33]

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside diameter of the shell exceeds 60 in. (1 520 mm), the length shall be taken as 60 in. (1 520 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable working pressure is based. When the inside radius of the shell exceeds 30 in. (760 mm), the length shall be taken as 30 in. (760 mm) in applying this rule.

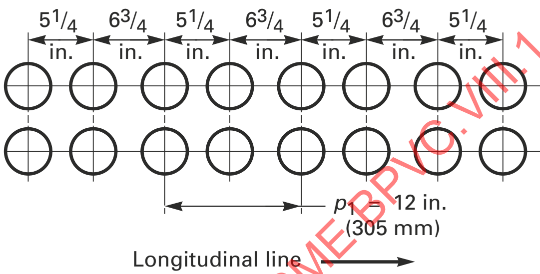
(i) When ligaments occur in cylindrical shells made from welded pipe or tubes, and their calculated efficiency is less than 85% (longitudinal) or 50% (circumferential), the efficiency to be used in the equations of UG-27 is the calculated ligament efficiency. In this case, the appropriate stress value in tension (see UG-23) may be multiplied by the factor 1.18.

Figure UG-53.1
Example of Tube Spacing With Pitch of Holes Equal in Every Row



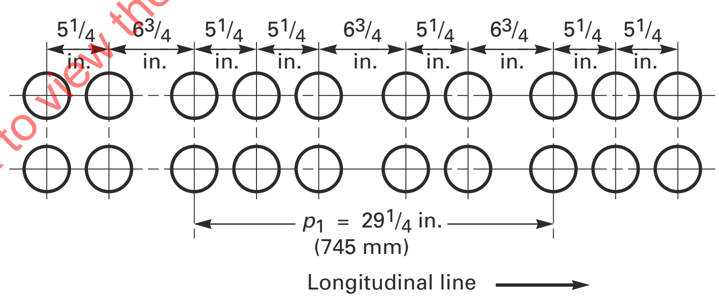
GENERAL NOTE: 5$^1/_4$ in. = 133 mm.

Figure UG-53.2
Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row



GENERAL NOTE: 5$^1/_4$ in. = 135 mm; 6$^3/_4$ in. = 170 mm.

Figure UG-53.3
Example of Tube Spacing With Pitch of Holes Varying in Every Second and Third Row



GENERAL NOTE: 5$^1/_4$ in. = 135 mm; 6$^3/_4$ in. = 170 mm.

Figure UG-53.4
Example of Tube Spacing With Tube Holes on Diagonal Lines