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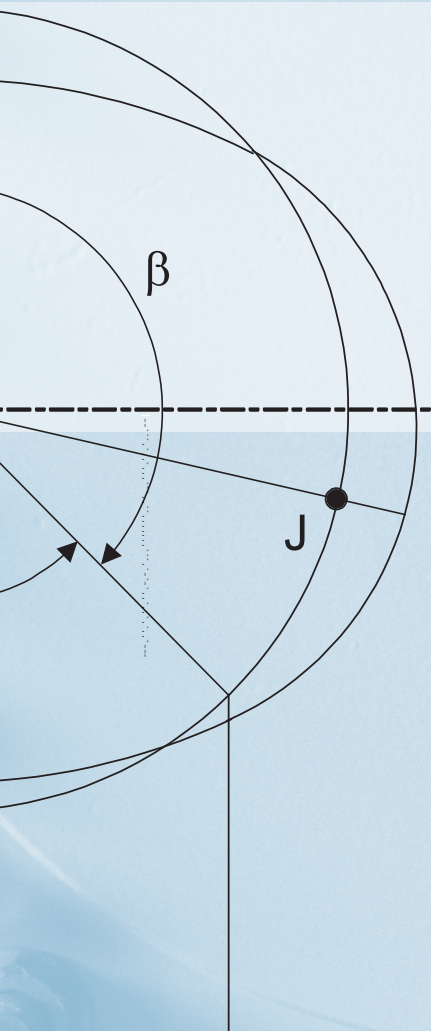
2013 ASME Boiler and Pressure Vessel Code

AN INTERNATIONAL CODE

III

Rules for Construction of Nuclear Facility Components

Division 1 — Subsection ND Class 3 Components



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Division 1 - Subsection ND

Class 3 Components

ASME Boiler and Pressure Vessel Committee
on Nuclear Power



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INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code.

Interpretations of the Code are posted in January and July at <http://cstools.asme.org/interpretations.cfm>. Any Interpretations issued during the previous two calendar years are included with the publication of the applicable Section of the Code. Interpretations of Section III, Divisions 1 and 2 and Section III Appendices are included with Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2013 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2015 Code.

FOREWORD

(This Foreword is provided as an aid to the user and is not part of the rules of this Code.)

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees: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 and Brazing (IX)
- (h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
- (i) Committee on Nuclear Inservice Inspection (XI)
- (j) Committee on Transport Tanks (XII)

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 only to pressure integrity, which govern the construction^{*} of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. The Committee also interprets these rules when questions arise regarding their intent. This 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. 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 pressure vessels. 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.

This 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 judgement* 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 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.

^{*} *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

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 this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). 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://cstools.asme.org/csconnect/public/index.cfm?PublicReview=Revisions> 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 an ASME Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

STATEMENT OF POLICY ON THE USE OF THE 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 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 Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the 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 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 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 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 Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the Certification Mark. General usage is permitted only when all of a manufacturer’s items are constructed under the rules.

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 official Certification Mark described in the governing Section of the Code.

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME” or the 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.

(13) SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the committees. See Guideline on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code in Section II, Parts C and D for additional requirements for requests involving adding new materials to the Code. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code Interpretations, as described below.

(1) *Code Revisions.* Code revisions are considered to accommodate technological developments, address administrative requirements, incorporate Code Cases, or to clarify Code intent.

(2) *Code Cases.* Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit the use of a new material for Code construction

(-c) to gain experience with new materials or alternative rules prior to incorporation directly into the Code

(3) *Code Interpretations.* Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.

(b) The Code rules, Code Cases, and Code Interpretations established by the committees 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 rules.

(c) Inquiries that do not comply with these provisions or that do not provide sufficient information for a committee's full understanding may result in the request being returned to the inquirer with no action.

2 INQUIRY FORMAT

Submittals to a committee shall include:

(a) *Purpose.* Specify one of the following:

(1) revision of present Code rules

(2) new or additional Code rules

(3) Code Case

(4) Code Interpretation

(b) *Background.* Provide the information needed for the committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda (if applicable), paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) *Presentations.* The inquirer may desire or be asked to attend a meeting of the committee to make a formal presentation or to answer questions from the committee members with regard to the inquiry. Attendance at a committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the committee.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) *Proposed Revisions or Additions.* For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) *Statement of Need.* Provide a brief explanation of the need for the revision or addition.

(c) *Background Information.* Provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request that will allow the committee to adequately evaluate the proposed revision or addition. Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision or addition and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

4 CODE CASES

Requests for Code Cases shall provide a Statement of Need and Background Information similar to that defined in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure, etc.) must be defined and it must be confirmed that the request is in connection with equipment that will bear the Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Editions and Addenda (if applicable) to which the proposed Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations shall provide the following:

(1) *Inquiry.* Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a “yes” or a “no” *Reply*, with brief provisos if needed, is acceptable. The question should be technically and editorially correct.

(2) *Reply.* Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be “yes” or “no,” with brief provisos if needed.

(3) *Background Information.* Provide any background information that will assist the committee in understanding the proposed *Inquiry* and *Reply*.

(b) Requests for Code Interpretations must be limited to an interpretation of a particular requirement in the Code or a Code Case. The committee cannot consider consulting type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements;

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation;

(3) a request seeking the rationale for Code requirements.

6 SUBMITTALS

Submittals to and responses from the committees shall meet the following:

(a) *Submittal.* Inquiries from Code users shall be in English and preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, fax number, and e-mail address, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

As an alternative, inquiries may be submitted via e-mail to: SecretaryBPV@asme.org.

(b) *Response.* The Secretary of the appropriate committee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the committee.

PERSONNEL

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January 1, 2013

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G. H. DeBoo	C. J. Wirtz
R. L. Dyle	T. Yuhara
E. V. Farrell, Jr.	H. D. Chung, <i>Delegate</i>
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T. J. Griesbach	D. A. Scarth
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B. Bezensek	H. S. Mehta
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B. R. Ganta	T. V. Vo
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F. E. Dohmen	R. V. Swain
M. E. Gothard	G. Tang
D. O. Henry	C. J. Wirtz

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D. O. Henry	C. J. Wirtz
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Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (BPV XI)

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P. D. Fisher	R. W. Swayne
J. M. Gamber	D. L. Tilly
R. E. Gimple	D. E. Waskey
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T. P. Lokey	L. H. Strouse, <i>Contributing Member</i>

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U.S. Technical Advisory Group ISO/TC 185 Safety Relief Valves

T. J. Bevilacqua, <i>Chair</i>	D. B. DeMichael
C. E. O'Brien, <i>Staff Secretary</i>	D. Miller
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ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter “N” for Division 1, by the letter “C” for Division 2, by the letter “W” for Division 3, and by the letter “H” for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
 - Subsection NB — Class 1 Components
 - Subsection NC — Class 2 Components
 - Subsection ND — Class 3 Components
 - Subsection NE — Class MC Components
 - Subsection NF — Supports
 - Subsection NG — Core Support Structures
 - Subsection NH — Class 1 Components in Elevated Temperature Service
- Division 2 — Code for Concrete Containments
 - Subsection CC — Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste
 - Subsection WA — General Requirements for Division 3
 - Subsection WB — Class TC Transportation Containments
 - Subsection WC — Class SC Storage Containments
- Division 5 — High Temperature Reactors
 - Subsection HA — General Requirements
 - Subpart A — Metallic Materials
 - Subpart B — Graphite Materials
 - Subpart C — Composite Materials
 - Subsection HB — Class A Metallic Pressure Boundary Components
 - Subpart A — Low Temperature Service
 - Subpart B — Elevated Temperature Service
 - Subsection HC — Class B Metallic Pressure Boundary Components
 - Subpart A — Low Temperature Service
 - Subpart B — Elevated Temperature Service
 - Subsection HF — Class A and B Metallic Supports
 - Subpart A — Low Temperature Service
 - Subsection HG — Class A Metallic Core Support Structures
 - Subpart A — Low Temperature Service
 - Subpart B — Elevated Temperature Service
 - Subsection HH — Class A Nonmetallic Core Support Structures
 - Subpart A — Graphite Materials
 - Subpart B — Composite Materials

2 SUBSECTIONS

Subsections are divided into Articles, subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection, except NCA, in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) *References to Other Portions of Section III.* When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in subarticle NB-3200; reference to NB-3230 includes all paragraphs, NB-3231 through NB-3236.

(b) *References to Other Sections.* Other Sections referred to in Section III are the following:

(1) *Section II, Materials.* When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

(2) *Section V, Nondestructive Examination.* Section V references begin with the letter “T” and relate to the nondestructive examination of material or welds.

(3) *Section IX, Welding and Brazing Qualifications.* Section IX references begin with the letter “Q” and relate to welding and brazing requirements.

(4) *Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.* When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute. When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-89-2003.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 Doral Boulevard, Suite 130, Doral, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix “SF,” for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605-1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) References to Appendices. Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled “Appendices.” These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-2131. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

* The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix “ASA” followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix “USAS” followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

SUMMARY OF CHANGES

The 2013 Edition of this Code contains revisions in addition to the 2010 Edition with 2011 Addenda.

After publication of the 2013 Edition, Errata to the BPV Code may be posted on the ASME Web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published on the ASME Web site under the BPVC Resources page at <http://www.asme.org/kb/standards/publications/bpvc-resources>.

Changes given below are identified on the pages by a margin note, **(13)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in "List of Changes in Record Number Order" following this Summary of Changes.

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
xii	List of Sections	Revised (12-749)
xiv	Foreword	Revised in its entirety (09-760)
xvii	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	Revised (12-1641)
xix	Personnel	Updated
xxxiv	Organization of Section III	Revised (12-749, 12-1878)
xl	Cross-Referencing and Stylistic Changes in the Boiler and Pressure Vessel Code	Added
31	ND-3111	Subparagraph (b) deleted and subparas. (c) through (h) redesignated (b) through (g), respectively (11-1426)
34	ND-3133.4	(1) In subpara. (e)(1)(-b), Step 1, reference to "(e)(1)(a)" corrected by errata to read "(e)(1)(-a)" (12-989) (2) In subpara. (e)(1)(-b), Step 3, " P_{a1} " corrected by errata to read " P_{a2} " (12-989) (3) In subpara. (e)(1)(-b), Step 3, second part of equation corrected by errata to be enclosed in parentheses (12-989)
48	ND-3324.11(b)(5)	Subparagraphs (-a) and (-b) revised (11-1985)
50	Figure ND-3325-1	In illustration (g), the callout "Protection beyond weld is optional" corrected by errata to read "Projection beyond weld is optional" (12-1266)
72	ND-3362	Subparagraph (a) revised (12-441)
97	ND-3512.1	Subparagraphs (a)(3), (b)(1), and (b)(2) revised (12-441)
105	ND-3611.2	In subpara. (c)(1), last sentence added (10-1402)
110	ND-3641.1	In the nomenclature, definition of P_a revised (10-1402)
115	Figure ND-3643.3(c)(1)-1	In Example B illustration, extra arrow below "Excess wall in header" deleted by errata (12-1313)
126	ND-3654.1	Last sentence added (10-1402)

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
127	ND-3655	(1) In subpara. (a)(1), last sentence added (10-1402) (2) Subparagraph (b)(1) revised (10-1821) (3) In subpara. (b)(3) equation, and nomenclature following the equation, " P_D " changed to " P_E " and (10-1821)
128	ND-3658.2	In first sentence, cross-reference to "MSS SP-44" deleted (12-441)
132	ND-3673.2	In subpara. (d), definition of S in the nomenclature corrected by errata (12-1313)
162	ND-3923.2	In subpara. (b)(1), last sentence reformatted by errata (12-989)
168	ND-3932.3	In subpara. (d), Step 5, equation reformatted by errata (12-989)
229	Table ND-4622.1-1	First row under fifth column revised (11-936)
231	Table ND-4622.7(b)-1	(1) For P-No. "4" and P-Nos. "5A, 5B, 5C" entries in "Type of Weld" column revised (12-920) (2) Note (3) revised (11-1093)

NOTE: Volume 62 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of Subsection NCA.

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
09-760	Added an introductory subtitle clarifying the purpose and limitations of the Foreword. Revised history paragraph to recognize the realignment of the BPV into several BPVs. Deleted the paragraph on tolerances. Made editorial changes to recognize the new committee structure. Deleted words addressing governing code editions. Deleted paragraph concerning materials. Deleted the paragraph dealing with what the committee considers in the formulation of these rules.
10-1402	Revised the definition of P_a in ND-3641.1 and added P_a calculation basis in ND-3611.2(c)(1), ND-3654.1, and ND-3655(a)(1).
10-1821	Changed P_D to P_E in ND-3655(b)(3).
11-936	Editorial clarifications/revisions were made to Table ND-4622.1-1.
11-1093	Deleted Note (3) from Table ND-4622.7(b)-1.
11-1426	Revised ND-3111 to delete impact forces.
11-1985	Revised ND-3324.11(b)(5)(-b) as discussed in the Proposal and Explanation sections of this record.
12-441	Deleted MSS SP-42 from ND-3362 and updated title of ASME B16.24. Deleted MSS SP-44 from ND-3512.1. Deleted MSS SP-44 from ND-3658.2.
12-749	Changed the existing Division 1 Appendices to Section III Appendices and added a reference table addressing each Section III Appendix and each Division/Subsection. Revised pages from Section III Subsections to reflect that the Division 1 Appendices no longer exist. Revised Appendices that remain specific to just a single subsection (Subsections NH and CC) to identify their association within that Subsection and to eliminate any duplicate appendix callouts. Made minor editorial and errata corrections.
12-920	Revised PWHT exemption tables for P4, P5A, P5B, and P5C to state all welds meeting the exemption requirements to be exempt from PWHT. Previously, the code listed circumferential butt welds, socket welds, and attachment welds to be exempt. The proposed change is similar to what is currently allowed for ASME B31.1 and ASME B31.3.
12-989	Errata correction. See Summary of Changes for details.
12-1266	Errata correction. See Summary of Changes for details.
12-1313	Errata correction. See Summary of Changes for details.
12-1641	Deleted “— Mandatory” from “Submittal of Technical Inquiries to the Boiler and Pressure Vessel Committee — Mandatory” in the front matter.
12-1878	Deleted the “Scope” page from the front matter of Division 5 and incorporated the pertinent information into the “Organization of Section III” pages.

(13) CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
 - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
 - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
 - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
 - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

ARTICLE ND-1000 INTRODUCTION

ND-1100 SCOPE

(a) Subsection ND contains rules for the materials, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of items that are intended to conform to the requirements for Class 3 construction.

(b) The rules of Subsection ND cover the requirements for the strength and pressure integrity of items the failure of which would violate the pressure retaining boundary. The rules cover load stresses, but do not cover deterioration that may occur in service as a result of corrosion, radiation effects, or instability of material. NCA-1130 gives further limits to the rules of this Subsection.

(c) Subsection ND does not contain rules to cover all details of construction of Class 3 vessels and storage tanks. Where complete details are not provided in this Subsection, it is intended that the Certificate Holder, subject to the approval of the Owner or his designee and acceptance by the Inspector, shall provide details of construction that will be consistent with those provided by the rules of this Subsection.

ND-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

ND-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall not be closer to a vessel, tank, pump, or valve than

(a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);

(b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);

(c) the first threaded joint in screwed connections.

ND-1132 Boundary Between Components and Attachments

ND-1132.1 Attachments.

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure retaining portion of a component.

(b) Attachments will have either a pressure retaining function or a nonpressure-retaining function.

(1) Attachments with a pressure retaining function include items such as

(-a) pressure boundary stiffeners;

(-b) branch and vessel opening reinforcement.

(2) Attachments with a nonpressure-retaining function include items such as

(-a) valve guides, thermal sleeves, and turning vanes;

(-b) vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, skirts, and other items within the component support load path.

(c) Attachments will also have either a structural or nonstructural function.

(1) Attachments with a structural function (structural attachments)

(-a) perform a pressure retaining function;

(-b) are in the component support load path.

(2) Attachments with a nonstructural function (non-structural attachments)

(-a) do not perform a pressure retaining function;

(-b) are not in the component support load path;

(-c) will be permanent or temporary.

Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

ND-1132.2 Jurisdictional Boundary. The jurisdictional boundary between a pressure retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure retaining portion of the component than as defined in (a) through (g) below. [Figures ND-1132.2-1](#) through [ND-1132.2-3](#) are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure retaining function shall be considered part of the component.

(c) Except as provided in (d) and (e) below, the boundary between a pressure retaining component and an attachment not having a pressure retaining function shall be at the surface of the component.

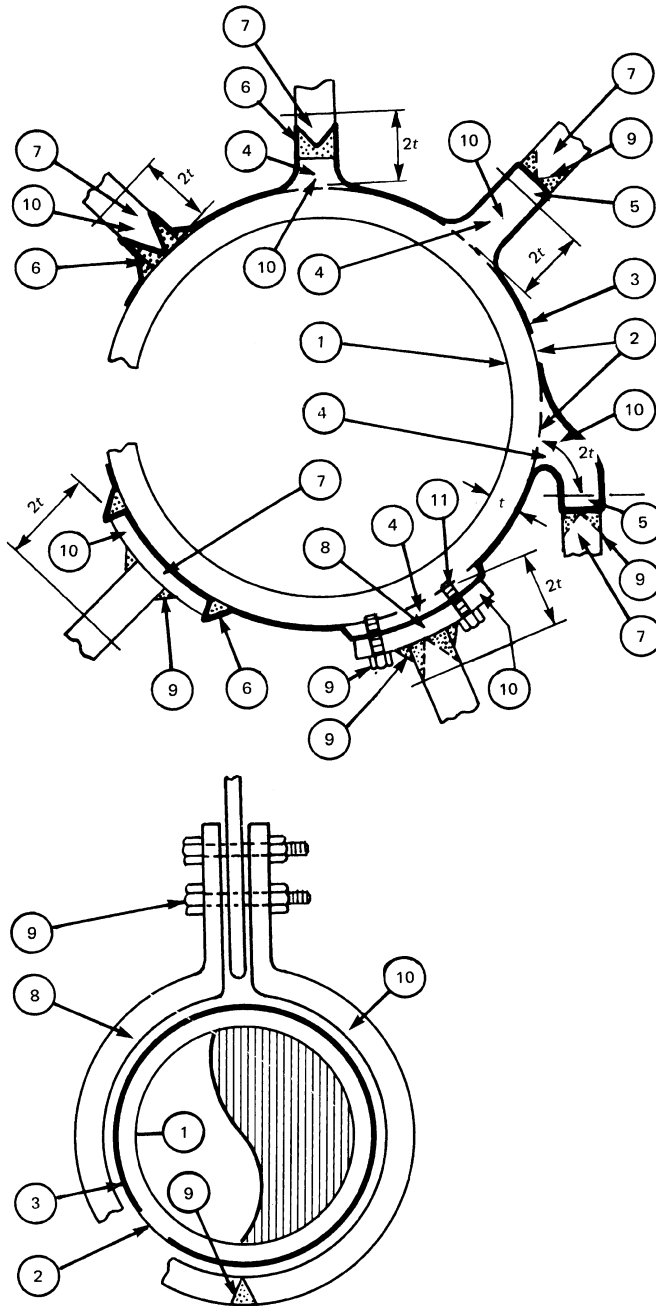
(d) The first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material. Beyond $2t$ from the pressure retaining portion of the component, the first weld shall be considered part of the attachment.

(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure retaining portion of the component the first connecting weld shall conform to [ND-4430](#).

(f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the component shall be considered part of the attachment.

(g) The boundary may be located further from the pressure retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

Figure ND-1132.2-1
Attachments in the Component Support Load Path that Do Not Perform a Pressure Retaining Function



- ① Component shall conform to Subsection ND.
- ② Pressure retaining portion of the component.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection ND.
- ⑤ Beyond $2t$ from the pressure retaining portion of the component, the design rules of NF-3000 may be used as a substitute for the design rules of ND-3000
- ⑥ At or within $2t$ from the pressure retaining portion of the component, the first connecting weld shall conform to Subsection ND.
- ⑦ Beyond $2t$ from the pressure retaining portion of the component or beyond the first connecting weld, the attachment shall conform to Subsection NF [Note (1)]
- ⑧ Bearing, clamped, or fastened attachment shall conform to Subsection NF [Note (1)]
- ⑨ Attachment connection shall conform to Subsection NF [Note (1)]
- ⑩ At or within $2t$ from the pressure retaining portion of the component, the interaction effects of the nonstructural attachment shall be considered in accordance with ND-3135.
- ⑪ Drilled holes shall conform to Subsection ND.

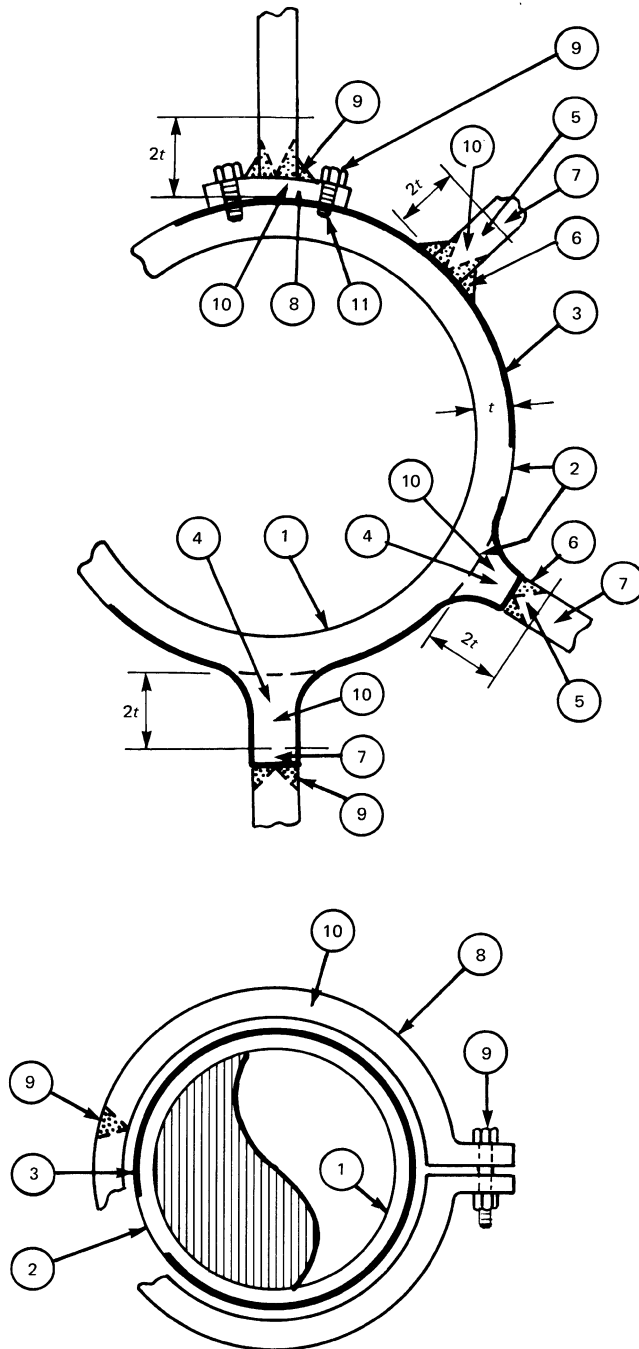
GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

(1) If the attachment is an intervening element [NF-1110(c)], material, design, and connections, as appropriate, are outside Code jurisdiction.

Figure ND-1132.2-2
Attachments that Do Not Perform a Pressure Retaining Function and Are Not in the Component Support
Load Path
(Nonstructural Attachments)

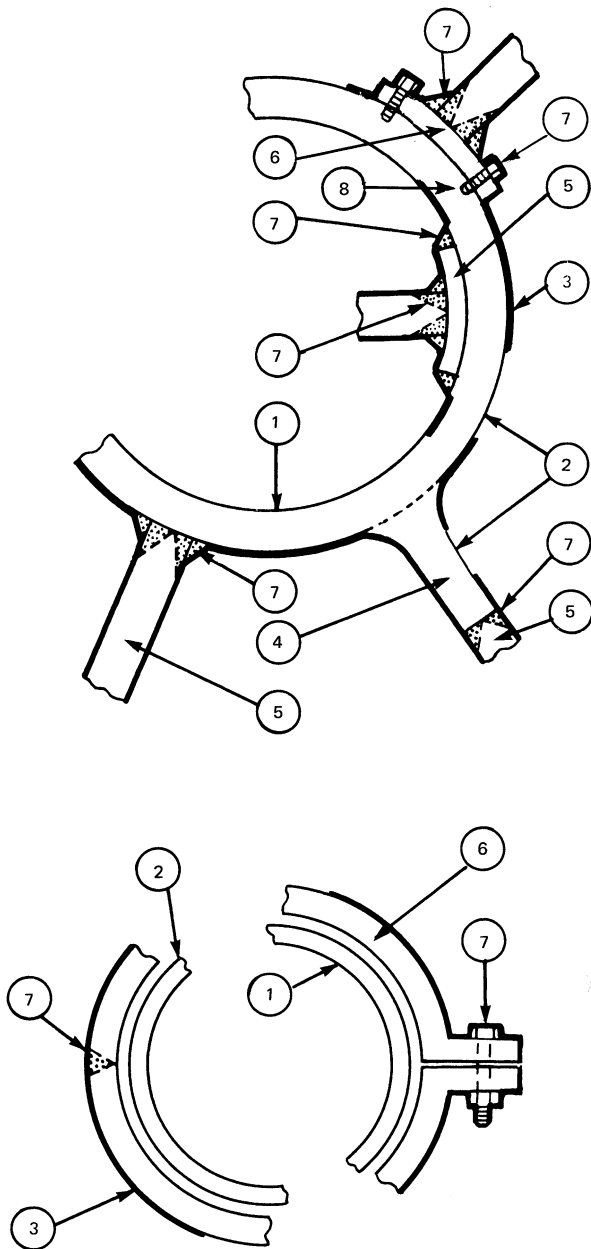


- ① Component shall conform to Subsection ND.
- ② Pressure retaining portion of the component.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection ND.
- ⑤ At or within $2t$ from the pressure retaining portion of the component, the material of the first welded nonstructural attachment shall conform to ND-2190; design is outside Code jurisdiction.
- ⑥ At or within $2t$ from the pressure retaining portion of the component, the first connecting weld shall conform to ND-4430.
- ⑦ Beyond $2t$ from the pressure retaining portion of the component, the nonstructural attachment is outside Code jurisdiction.
- ⑧ Bearing, clamped, or fastened nonstructural attachment is outside Code jurisdiction.
- ⑨ Nonstructural attachment connection is outside Code jurisdiction.
- ⑩ At or within $2t$ from the pressure retaining portion of the component, the interaction effects of the nonstructural attachment shall be considered in accordance with ND-3135.
- ⑪ Drilled holes shall conform to Subsection ND.

GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

Figure ND-1132.2-3
Attachments That Perform a Pressure Retaining Function



- ① Component shall conform to Subsection ND.
- ② Pressure retaining portion of the component.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection ND.
- ⑤ Welded attachment shall conform to Subsection ND.
- ⑥ Bearing, clamped, or fastened attachment shall conform to Subsection ND.
- ⑦ Attachment connection shall conform to Subsection ND.
- ⑧ Drilled holes shall conform to Subsection ND.

GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

ARTICLE ND-2000 MATERIAL

ND-2100 GENERAL REQUIREMENTS FOR MATERIAL

ND-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The term *pressure retaining material* as used in this Subsection applies to items such as vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting that joins pressure retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* — the thickness is the dimension of the short transverse direction;

(2) *forgings* — the thickness is the dimension defined as follows:

(-a) *hollow forgings* — the nominal thickness is measured between the inside and outside surfaces (radial thickness);

(-b) *disk forgings* (axial length less than the outside diameter) — the nominal thickness is the axial length;

(-c) *flat ring forgings* (axial length less than the radial thickness) — for axial length ≤ 2 in. (50 mm), the axial length is the nominal thickness; for axial length > 2 in. (50 mm), the radial thickness is the nominal thickness;

(-d) *rectangular solid forgings* — the least rectangular dimension is the nominal thickness;

(3) castings

(-a) thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping;

(-b) thickness t for heat treatment purposes is defined as the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure-retaining.

ND-2120 PRESSURE RETAINING MATERIAL

ND-2121 Permitted Material Specifications

(a) Pressure retaining material shall conform to the requirements of one of the specifications for materials listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, including all applicable footnotes in the table, and to all of the requirements of this Article that apply to the product

form in which the material is used. Attachments which perform a pressure retaining function shall be pressure retaining material.

(b) The requirements of this Article do not apply to material for items not associated with the pressure retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, and wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Tables 1A and 1B, Section II, Part D, Subpart 1 may be used for the following applications:

(1) *safety valve disks and nozzles* — when the nozzles are internally contained by the external body structure

(2) *control valve disks and cages* — when valves function for flow control only

(3) *line valve disks in valves* — whose inlet connections are NPS 2 (DN 50) and smaller

(d) Material for line fittings and valves, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, provided that the fittings are in conformance with the requirements of ND-3671.4 the valves meet the requirements of ND-3500, and the material is determined to be adequate for the service conditions by the piping system designer for fittings.

(e) Welding and brazing materials used in manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

(f) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay that is 10% or less of the thickness of the base material (ND-3122).

ND-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements [NCA-3856]. Where the special requirements include an examination, test, or treatment that is also required by the material specification, the examination test or treatment need be

performed only once. Required nondestructive examinations shall be performed as specified for each product form in [ND-2500](#). Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in [ND-4121.1](#). Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in accordance with [ND-6114](#), except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

(b) In addition to tension testing required by the material specification, forgings produced for flat heads and tubesheets with integrally forged hubs, for butt welding to the adjacent shell, head, or other pressure part, shall have tensile tests performed in accordance with [ND-4243.1](#). The tension test specimen shall be located in accordance with [ND-4243.1](#) and [Figure ND-4243.1-1](#).

ND-2124 Material Size Ranges and Tolerances

(a) Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in this Subsection. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-3856).

(b) Plate material shall be ordered not thinner than the design thickness. Components, except for piping, made of plate furnished with an undertolerance of not more than the smaller value of 0.01 in. (0.3 mm), or 6% of the ordered thickness may be used at the full Design Pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.01 in. (0.3 mm) or 6% under the design thickness.

(c) If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Section II, Part D. After the minimum wall thickness is determined ([ND-3641.1](#)), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

ND-2125 Materials in Combination¹

A component may be constructed of any combination of materials permitted in [ND-2000](#), provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

ND-2126 Finned Tubes

ND-2126.1 Integrally Finned Tubes. Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Tables 1A and 1B, Section II, Part D, Subpart 1 and to all of the special requirements of this Article that apply to that product form. In addition, the following requirements shall apply:

(a) The requirements of [ND-2550](#) shall be met by the tube before finning.

(b) The tubes, after finning, shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The allowable stress values shall be those given in Tables 1A and 1B, Section II, Part D, Subpart 1 for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi (1.7 MPa) without evidence of leakage. The test method, such as immersion of the tube under water during the test, shall permit visual detection of any leakage.

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure that permits complete examination of the tube for leakage.

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable.

ND-2126.2 Welded Finned Tubes. Welded finned tubes may be made from P-No. 1 and P-No. 8 tubular products (pipe or tubing) that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Table 1A, and to all of the special requirements of this Article that apply to that product form. Heat transfer fins shall be of the same P-Number as the tube and shall be attached by a machine welding process, such as the electric resistance welding or the high frequency resistance welding process. In addition, the following requirements shall apply:

(a) The heat transfer fins need not be certified material. The material for the heat transfer fins shall be identified and suitable for welding, however, Certified Material Test Reports are not required.

(b) The machine welding process used to weld the heat transfer fins to the tubular material shall be performed in accordance with a Welding Procedure Specification.

(c) The procedure qualification shall require that a minimum of 12 cross sections through the weld zone shall be examined at 5X minimum magnification. There shall be

no cracks in the base material or weld; and the weld penetration shall be limited to 20% of the nominal tube wall thickness.

(d) For P-No. 1 material, the weld that attaches the fins to the tubing shall be heat treated after welding to a minimum temperature of 1,000°F (540°C).

(e) The fin is not considered to provide any support to the tube under pressure loading.

ND-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Table 3, Section II, Part D, Subpart 1. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Table 3, Section II, Part D, Subpart 1.

(b) The use of washers is optional. When used, they shall be made of wrought material, with mechanical properties compatible with the nuts with which they are to be employed.

ND-2130 CERTIFICATION OF MATERIAL

All materials used in construction of components shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure retaining material, except as provided by NCA-3861, and for small products as defined in ND-2610(c). A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

ND-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see ND-2400.

ND-2150 MATERIAL IDENTIFICATION

All material shall be marked in accordance with the marking requirements of the material specification. Material for small items shall be controlled during manufacture and installation of the component so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (ND-4122).

ND-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications

(NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

ND-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

ND-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

ND-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure retaining function (see ND-1130) welded to pressure retaining material shall meet the requirements of NF-2000.

(b) Material not performing a pressure retaining function and not in the component support load path (non-structural attachments) welded at or within $2t$ of the pressure retaining portion of the component need not comply with ND-2000 or NF-2000 provided the requirements of ND-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

ND-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

ND-2210 HEAT TREATMENT REQUIREMENTS

ND-2211 Test Coupon Heat Treatment for Ferritic Material²

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the

component, except that test coupons and specimens for P-No. 1, Group Nos. 1 and 2, material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated where nominal thickness for flanges refers to the wall thickness at the weld joint to the pipe or component. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

ND-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

ND-2212.1 Cooling Rates. Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (ND-2223.3 and ND-2226). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in ND-2212.2 or one of the specific procedures described in ND-2220 shall be used for each product form.

ND-2212.2 General Procedures. One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with ND-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used that can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($\frac{1}{4}t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in ND-2220 are used, faster cooling rates at the edges may be compensated for by

(1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (that completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

ND-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

ND-2221 General Requirements

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this Subarticle. References to dimensions signify nominal values.

ND-2222 Plates

ND-2222.1 Orientation and Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

ND-2222.2 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with ND-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

ND-2223 Forgings and Forged Bars

ND-2223.1 Location of Test Coupons. The longitudinal axis of the test specimens shall be located at least $\frac{1}{4}t$ from the nearest surface. The gage length of tension test specimens and the area under the notch of Charpy specimens shall be located at a distance of at least t from any second surface to compensate for faster cooling rates at the edges. The variable t is the maximum nominal heat-treated thickness or cross section of the forging. Either of the following methods may be used to obtain the required distance from any second surface.

(a) *Method A.* A thermal buffer ring, at least $t \times t$ in cross section, or sections of such a ring at least $3t$ in length, shall be welded to the test end of a forging prior to heat treatment for mechanical properties. The buffer material may be any weldable carbon or low alloy steel and shall be joined to the forging with a partial penetration-type weld that completely seals the buffered surface. The test

coupons shall be removed from the forging in the region buffered by the ring or ring segments. If ring segments are used, the test coupons shall be removed from the forging in the area under the center one-third of the buffer ring segment length. In either case, the longitudinal axis of the test specimens shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface of the forging, and at least $\frac{1}{4}t$ from a quenched surface of the forging.

(b) *Method B.* Thermal insulation or other thermal barriers shall be used during the heat treatment adjacent to the product surface where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen location is no faster than that attained by the method described in ND-2223.1, or Method A. Test specimen locations shall be the same as stated for Method A. Details of thermal insulation, including substantiation data, shall be available from the agency performing the heat treatment.

ND-2223.2 Very Thick and Complex Forgings. For forgings that are very thick and complex (for example, thick tubesheets, flanges, nozzles, pump and valve bodies, and other complex forgings that are contour-shaped or machined essentially to the inservice configuration prior to heat treatment), the purchaser shall specify the surfaces of the finished product subjected to significant tension loading in service. The test specimens shall be removed from a prolongation or other stock from the forging or from a test forging in accordance with ND-2223.4. They shall be taken so that the longitudinal center line is at a distance below the nearest heat treated surface equivalent to at least the greatest distance that the significantly stressed location is from the nearest heat treated surface. The gage length of tension test specimens and the area under the notch of Charpy specimens, shall be located at least twice this distance from any second heat treated surface. These respective locations, however, shall not be closer than $\frac{3}{4}$ in. (19 mm) from the nearest surface and $1\frac{1}{2}$ in. (38 mm) from any second surface.

ND-2223.3 Multiple Forgings.

(a) *Multiple Forgings Separated Into Identical Individual Forgings Prior to Quenching and Tempering Treatment.* At least one individual forging from each multiple forging in each heat treating lot shall be tested using the test specimen locations of ND-2223.1 or ND-2223.2 as specified on the purchase order, except that test specimens located at midlength may be closer to the ends of the production forging than the specified distance to the second surfaces. All forgings shall be quenched simultaneously and tempered in the same furnace charge. All forgings from the multiple shall be Brinell hardness tested after heat treatment and forgings not tested for mechanical properties shall have a BHN within 20 points of the BHN of the forging that has been tested for mechanical properties.

(b) *Multiple Forgings Separated After Quench and Temper Treatment.* The multiple forging shall have an integral prolongation and when the heat treated length of the multiple (excluding test metal) exceeds 80 in. (2 000 mm), each end shall have an integral prolongation. Test specimen locations shall meet the requirements of ND-2223.1 or ND-2223.2 as specified on the purchase order.

ND-2223.4 Forgings Tested With Representative, Separately Forged Test Pieces. Separately forged test pieces shall be used. Test specimens shall be taken from a representative separate test forging made from the same heat of steel as the production forgings. Separate test forgings shall receive substantially the same reduction and type of hot working as the production forgings, except that a longitudinal forged bar with dimensions not less than $3t \times t$ may be used to represent a ring forging. Test forgings shall be of the same nominal thickness as the as-quenched production forgings, and shall be heat treated in the same furnace charge and under the same conditions as the production forgings. For forgings requiring impact testing, the use of representative separate test pieces shall be limited to forgings with machined weights of 1,000 lb (450 kg) or less, except in the case of forgings covered by ND-2223.1. Test specimen locations shall meet the requirements of ND-2223.1 or ND-2223.2 as applicable. When destructively tested production forgings are not of sufficient length to obtain the t distance from a second surface, the location from the second surface may be at midlength of the forging.

ND-2223.5 Quenched and Tempered Bars.

(a) For bars (other than those used for bolting materials) the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface. The gage length of tension test specimens and the area under the notch of Charpy specimens shall be indented at least one diameter or thickness from a heat treated end.

(b) *Bars With Thicknesses Exceeding $1\frac{1}{2}$ in. (38 mm).* For bars (other than those used for bolting materials) with diameters or thickness over $1\frac{1}{2}$ in. (38 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface. The gage length of tension test specimens and the area under the notch of Charpy specimens shall be located at least one diameter or thickness from a heat treated end.

ND-2224 Bars and Bolting Material

ND-2224.1 Bars With 2 in. (50 mm) Maximum Thickness. For bars with diameters or thicknesses 2 in. (50 mm) or less, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickness and with the midlength of the specimens at least one diameter or thickness from a heat treated end.

ND-2224.2 Bars With Thicknesses Exceeding 2 in. (50 mm). For bars with diameters or thicknesses over 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

ND-2224.3 Bolting Material. For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

ND-2225 Tubular Products

ND-2225.1 Tubular Products With 2 in. (50 mm) Maximum Thickness. For tubular products with 2 in. (50 mm) maximum wall thickness, the coupons shall be taken so that specimens shall have their longitudinal axes on a surface midway between the outside and inside surfaces and with the midlength of the specimens at least one wall thickness from a heat treated end.

ND-2225.2 Tubular Products Exceeding 2 in. (50 mm) Nominal Thickness. For tubular products with nominal wall thicknesses exceeding 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside surface and with the midlength of the specimens at least one wall thickness from a heat treated end.

ND-2225.3 Separately Produced Coupons Representing Fittings. Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of ND-2223.4 shall be met.

ND-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (50 mm), where t is the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure-retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply:

(1) The longitudinal centering of the thickness of the tension test specimen, shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (b). The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b) may be used.

(3) Where specimens are to be removed from the body of the casting, a steel thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface and $\frac{1}{4}t$ from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

ND-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

ND-2310 MATERIAL TO BE IMPACT TESTED

ND-2311 Material for Which Impact Testing Is Required

(a) Pressure retaining material shall be impact tested in accordance with the requirements of ND-2330, except that impact testing of the material described in (1) through (9) below is not a requirement of this Subsection:

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less where the thickness shall be taken as defined in (-a) through (-d) below:

(-a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(-b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(-c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(-d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;

(3) bars with a nominal cross-sectional area of 1 in.² (650 mm²) and less;

(4) all thicknesses of material for pipe, tube, fittings, pumps, and valves with a NPS 6 diameter (DN 150) and smaller;

(5) material for pumps, valves, and fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steel, including precipitation hardened austenitic Grade 660 (UNS S66286);

(7) nonferrous material;

(8) materials listed in Table ND-2311-1 in the thicknesses shown and for Lowest Service Temperatures³ equal to or more than the tabulated temperatures. This exemption does not exempt either the weld metal (ND-2430) or the welding procedure qualification (ND-4335) from impact testing.

(9) materials for components for which the Lowest Service Temperature exceeds 100°F (38°C).

(b) The Design Specification shall state the Lowest Service Temperature for the component.

ND-2320 IMPACT TEST PROCEDURES

ND-2321 Charpy V-Notch Tests

The Charpy V-notch test C_v , when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the

orientation and location of all tests performed to meet the requirements of ND-2330 shall be reported in the Certified Material Test Report.

ND-2322 Test Specimens

ND-2322.1 Location of Test Specimens. Impact test specimens shall be removed from the locations specified for tensile test specimens in the material specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end, except when the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size, except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

ND-2322.2 Orientation of Impact Test Specimens. Specimens for C_v impact tests shall be oriented as required in ND-2200 for the tensile test specimen, or, alternatively, the orientation may be in the direction of maximum stress. The notch of the C_v specimen shall be normal to the surface of the material.

ND-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

ND-2331 Pressure Retaining Material Other Than Bolting

Pressure retaining material other than bolting for vessels, tanks, piping (pipe and tubes), pumps, valves, and fittings shall be tested as required by (a) and (b) below.

(a) A Charpy V-notch test shall be performed at a temperature lower than or equal to the Lowest Service Temperature. All three specimens shall meet one of the acceptance standards applicable to the specific test method.

(1) *Charpy V-Notch Testing for the Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table ND-2331(a)-1.

(2) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table ND-2331(a)-2.

(b) Apply the procedures of (a) above to

(1) the base material;⁴

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with ND-4330; and

(3) the weld metal of ND-2431.

Table ND-2311-1
Exemptions From Impact Testing Under ND-2311(a)(8)

Material	Material Condition [Note (1)]	Lowest Service Temperature for the Thickness Shown			
		Over $\frac{5}{8}$ in. to $\frac{3}{4}$ in. (16 mm to 19 mm), Incl.	Over $\frac{3}{4}$ in. to 1 in. (19 mm to 25 mm), Incl.	Over 1 in. to $1\frac{1}{2}$ in. (25 mm to 38 mm), Incl.	Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. (38 mm to 64 mm), Incl.
SA-516 Grade 70	N	-30°F (-34°C)	-20°F (-29°C)	0°F (-18°C)	0°F (-18°C)
SA-537 Class 1	N	-40°F (-40°C)	-30°F (-34°C)	-30°F (-34°C)	-30°F (-34°C)
SA-516 Grade 70	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	-10°F (-23°C)
SA-508 Class 1	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	10°F (-12°C)
SA-508 Class 2	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	40°F (4°C)
SA-533 Grade B Class 1	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	10°F (-12°C)
[Note (3)]					
SA-216 Grades WCB, WCC	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	30°F (-1°C)
SA-299 [Note (3)]	N	[Note (2)]	[Note (2)]	[Note (2)]	20°F (-7°C)

NOTES:

(1) Material Condition letters refer to:

N : Normalize

Q & T : Quench and Temper

(2) The lowest service temperature shown in the column Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. (38 mm to 64 mm) may be used for these thicknesses.

(3) Material made to a fine grain melting practice.

ND-2333 Bolting Material

For bolting material, including studs, nuts, and bolts, a Charpy V-notch test shall be performed at a temperature equal to or less than the preload temperature or the Lowest Service Temperature, whichever is less. All three specimens shall meet the requirements of Table ND-2333-1.

ND-2340 NUMBER OF IMPACT TESTS REQUIRED**ND-2341 Plates**

A Charpy V-notch test shall be performed for each plate as heat treated. Where plates are furnished in the non-heat treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

ND-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment charge.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging or casting of 1,000 lb to 10,000 lb (450 kg to 4 500 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided

the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch. The location of C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(f) As an alternative to (e) for static castings, a separately cast coupon [ND-2226(b)(2)] may be used; one test shall be made for Charpy V-notch.

ND-2343 Bars

One test shall be made for each lot of bars with cross-sectional area greater than 1 in.² (650 mm²) where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

ND-2344 Tubular Products and Fittings

On products that are seamless or welded without filler metal, one test shall be made from each lot. On products that are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in

Table ND-2331(a)-1
Required C_v Lateral Expansion Values for
Pressure Retaining Material (Except Bolting)

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ (16) or less [Note (2)]	...	...
Over $\frac{5}{8}$ to $\frac{3}{4}$ (16 to 19), incl.	13 (0.33)	10 (0.25)
Over $\frac{3}{4}$ to 1 (19 to 25), incl.	15 (0.38)	10 (0.25)
Over 1 to $1\frac{1}{2}$ (25 to 38), incl.	20 (0.50)	15 (0.38)
Over $1\frac{1}{2}$ to $2\frac{1}{2}$ (38 to 64), incl.	25 (0.64)	20 (0.50)
Over $2\frac{1}{2}$ (64)	30 (0.75)	25 (0.64)

GENERAL NOTES:

- (a) When two base materials having different specified minimum lateral expansion values are joined, the weld impact lateral expansion requirements of the welding procedure qualification (ND-4330) shall conform to the requirements of either of the base materials.
- (b) When the weld metal tests of ND-2400 are performed to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.

NOTES:

- (1) See (a) through (d) below.
- (a) For pumps, valves, and fittings, use the largest nominal wall thickness of the connecting pipes.
- (b) For vessels and tanks, use the nominal thickness of the shell or head, as applicable.
- (c) For nozzles or other items welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections.
- (d) For flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub.
- (2) No test required.

a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

ND-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

Diameter	Weight
$1\frac{3}{4}$ in. (44 mm) and less	1,500 lb (680 kg)
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. (44 mm to 64 mm)	3,000 lb (1 350 kg)
Over $2\frac{1}{2}$ in. to 5 in. (64 mm to 125 mm)	6,000 lb (2 700 kg)
Over 5 in. (125 mm)	10,000 lb (4 500 kg)

ND-2350 RETESTS

ND-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by ND-2330, one retest at the same temperature may be conducted, provided:

(1) the average value of the test results meets the average of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable.

ND-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by ND-2330, one retest at the same temperature may be conducted, provided

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

ND-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3858.2 at least once in each 3-month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3858.2. The calibrations shall be performed using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology or any supplier of subcontracted calibration services accredited in accordance with the requirements of NCA-3126 and NCA-3853.3(c).

Table ND-2331(a)-2
Required C_v Energy Values for Pressure Retaining Material (Except Bolting)

Nominal Wall Thickness, in. (mm) [Note (1)]	Energy, ft-lb (J), for Materials of Specified Minimum Yield Strength, ksi (MPa)					
	40 ksi (275 MPa) or Below		Over 40 ksi to 55 ksi (275 MPa to 380 MPa)		Over 55 ksi to 105 ksi (380 MPa to 725 MPa)	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ (16) or less [Note (2)]	...	...	...	...	...	...
Over $\frac{5}{8}$ to $\frac{3}{4}$ (16 to 19), incl.	13 (18)	10 (14)	15 (20)	10 (14)	20 (27)	15 (20)
Over $\frac{3}{4}$ to 1 (19 to 25), incl.	15 (20)	10 (14)	20 (27)	15 (20)	25 (34)	20 (27)
Over 1 to $1\frac{1}{2}$ (25 to 38), incl.	20 (27)	15 (20)	25 (34)	20 (27)	30 (41)	25 (34)
Over $1\frac{1}{2}$ to $2\frac{1}{2}$ (38 to 64), incl.	25 (34)	20 (27)	35 (48)	30 (41)	40 (54)	35 (48)
Over $2\frac{1}{2}$ (64)	30 (41)	25 (34)	40 (54)	35 (48)	45 (61)	40 (54)

GENERAL NOTES:

- (a) When two base materials having different specified minimum energy values are joined, the weld impact energy requirements of the welding procedure qualification (ND-4330) shall conform to the requirements of either of the base materials.
- (b) When the weld metal tests of ND-2400 are performed to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:

- (1) See (a) through (d) below.
- (a) For pumps, valves, and fittings, use the largest nominal wall thickness of the connecting pipes.
- (b) For vessels and tanks, use the nominal thickness of the shell or head, as applicable.
- (c) For nozzles or other items welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections.
- (d) For flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub.
- (2) No test required.

ND-2400 WELDING MATERIAL**ND-2410 GENERAL REQUIREMENTS**

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in ND-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

- (1) welding process;
- (2) SFA specification and classification;
- (3) other identification if no SFA specification applies;
- (4) minimum tensile strength [ND-2431.1(e)] in the as-welded or heat treated condition, or both [ND-2431.1(c)];
- (5) Charpy V-notch test for material as welded, or heat treated, or both (ND-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (6) the preheat and interpass temperature to be used during welding of the test coupon [ND-2431.1(c)];
- (7) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [ND-2431.1(c)];
- (8) elements for which chemical analysis is required per the SFA specification or WPS, and ND-2432;
- (9) minimum delta ferrite (ND-2433).

Table ND-2333-1
Required C_v Values for Bolting Material

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 through 4 (25 through 100)	15 (0.38)	30 (41)
Over 4 (100)	20 (0.50)	35 (48)

ND-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslog flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by ND-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [and (b) above, respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil

shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslog flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9 000 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A *chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the

welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

ND-2430 WELD METAL TESTS

ND-2431 Mechanical Properties Test

Tensile and impact tests shall be made in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

(a) austenitic stainless steel and nonferrous welding materials;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base materials exempted from impact testing by ND-2311(a)(1) through ND-2311(a)(7) or ND-2311(a)(9) shall also be exempted from the impact testing required by this paragraph.

ND-2431.1 General Test Requirements. The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time² shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table ND-4622.1-1 or Table ND-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness

of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table ND-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) The tensile specimens, and the C_v impact specimens when required, shall be located and prepared in accordance with the requirements of SFA-5.1, or the applicable SFA Specification. Drop weight impact test specimens, when required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face, or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable requirements of ND-2321.1 and ND-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $\frac{1}{4}t$ from a surface, where t is the thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the tensile strength results shall conform to either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested when impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of ND-2330 applicable to the base material. When different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

ND-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in ND-2431.1, tensile and impact tests may be made in accordance with this subparagraph when they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing as listed in ND-2431 shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens required by ND-2331 when applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The PWHT temperatures shall be in accordance with Table ND-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr

(this qualifies PWHT of 10 hr or less). When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of ND-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5 as applicable.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the SFA specification for the applicable electrode classification.

(f) The requirements of ND-2431.1(f) shall be applicable to the impact testing of this option.

ND-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with ND-2420 and as required by the following subparagraphs.

ND-2432.1 Test Method. The chemical analysis test shall be performed in accordance with this subparagraph and Table ND-2432.1-1, and the results shall conform to ND-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the

specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld⁵ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by ND-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of ND-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-214.3 for the minimum thickness for which the Welding Procedure Specification is qualified.

ND-2432.2 Requirements for Chemical Analysis. The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, QW-442) shall be analyzed for the elements listed in Table ND-2432.2-1 and any other elements specified in the welding material specification referenced by the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition

**Table ND-2432.1-1
Sampling of Welding Materials for Chemical Analysis**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

**Table ND-2432.2-1
Welding Material Chemical Analysis**

Materials	Elements
Cr-Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb

limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in [Table ND-2432.2-1](#) but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

ND-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

ND-2433.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of [ND-2432](#) in conjunction with [Figure ND-2433.1-1](#).

(a) Calibration of magnetic instruments shall conform to AWS A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with [ND-2432.1\(c\)](#).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

ND-2433.2 Acceptance Standards. The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of [ND-2130](#) or [ND-4120](#).

ND-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

ND-2500 EXAMINATION AND REPAIR OF PRESSURE RETAINING MATERIAL

ND-2510 PRESSURE RETAINING MATERIAL

Pressure retaining material shall be examined and repaired in accordance with the material specification and as otherwise required by this Subarticle. Pressure retaining material for ASME B16.34 Special Class category valves ([ND-3513](#)) shall be examined and repaired in

accordance with the requirements therein and as otherwise required by this Subarticle. If the examination and repair requirements of this Subarticle either duplicate or exceed the ASME B16.34 requirements, then only the requirements of this Subarticle need to be met. Size exclusions of this Subarticle shall not be applied so as to reduce the examination requirements of ASME B16.34 for Special Class category valves.

ND-2530 EXAMINATION AND REPAIR OF PLATE

ND-2531 Required Examination

Plates shall be examined in accordance with the requirements of the material specification.

ND-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Examinations required by the material specification shall be performed at the time of manufacture as specified in the material specification.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required heat treatment, except for P-No. 1 material that may be examined before or after any required postweld heat treatment.

ND-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) and (b) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) If the elimination of the defect reduces the thickness of the section below the minimum required by the design, the material shall be repaired in accordance with [ND-2539](#).

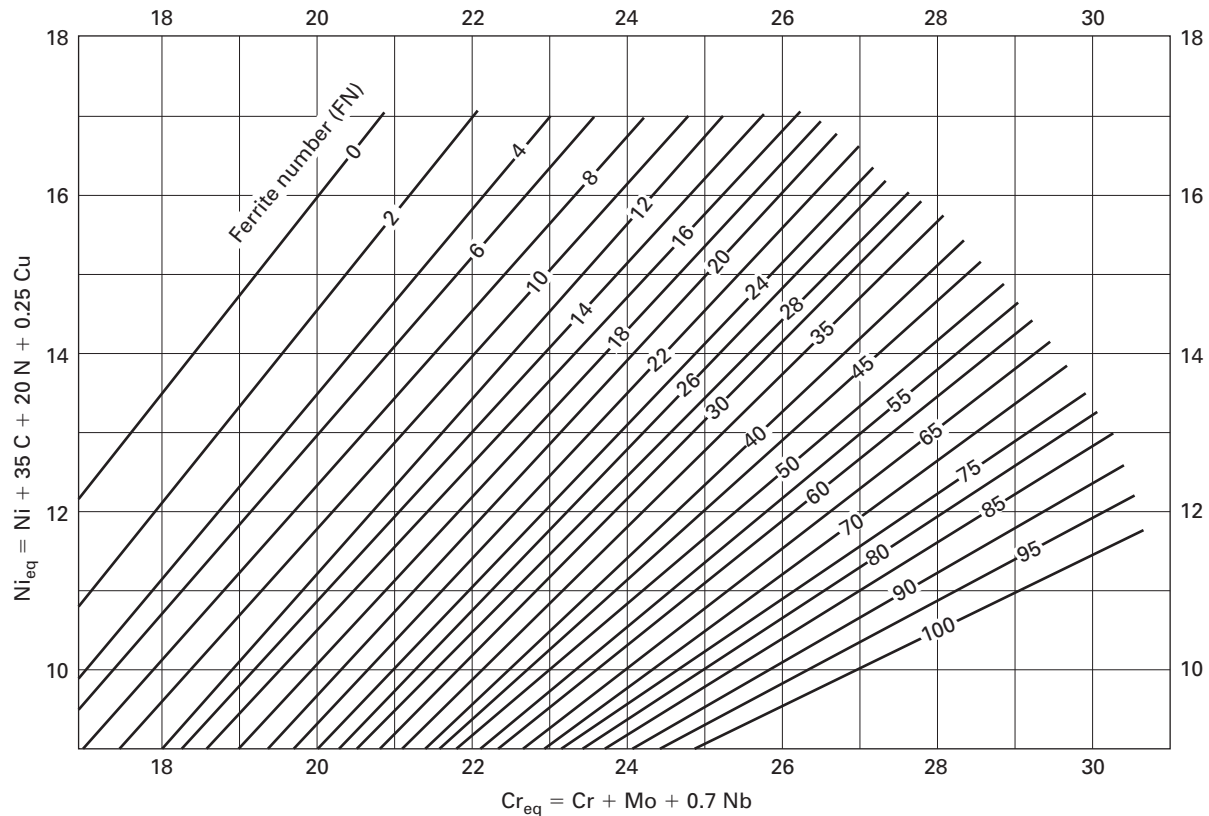
ND-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

ND-2539.1 Defect Removal. The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair ([ND-4211.1](#)).

ND-2539.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with the [ND-4000](#) and Section IX.

Figure ND-2433.1-1
Delta Ferrite Content



GENERAL NOTES:

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
- (1) GMAW welds — 0.08%, except that when self shielding flux cored electrodes are used — 0.12%
 - (2) Welds made using other processes — 0.06%.
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

ND-2539.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

ND-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (ND-2545) or by the liquid penetrant method (ND-2546). In addition, when the depth of repair cavities exceeds the lesser of $\frac{3}{8}$ in. (10 mm), or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of ND-5320. The image quality indicator (IQI) shall be based upon the section thickness of the repaired area.

ND-2539.5 Heat Treatment After Repair. The product shall be heat treated after repair in accordance with the heat treatment requirements of ND-4620.

ND-2539.6 Material Report Describing Defects and Repair. Each defect repair that is required to be radiographed shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece

shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographs.

ND-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

ND-2541 Required Examination

Forgings and bars shall be examined in accordance with the requirements of the material specification except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of ND-2545 or ND-2546, as applicable.

ND-2545 Magnetic Particle Examination

ND-2545.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

ND-2545.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications that are not relevant.

(b) Any indication in excess of the ND-2545.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

ND-2545.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.5 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $\frac{3}{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (5 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.² (4 000 mm²) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

ND-2546 Liquid Penetrant Examination

ND-2546.1 Examination Procedure. The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

ND-2546.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications that are not relevant.

(b) Any indication in excess of the ND-2546.3 acceptance standards that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

ND-2546.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.5 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $\frac{3}{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (5 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.² (4 000 mm²) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

ND-2547 Time of Examination

Acceptance examinations shall be performed as follows:

(a) Magnetic particle or liquid penetrant examination shall be performed in the finished condition.

(b) Forged and rolled bars that are to be bored or turned to form tubular products or fittings shall be examined after boring or turning, except for threaded or drilled holes.

ND-2548 Elimination of Surface Defects

(a) Unacceptable surface defects shall be removed by grinding or machining, provided the requirements of (1) through (4) below are met.

(1) The remaining thickness of the section is not reduced below that required by ND-3000.

(2) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(3) After defect elimination, the area is reexamined by the magnetic particle method in accordance with ND-2545 or the liquid penetrant method in accordance with ND-2546 to ensure that the defect has been removed or the indication reduced to an acceptable size.

(4) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant method.

(b) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy [ND-3000](#), the product shall be repaired in accordance with [ND-2549](#).

ND-2549 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the requirements of the following subparagraphs are met.

ND-2549.1 Defect Removal. The defect shall be removed or indication reduced to an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair ([ND-4211.1](#)).

ND-2549.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with [ND-4000](#) and Section IX.

ND-2549.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

ND-2549.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method ([ND-2545](#)) or by the liquid penetrant method ([ND-2546](#)). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with [ND-5000](#). The penetrometer and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness at the repaired area.

ND-2549.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the heat treatment requirements of [ND-4620](#).

ND-2549.6 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

ND-2550 EXAMINATION AND REPAIR OF SEAMLESS AND (WELDED WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

ND-2551 Required Examination

Wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of [ND-2557](#), [ND-2558](#), and [ND-2559](#) in addition to the basic material specification.

ND-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) Magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (50 mm) and less nominal thickness.

(2) Forgings and rolled bars that are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

(3) When surface examination is required all external surfaces and all accessible internal surfaces shall be examined except for bolt holes and threads.

ND-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is examined by the method that originally disclosed the defect to ensure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of [ND-3000](#), the product shall be repaired in accordance with [ND-2559](#).

ND-2559 Repair by Welding

Repair of defects shall be in accordance with [ND-2539](#), except repair by welding is not permitted on copper alloy and nickel alloy heat exchanger tubes.

ND-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

ND-2561 Required Examinations

(a) Welded (with filler metal) tubular products such as pipe made in accordance with SA-134, SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420 that are made by welding with filler metal shall be treated as materials; however, inspection by an Inspector and stamping with the Certification Mark with NPT Designator shall be in accordance with Section III requirements. In addition to the Certification Mark with NPT Designator, the numeral 3 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification, tubular products shall comply with this Article.

(c) Weld joint efficiency factors listed in Tables 1A and 1B, Section II, Part D, Subpart 1 shall apply.

(d) Tubular products and fittings that have been radiographed shall be marked to indicate that radiography has been performed. The radiographs and a radiographic report showing exposure locations shall be provided with the Certified Material Test Report.

(e) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 in accordance with NCA-5290.

ND-2567 Time of Examination

The time of examination shall be in accordance with the requirements of ND-2557.

ND-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of ND-2558.

ND-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of ND-2559. Repair welding of weld seam defects shall be in accordance with ND-4450.

ND-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article, statically and centrifugally cast products shall comply with the following subparagraphs.

ND-2571 Required Examinations

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table ND-2571-1 Class 3 castings.

(b) For cast valves furnished to ASME B16.34 special class category, examination of castings, including procedure and acceptance requirements, shall be as required by ASME B16.34.

ND-2572 Time of Nondestructive Examination

ND-2572.1 Acceptance Examinations. Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table ND-2571-1.

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses:

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 20% of the finished thickness, whichever is greater. The IQI and the reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (150 mm), castings shall be radiographed within 20% of the finished thickness. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (150 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions:

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (50 mm), acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E186. The IQI shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (50 mm) or less, the reference radiographs of ASTM E446 shall be used and the IQI shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld) from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (1) and (2) above and the IQI shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by

**Table ND-2571-1
Required Examinations**

Nominal Pipe Size	Item	Applicable Special Requirements for Class 3 Castings
Inlet piping connections of NPS 2 (DN 50) and less	Cast Pipe fittings, pump, and valves	None, except for ASME B16.34 special class category valves, which shall be in accordance with ND-2571(b) .
	Cast pressure retaining material with a Quality Factor of 0.80, excluding pipe fittings, pumps, and valves	Visual examination required
	Cast pressure retaining material with a Quality Factor of 0.85, excluding pipe fittings, pumps, and valves	Magnetic particle or liquid penetrant examination shall be performed on all external surfaces and on all accessible internal surfaces.
	Cast pressure retaining material with a Quality Factor of 1.00, excluding pipe fittings, pumps, and valves	Radiographic or ultrasonic examination required; magnetic particle or liquid penetrant examination optional
	Repair welds	(a) When magnetic particle or liquid penetrant examination of the casting is required, each repair shall be examined by the magnetic particle method or by the liquid penetrant method. (b) When radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with ND-2575 . (c) When partial radiography of a casting is required, repairs located in an area of the casting which is not covered by radiography need only be examined by the magnetic particle method or by the liquid penetrant method.
Inlet piping connections over NPS 2 (DN 50)	Cast valves	None, except for ASME B16.34 special class category valves, which shall be in accordance with ND-2571(b) .
	Cast pressure retaining material with a Quality Factor of 0.80, excluding valves	Visual examination required
	Cast pressure retaining material with a Quality Factor of 0.85, excluding valves	Magnetic particle or liquid penetrant examination shall be performed on all external surfaces and on all accessible internal surfaces.
	Cast pressure retaining material with a Quality Factor of 1.00, excluding valves	Radiographic or ultrasonic examination required, magnetic particle or liquid penetrant examination optional
	Repair welds	(a) When magnetic particle or liquid penetrant examination of the casting is required, each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. (b) When radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall be radio-graphed in accordance with ND-2575 . (c) When partial radiography of a casting is required, repairs located in an area of the casting which is not covered by radiography need only be examined by the magnetic particle method or by the liquid penetrant method.

the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (50 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machine surfaces, except threaded surfaces and small deep holes, shall also be examined by magnetic particle or liquid penetrant methods.

ND-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

ND-2573.1 Defect Removal. The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

ND-2573.2 Repair by Welding. The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

ND-2573.3 Qualification of Welding Procedures and Welders. Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by ND-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by ND-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

ND-2573.4 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

ND-2573.5 Examination of Repair Welds.

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of ND-2577 or by the liquid penetrant method in accordance with the requirements of ND-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser or $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair, except that weld slag,

including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The IQI and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repaired area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for pumps and valves with inlet piping connections NPS 2 (DN 50) and less.

ND-2573.6 Heat Treatment After Repairs. The material shall be heat treated after repair in accordance with the heat treatment requirements of ND-4620, except that the heating and cooling rate limitations of ND-4623 do not apply.

ND-2573.7 Elimination of Surface Defects. Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is reexamined by the magnetic particle method in accordance with ND-2577 or the liquid penetrant method in accordance with ND-2576 to ensure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with ND-2539.

ND-2573.8 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs, when radiography is specified in the order for the original casting.

ND-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-571.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of ND-2574 and shall make the procedure available for approval upon request.

ND-2574.1 Acceptance Standards.

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated.

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm);

(2) Quality Level 3 for thicknesses 2 in. to 4 in. (50 mm to 100 mm);

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm)

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area [Note (1)], [Note (2)], [Note (3)]
1	1.5 in. (38 mm)
2	2.0 in. (50 mm)
3	2.5 in. (64 mm)
4	3.0 in. (75 mm)

NOTES:

- (1) The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which a continuous indication exceeding the transfer corrected distance amplitude curve is maintained.
- (2) Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point
- (3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. through 4 in. (50 mm through 100 mm), and greater than permitted for Quality Level 3 for thicknesses greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

ND-2575 Radiographic Examination

ND-2575.1 Examination. Cast pressure retaining materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either radiographic or ultrasonic methods, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by the radiographic method.

ND-2575.2 Extent. Radiographic examination shall be performed on pressure retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Figure ND-2575.2-1.

ND-2575.3 Examination Requirements. Radiographic examination shall be performed in accordance with Section V, Article 2, Mandatory Appendix VII, Radiographic Examination of Metallic Castings, with the following modifications:

(a) The geometric unsharpness limitations of T-274.2 need not be met.

(b) The examination procedure or report shall also address the following:

(1) type and thickness of filters, if used

(2) for multiple film technique, whether viewing is to be single or superimposed, if used

(3) blocking or masking technique, if used

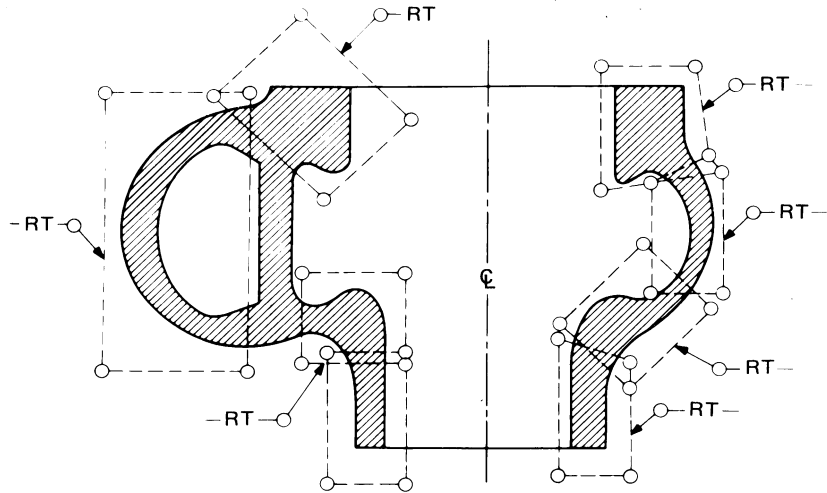
(4) orientation of location markers

(5) description of how internal markers, when used, locate the area of interest

(c) The location of location markers (e.g., lead numbers or letters) shall be permanently stamped on the surface of the casting in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by ND-2575.2 has been obtained. For castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state and a radiographic exposure map shall be provided.

ND-2575.6 Acceptance Criteria. Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E446, Reference Radiographs for Steel Castings up to 2 in. (50 mm) in Thickness; ASTM E186, Reference Radiographs for Heavy-Walled [2 in. to 4½ in. (50 mm to 114 mm)] Steel Castings; or ASTM E280, Reference Radiographs for Heavy Walled [4½ in. to 12 in. (114 mm to 300 mm)] Steel Castings, as applicable for the thickness being radiographed, except Category D, E,

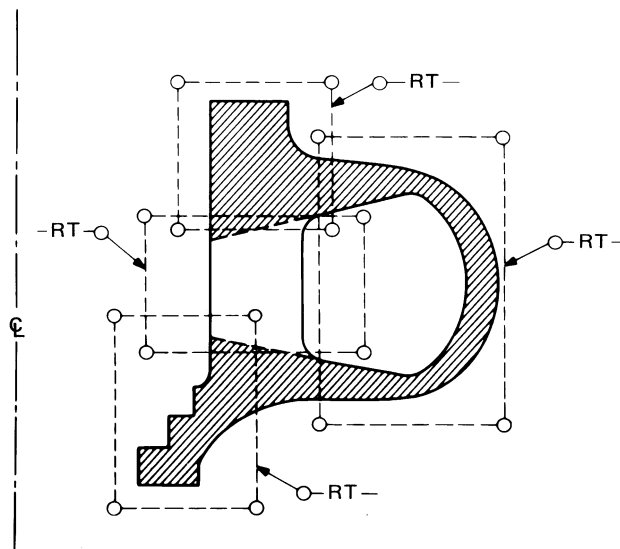
Figure ND-2575.2-1
Typical Pressure Retaining Parts of Pumps and Valves



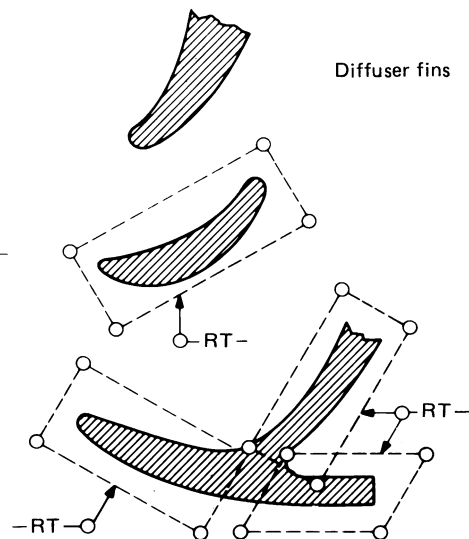
(a) Typical Volute-Type Pump Case

GENERAL NOTES:

- (a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
- (b) For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: — RT — ⌀
- (c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.

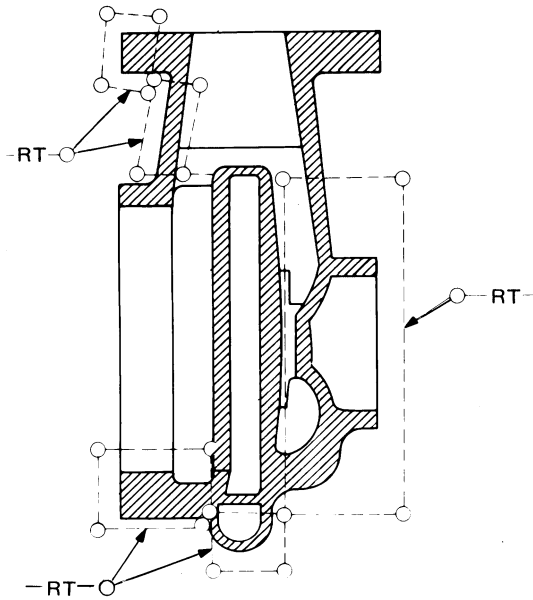


(b) Typical Diffuser-Type Pump Case

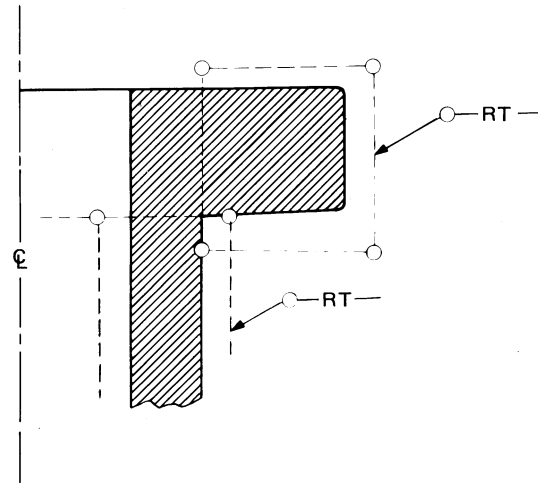


(c) Typical Diffuser-Type Pump Case Detail

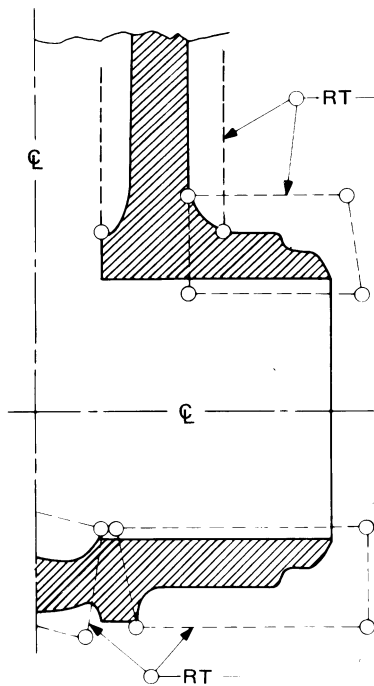
Figure ND-2575.2-1
Typical Pressure Retaining Parts of Pumps and Valves (Cont'd)



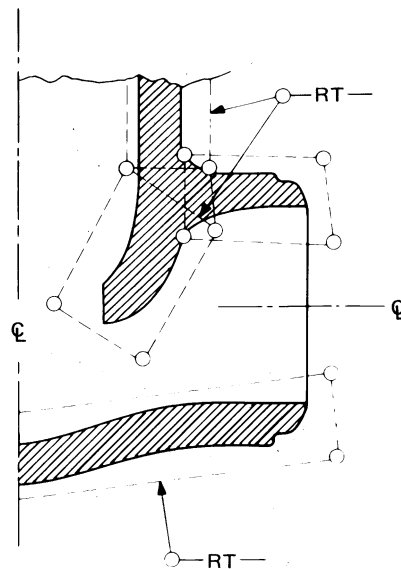
(d) Typical Single Stage Pump Case



(e) Typical Flange



(f) Typical Gate Valve



(g) Typical Globe Valve

F, or G defects are not acceptable. The requirements of ASTM E280 shall apply for castings over 12 in. (300 mm) in thickness.

ND-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.5 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $\frac{3}{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (5 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more indications in any 6 in.² (4 000 mm²) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

ND-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be

nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those that are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.5 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $\frac{3}{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (5 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.² (4 000 mm²) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

ND-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

ND-2581 Requirements

All bolting materials shall be visually examined in accordance with ND-2582.

ND-2582 Visual Examination

Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

ND-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

ND-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by ND-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these

products, the Certificate Holder's Quality Control System (NCA-8120) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 in.² (650 mm²) and less;

(4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less;

(5) material exempted by ND-2121(c).

ND-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications of Table NCA-7100-1.

ARTICLE ND-3000 DESIGN

ND-3100 GENERAL DESIGN

ND-3110 LOADING CRITERIA

(13) ND-3111 Loading Conditions

The loadings that shall be taken into account in designing a component shall include, but are not limited to, those in (a) through (g) below:

- (a) internal and external pressure;
- (b) impact loads, including rapidly fluctuating pressures;
- (c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;
- (d) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;
- (e) wind loads, snow loads, vibrations, and earthquake loads where specified;
- (f) reactions of supporting lugs, rings, saddles, or other types of supports;
- (g) temperature effects.

ND-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

ND-3112.1 Design Pressure. The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a).

ND-3112.2 Design Temperature. The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in conjunction with Design Pressure. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in Tables 1A and 1B, Section II, Part D, Subpart 1 nor exceed the temperature limitations specified elsewhere in this Subsection.

ND-3112.3 Design Mechanical Loads. The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

ND-3112.4 Design Allowable Stress Values.

(a) Allowable stresses for design for material are listed in Tables 1A and 1B, Section II, Part D, Subpart 1. The material shall not be used at metal and design temperatures that exceed the temperature limit in the applicability column for which stress values are given. The values in the Tables may be interpolated for intermediate temperatures.

(b) The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell 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 from ND-3133.6(b).

(c) The wall thickness of a component computed by the rules of this Subsection shall be determined so that the general membrane stress, due to any combination of mechanical loadings listed in ND-3111 which are expected to occur simultaneously during a condition of loading for which Service Level A is designated for the component, does not exceed⁶ the maximum allowable stress value permitted at the Design Temperature unless specifically permitted in other paragraphs of this Subsection. These allowable stress values may be interpolated for intermediate Design Temperatures.

(d) When welding or brazing is performed on nonferrous material having increased tensile strength produced by hot or cold working, the allowable stress value for the material in the annealed condition shall be used for the joint design. One piece heads and seamless shells may be designed on the basis of the actual temper of the material.

(e) When welding or brazing is done on nonferrous material having increased tensile strength produced by heat treatment, the allowable stress value for the material in the annealed condition shall be used for the joint design unless the stress values for welded construction are given in Tables 1A and 2B, Section II, Part D, Subpart 1 or unless the finished construction is subjected to the same heat treatment as that which produced the temper in the *as-received* material, provided the welded joint and the base metal are similarly affected by the heat treatment.

ND-3113 Service Conditions

(a) Each condition to which the components may be subjected shall be classified in accordance with NCA-2142(b) designated in the Design Specifications in such detail as will provide a complete basis for design in accordance with this Article.

(b) When any Level B, Level C, or Level D Conditions are specified in the Design Specifications, they shall be evaluated in accordance with NCA-2140 and in compliance with the applicable design rules and stress limits of this Article.

ND-3115 Casting Quality Factors

A casting quality factor shall be applied to the allowable stress values for cast material given in Tables 1A, 1B, 2B, and 3, Section II, Part D, Subpart 1.

ND-3120 SPECIAL CONSIDERATIONS**ND-3121 Corrosion**

(a) Materials subject to thinning by corrosion, erosion, mechanical, or other environmental effects shall have provision made for these effects in the Design Specifications by indicating the increase in the thickness of the material over that determined by the design equations. Other suitable methods of protection may be used. Material added for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas.

(b) Except as required in (c) below, 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.

(c) Vessels constructed of materials listed in Tables 1A and 2B, Section II, Part D, Subpart 1 with a required minimum thickness of less than $\frac{1}{4}$ in. (6 mm) that are to be used in compressed air service, steam service, or water service shall be provided with a corrosion allowance on the metal surface in contact with such substance of not less than one-sixth of the calculated plate thickness.

(d) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a minimum. When telltale holes are provided, they shall be at least $\frac{3}{16}$ in. (5 mm) in diameter and have a depth not less than 80% of the thickness required for a section of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

ND-3122 Cladding

The rules of this paragraph apply to the design of clad components constructed of material permitted in Tables 1A and 2B, Section II, Part D, Subpart 1.

ND-3122.1 Stresses. No structural strength shall be attributed to the cladding.

ND-3122.2 Design Dimensions. The dimensions given in (a) and (b) below shall be used in the design of the component.

(a) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

ND-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this Article, caution shall be exercised in construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion in order to avoid difficulties in service.

ND-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

ND-3130 GENERAL DESIGN RULES**ND-3131 General Requirements**

The design shall be such that the design rules of this Article are satisfied for all configurations and loadings using the maximum allowable stress values S of Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 in the various equations and including the use of the standard products listed in Table NCA-7100-1.

ND-3131.1 Design Reports. The N Certificate Holder is required to provide a Design Report as part of the responsibility for achieving structural integrity of the component. The Design Report shall be certified when required by NCA-3550.

ND-3131.2 Proof Tests to Establish Maximum Allowable Pressure. When the configuration of a component is such that the stresses resulting from internal or external pressure cannot be determined with adequate accuracy by the rules of this Article, the maximum allowable pressure shall be determined by proof testing in accordance with the rules of ND-6900, except for piping as otherwise provided in this Article.

ND-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NCA-7100-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

ND-3133 Components Under External Pressure

ND-3133.1 General. Rules are given in this paragraph for determining the thickness under external pressure loading in spherical shells, conical sections, cylindrical shells with or without stiffening rings, formed heads, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells and hemispherical heads are given in Section II, Part D, Subpart 3.

ND-3133.2 Nomenclature. The symbols used in this paragraph are defined as follows:

- A = factor determined from Figure G, Section II, Part D, Subpart 3 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 ND-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.
- A_s = cross-sectional area of a stiffening ring
- B = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi (MPa)
- D_L = outside diameter at large end of conical section under consideration
- D_o = outside diameter of the cylindrical shell course, head skirt, or tube under consideration
- $D_o/2h_o$ = 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 ND-3332.2-1)
- D_s = outside diameter at small end of conical section under consideration
- E = modulus of elasticity of material at Design Temperature. For external pressure and axial compression 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.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Table TM, Section II, Part D, Subpart 2 for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
- 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)

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

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

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

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

K_1 = factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table ND-3332.2-1)

L = total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:

(a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings (excluding conical heads and sections);

(b) the distance between cone-to-cylinder junctions for vessels with a cone or conical head if there are no stiffening rings;

(c) the greatest center-to-center distance between any two adjacent stiffening rings;

(d) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head (excluding conical heads and sections), all measured parallel to the axis of the vessel;

(e) the distance from the first stiffening ring in the cylinder to the cone-to-cylinder junction; or

(f) the axial length of the conical heads and sections as given in ND-3133.4(e), and Appendix XXII.

L_e = equivalent length of conical section
 $= (L/2)(1 + D_s/D_L)$

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 component. A line of support is

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

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line;

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

(d) a cone-to-cylinder junction.

P = external Design Pressure, (gage or absolute, as required)

P_a = allowable external pressure, (gage or absolute, as required)

R = inside radius of cylindrical shell or tubular product in the corroded condition

R_o = for hemispherical heads, the outside radius in the corroded condition

= for ellipsoidal heads, the equivalent outside spherical radius taken as $K_1 D_o$ in the corroded condition

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

S' = the lesser of twice the allowable stress at design metal temperature from Tables 1A and 1B, Section II, Part D, Subpart 1, or 0.9 times the tabulated yield strength at design metal temperature from Table Y-1, Section II, Part D, Subpart 1

T = minimum required thickness of cylindrical shell or tube, spherical shell, or formed head after forming, in the corroded condition

T_e = effective thickness of conical section

= $T \cos \alpha$

T_n = nominal thickness used, less corrosion allowance, of a cylindrical shell or tube

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

ND-3133.3 Cylindrical Shells and Tubular Products.

The thickness of cylinders under external pressure shall be as determined by the procedure given in (a) or (b) below.

(a) 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 Figure G, Section II, Part D, Subpart 3 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 $L/D_o < 0.05$, enter the chart at a value of L/D_o of 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 . From this point of intersection move vertically downward to determine the value of factor A .

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. 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 B .

Step 6. Using this value of B , calculate the value of the maximum allowable external 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:

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

Step 8. 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 of P_a is obtained that is equal to or greater than P .

(b) Cylinders having D_o/T values < 10 :

Step 1. Using the same procedure as given in (a) above, 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:

$$P_{a2} = \frac{2S'}{(D_o/T)} \left[1 - \frac{1}{(D_o/T)} \right]$$

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 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 .

ND-3133.4 Spherical Shells and Formed Heads. (13)

(a) **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 procedure given in **Steps 1** through **6**.

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. Interpolation may be made between lines for intermediate temperatures. 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. 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 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 for the Design Temperature, the value of P_a can be calculated using the following equation:

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

Step 6. Compare P_a obtained in [Step 4](#) or [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 .

(b) 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 (a) above for determining the thickness for a spherical shell.

(c) 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 equation:

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

Step 2. Using the value of A calculated in [Step 1](#), follow the same procedure as that given for spherical shells in (a) [Steps 2](#) through [6](#) above.

(d) 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 (c) above, using the appropriate value for R_o .

(e) Conical Heads and Sections. 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 be determined in accordance with the following subparagraphs.

(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 Figure G, Section II, Part D, Subpart 3 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 . From this point of intersection move vertically downward to determine the value of factor A .

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 [ND-3112.2](#)). 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 .

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

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

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 equation:

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

Step 8. Compare the calculated value of P_a obtained in [Step 6](#) or [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 reinforcement of the cone-to-cylinder juncture according to Appendix XXII.

(-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 equation:

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

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 equation:

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

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

$$P_{a2} = \frac{2S'}{(D_L/T_e)} \left[1 - \frac{1}{(D_L/T_e)} \right]$$

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 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 reinforcement of the cone-to-cylinder juncture according to Appendix XXII.

(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 [ND-3325](#)).

(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.

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

(1) For sketch (c) in [Figure ND-3133.4-1](#)

$$L_e = r_1 \sin \theta_1 + \frac{L}{2} \left(\frac{D_L + D_s}{D_{Ls}} \right)$$

(2) For sketch (d) in [Figure ND-3133.4-1](#)

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin \theta_2 + \frac{L}{2} \left(\frac{D_L + D_s}{D_L} \right)$$

(3) For sketch (e) in [Figure ND-3133.4-1](#)

$$L_e = r_1 \sin \theta_1 + r_2 \frac{D_{ss}}{D_{Ls}} \sin \theta_2 + \frac{L}{2} \left(\frac{D_L + D_s}{D_{Ls}} \right)$$

(g) 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.

(h) The required length of skirt on heads convex to pressure shall comply with the provisions of [ND-3324.5\(c\)](#), and [ND-3324.5\(i\)](#) for heads concave to pressure.

(i) Openings in heads convex to pressure shall comply with the requirements of [ND-3330](#).

(j) When necessary, provisions shall be made to vessels and heads to prevent overstressing and excessive distortion due to external loads other than pressure and temperature (see [ND-3111](#)).

ND-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two equations:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{14}$$

$$I'_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

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. Stiffening rings shall be designed to preclude lateral buckling.

(b) The available moment of inertia I or I' 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_n are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s . Then calculate factor B , psi, using the following equation:

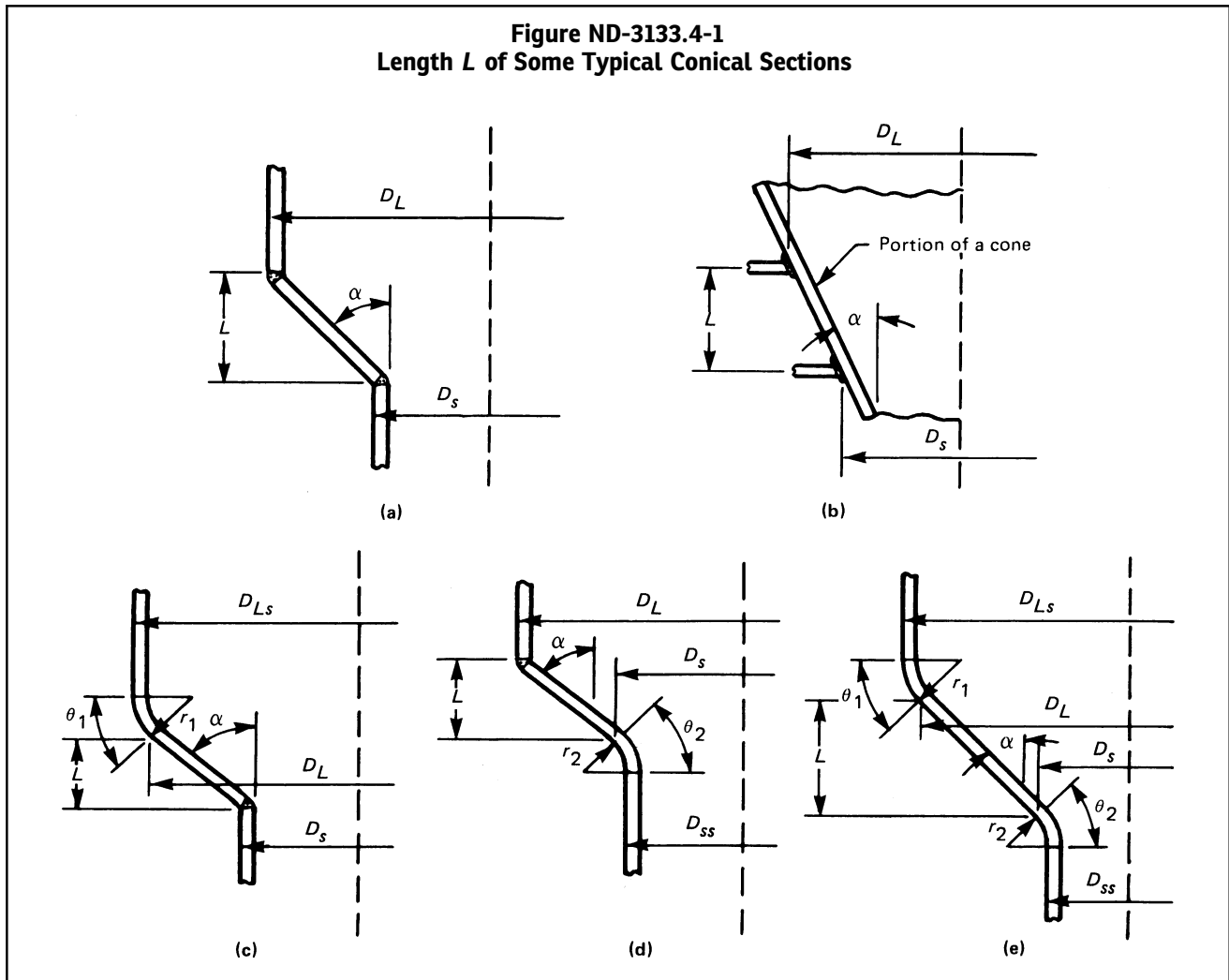
$$B = 3/4 \left(\frac{PD_o}{T_n + A_s / L_s} \right)$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 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](#) or [5](#) 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 .

Figure ND-3133.4-1
Length L of Some Typical Conical Sections



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 equation

$$A = 2B/E$$

Step 6. Compute the value of the required moment of inertia from the equations for I_s or I_s' above.

Step 7. Calculate the available moment of inertia I or I' of the stiffening ring using the section corresponding to that used in [Step 6](#).

Step 8. If the required moment of inertia is greater than the moment of inertia for the section selected in [Step 1](#), a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in [Step 1](#), that section should be satisfactory.

(c) For fabrication and installation requirements for stiffening rings, see [ND-4430](#).

ND-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive area to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) and (b) below:

(a) the S value for the applicable material at Design Temperature given in Tables 1A and 1B, Section II, Part D, Subpart 1;

(b) the value of the factor B determined from the applicable chart in Section II, Part D, Subpart 3. The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in [Steps 1](#) through [5](#).

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

$$A = \frac{0.125}{(R/T)}$$

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. Interpolation may be made between lines for intermediate temperatures. 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. 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 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:

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

Step 5. Compare the value of B determined in [Steps 3](#) or [4](#) with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . 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. The joint efficiency for butt welded joints may be taken as unity.

ND-3133.7 Tubes and Pipes When Used as Tubes.

The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with [Figure ND-3133.7-1](#).

ND-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in [ND-1130](#) shall meet the stress limits of the component.

(b) The design of the component shall include consideration of the interaction effects and loads transmitted through the attachment to and from the pressure retaining portion of the component.

(c) Beyond $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material, the appropriate design rules of NF-3000 may be used as a substitute for the design rules of [ND-3000](#) for portions of attachments that are in the component support load path.

(d) Nonstructural attachments shall meet the requirements of [ND-4435](#).

ND-3300 VESSEL DESIGN

ND-3310 GENERAL REQUIREMENTS

Class 3 vessel requirements as stipulated in the Design Specifications (NCA-3250) shall conform to the design requirements of this Article.

ND-3320 DESIGN CONSIDERATIONS

ND-3321 Stress Limits for Design and Service Loadings

Stress⁷ limits for Design and Service Loadings are specified in [Table ND-3321-1](#). The symbols used in [Table ND-3321-1](#) are defined as follows:

S = allowable stress value given in Tables 1A and 1B, Section II, Part D, Subpart 1. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress. This stress is the same as σ_m , except that it includes the effect of discontinuities.

σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

Typical examples of locations for which σ_b , σ_L , and σ_m are applicable are shown in [Table ND-3321-2](#).

ND-3322 Special Considerations

The provisions of [ND-3120](#) apply.

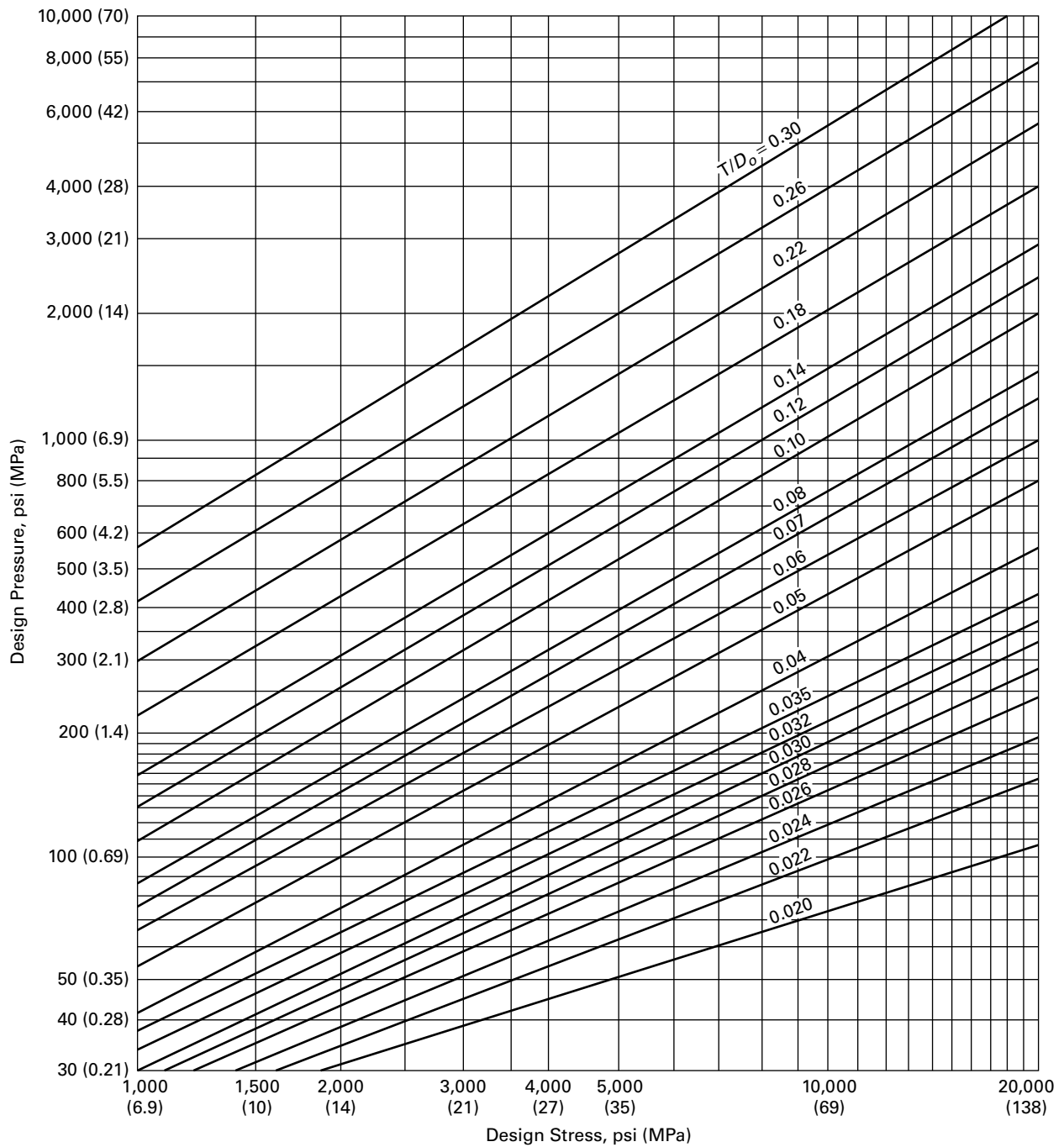
ND-3323 General Design Rules

The provisions of [ND-3130](#) apply except as modified by the rules of this Subarticle. In case of conflict, this Subarticle governs the design of vessels.

ND-3324 Components Under Internal Pressure

ND-3324.1 General Requirements. Equations are given for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, torispherical, conical, toriconical, and hemispherical heads. Provision shall be made for any of the other loadings listed in [ND-3111](#) when such loadings are specified.

Figure ND-3133.7-1
Chart for Determining Wall Thickness of Tubes Under External Pressure



GENERAL NOTE: For welded tubes or pipes, use the design stress for seamless material.

Table ND-3321-1
Stress Limits for Design and Service Loadings

Service Limit	Stress Limits [Note (1)]
Design and Level A	$\sigma_m \leq 1.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5 S$
Level B	$\sigma_m \leq 1.10 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$
GENERAL NOTE: See ND-3321.1 for definitions of symbols.	
NOTE: (1) These limits do not take into account either local or general buckling which might occur in thin wall vessels.	

ND-3324.2 Nomenclature. The symbols used in this paragraph and Figure ND-3324.2-1 are defined as follows:

- 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_o = outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis
- $D/2h$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table ND-3324.2-1
- D_1 = 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
- E = joint efficiency for, or the efficiency of, appropriate joint in the shell or head; for hemispherical heads this includes head-to-shell joints. For welded construction use the value of E specified in ND-3352. For seamless heads use $E = 1$, except for hemispherical heads furnished without a skirt, in which case the head-to-shell joint must be considered.
- L = inside spherical or crown radius for torispherical and hemispherical heads
- $L = K_1 D$ for ellipsoidal heads in which K_1 is obtained from Table ND-3332.2-1
- L_o = outside spherical or crown radius

h = one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line (head-bend line)

K = a factor in the equations for ellipsoidal heads depending on the head proportion $D/2h$ (Table ND-3324.2-1)

P = Design Pressure

R = inside radius of the shell course under consideration before corrosion allowance is added

R_o = outside radius of the shell course under consideration

r = inside knuckle radius

S = maximum allowable stress value (Tables 1A and 1B, Section II, Part D, Subpart 1)

t = minimum required thickness of shell or head after forming, exclusive of corrosion allowance

α = one-half of the included apex angle of the cone at the center line of the head, deg

ND-3324.3 Cylindrical Shells. The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) *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 equations shall apply:

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

(b) *Longitudinal Stress (Circumferential Joints).* When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following equations shall apply:

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

(c) *Thickness of Cylindrical Shells.* The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{SE + 0.4P} \quad \text{or} \quad P = \frac{SEt}{R_o - 0.4t}$$

(d) *Thick Cylindrical Shells*

(1) *Circumferential Stress (Longitudinal Joints).* When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when P exceeds $0.385SE$, the following equations shall apply. When P is known and t is desired

$$t = R(Z^{1/2} - 1) = R_o \frac{Z^{1/2} - 1}{Z^{1/2}}$$

where

$$Z = \frac{SE + P}{SE - P}$$

Table ND-3321-2
Classification of Stress in Vessels for Some Typical Cases

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	σ_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	σ_L Q [Note (1)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section.	σ_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section.	σ_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	σ_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	σ_m σ_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	σ_L [Note (2)] Q
Flat head	Center region	Internal pressure	Membrane Bending	σ_m σ_b
	Junction to shell	Internal pressure	Membrane Bending	σ_L [Note (1)] Q
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section) Bending (averaged through width of ligament, but gradient through plate) Peak	σ_m σ_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

Table ND-3321-2
Classification of Stress in Vessels for Some Typical Cases (Cont'd)

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Nozzle	Within the limits of reinforcement defined by ND-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	σ_m σ_m
		Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	σ_m
	Outside the limits of reinforcement defined by ND-3334	Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane Bending	σ_L σ_b
		Pressure and all external loads and moments	Membrane Bending Peak	σ_L Q F
	Nozzle wall	Gross structural discontinuities	Local membrane Bending Peak	σ_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temp. distribution [Note (3)]	Equivalent linear stress [Note (4)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

GENERAL NOTE: Q and F classifications of stresses refer to other than Design Condition.

NOTES:

- (1) If the bending moment at the edge is required to maintain the bending stress in the middle within acceptable limits, the edge bending is classified as σ_b . Otherwise, it is classified as Q .
- (2) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (3) Consider possibility of thermal stress ratchet.
- (4) Equivalent linear stress is defined as the linear distribution that has the same net bending moment as the actual stress distribution.

Figure ND-3324.2-1
Principal Dimensions of Typical Heads

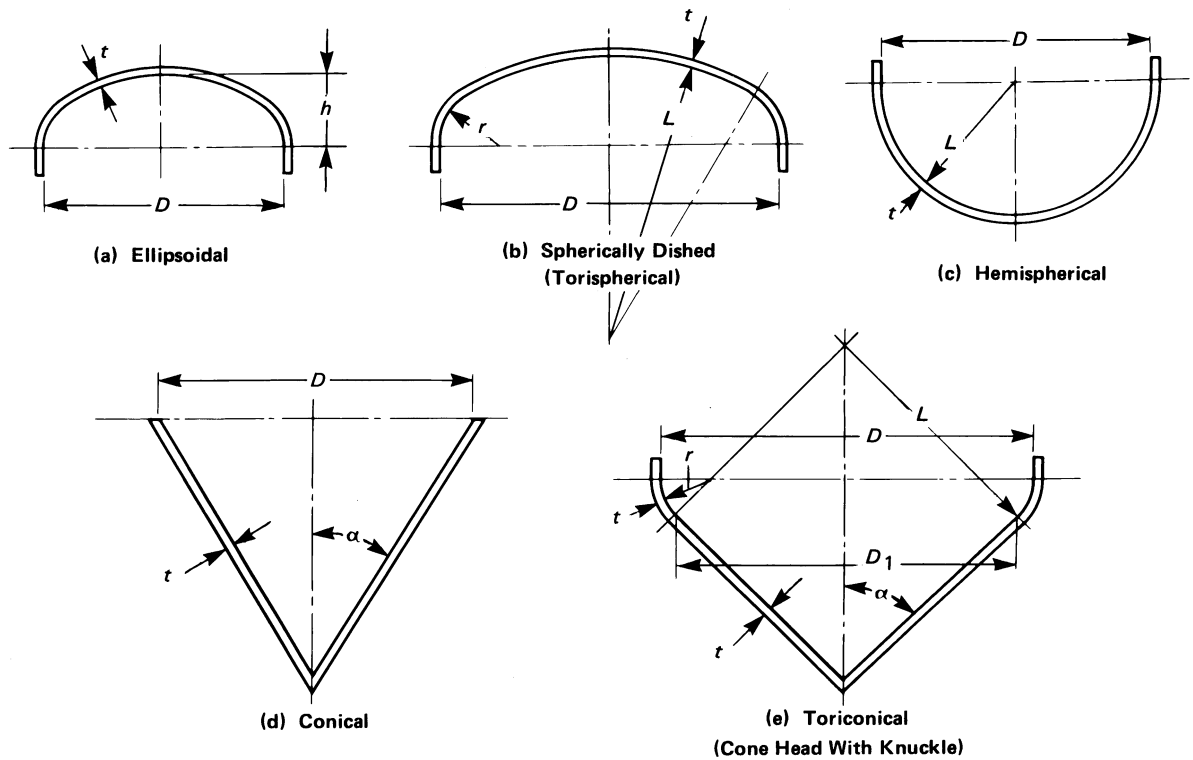


Table ND-3324.2-1
Values of Factor K

$D/2h$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$D/2h$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

GENERAL NOTE: Use nearest value of $D/2h$; interpolation unnecessary.

When t is known and P is desired

$$P = SE \left(\frac{Z - 1}{Z + 1} \right)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

(2) *Longitudinal Stress (Circumferential Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when P exceeds $1.25SE$, the following equations shall apply. When P is known and t is desired

$$t = R(Z^{1/2} - 1) = R_o \left(\frac{Z^{1/2} - 1}{Z^{1/2}} \right)$$

where

$$Z = \frac{P}{SE} + 1$$

When t is known and P is desired

$$P = SE(Z - 1)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

ND-3324.4 Spherical Shells.

(a) When the thickness of the shell of a spherical vessel does not exceed $0.356R$ or P does not exceed $0.665S$, the following equations shall apply. Any reduction in thickness within a shell course of a spherical shell shall be in accordance with ND-3361.

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

(b) The following equations, in terms of the outside radius, are equivalent and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{2SE + 0.8P}$$

$$P = \frac{2SEt}{R_o - 0.8t}$$

(c) When the thickness of the shell of a spherical vessel under internal pressure exceeds $0.356R$ or when P exceeds $0.665SE$, the following equations shall apply. When P is known and t is desired

$$t = R(Y^{1/3} - 1) = R_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(SE + P)}{2SE - P}$$

When t is known and P is desired

$$P = 2SE \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{R + t}{R} \right)^3 = \left(\frac{R_o}{R_o - t} \right)^3$$

ND-3324.5 Formed Heads, General Requirements.

Formed heads shall meet the requirements of (a) through (i) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Figure ND-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with ND-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of ND-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and 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 diameter.

(d) 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 three times the head thickness.

(e) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of ND-3324.5, it shall be stayed as a flat surface according to the rules of ND-3329.

(f) 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. ND-3325.2(b)(4) or eq. ND-3325.2(b)(5) using $C = 0.25$.

(g) Openings in formed heads under internal pressure shall comply with the requirements of ND-3330.

(h) A dished head with a reversed skirt may be used in a component, provided the maximum allowable pressure for the head is established in accordance with the requirements of [ND-6900](#).

(i) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints ([ND-4500](#)).

ND-3324.6 Ellipsoidal Heads.

(a) *2:1 Ellipsoidal Heads.* The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis (inside depth of the head minus the skirt) equals one-fourth the inside diameter of the head skirt, shall be determined by

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

(b) *Ellipsoidal Heads of Other Ratios.* The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by

$$t = \frac{PDK}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{KD + 0.2t}$$

$$t = \frac{PD_oK}{2SE + 2P(K - 0.1)}$$

or

$$P = \frac{2SEt}{KD_o - 2t(K - 0.1)}$$

where

$$K = \frac{1}{6} \left[2 + \left(\frac{D}{2h} \right)^2 \right]$$

Numerical values of the factor K are given in [Table ND-3324.2-1](#).

ND-3324.7 Hemispherical Heads.

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

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

(b) When the thickness of the hemispherical head under internal pressure exceeds $0.356L$ or when P exceeds $0.665SE$, the following equations shall apply:

$$t = L(Y^{1/3} - 1) = L_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(SE + P)}{2SE - P}$$

or

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{L + t}{L} \right)^3 = \left(\frac{L_o}{L_o - t} \right)^3$$

ND-3324.8 Torispherical Heads.

(a) *Torispherical Heads With 6% Knuckle Radius.* The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by

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

(b) *Torispherical Heads of Other Proportions.* The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by

$$t = \frac{PLM}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{LM + 0.2t}$$

$$t = \frac{PL_oM}{2SE + P(M - 0.2)} \quad (1)$$

or

$$P = \frac{2SEt}{ML_o - t(M - 0.2)} \quad (2)$$

where

$$M = \frac{1}{4} \left(3 + \sqrt{\frac{L}{r}} \right) \quad (3)$$

Numerical values of the factor M are given in [Table ND-3324.8\(b\)-1](#).

(c) Torispherical heads made of material having a specified minimum tensile strength exceeding 80 ksi (550 MPa) shall be designed using a value of S equal to 20 ksi (140 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in Tables 1A and 1B, Section II, Part D, Subpart 1.

ND-3324.9 Conical Heads 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

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

**Table ND-3324.8(b)-1
Values of Factor M**

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67 [Note (1)]
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

GENERAL NOTE: Use nearest value of L/r ; interpolation unnecessary.

NOTE:

(1) Maximum ratio allowed by ND-3324.5(d) when L equals the outside diameter of the skirt of the head.

For α greater than 30 deg, see ND-3324.11(b)(5). A compression ring shall be provided when required by the rule in ND-3324.11(b).

ND-3324.10 Toriconical Heads. Toriconical heads in which the inside 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 used when the angle α exceeds 30 deg except when the design complies with ND-3324.11. The required thickness of the knuckle shall be determined by the first equation of ND-3324.8(b) in which

$$L = \frac{D_1}{2 \cos \alpha}$$

The required thickness of the conical portion shall be determined by the equation in ND-3324.9, using D_1 in place of D .

ND-3324.11 Reducer Sections.

(a) General Requirements

(1) The rules of (a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

- A = required area of reinforcement
- A_e = effective area of reinforcement, due to excess metal thickness
- D_1 = inside diameter of reducer section at point of tangency to the knuckle or reverse curve
- m = the lesser of $(t_s/t) \cos(\alpha - \Delta)$ or

$$\frac{[t_c \cos \alpha \cos(\alpha - \Delta)]}{t}$$

- R_L = inside radius of larger cylinder
- r_L = inside radius of knuckle at larger cylinder
- R_s = inside radius of smaller cylinder
- r_s = radius to the inside surface of flare at the small end
- t_c = nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance
- t_e = the smaller of $(t_s - t)$ or $[t_c - (t/\cos \alpha)]$
- t_s = nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance

Δ = value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 30$ deg. When $\Delta \geq \alpha$, no reinforcement at the junction is required [Tables ND-3324.11(b)(2)-1 and ND-3324.11(b)(3)-1]

(3) 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 equation. In addition, provisions shall be made for any of the other loadings listed in ND-3111 when such loadings are expected.

(4) 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 (-a) and (-b) below are met.

(-a) *Conical Shell Section.* The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in ND-3324.9.

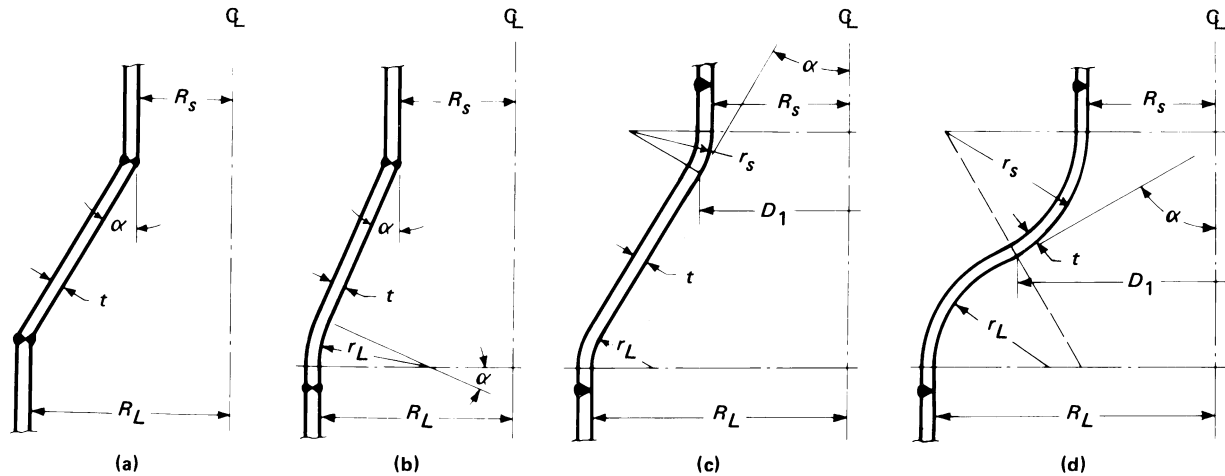
(-b) *Knuckle Tangent to the Larger Cylinder.* Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of ND-3324.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints, including the plate taper required by ND-3361, shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Figure ND-3324.11(a)(6)-1, sketch (a)] without knuckle provided the half apex angle α is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Figure ND-3324.11(a)(6)-1, sketch (b)] may be shaped as a portion of a toriconical shell, 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 (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

Figure ND-3324.11(a)(6)-1
Large Head Openings, Reverse Curve, and Conical Shell Reducer Sections



GENERAL NOTES:

- (a) r_L shall not be less than the smaller of $0.12 (R_L + t)$ or $3t$
 (b) r_s has no dimensional requirement

(8) Reverse curve reducers [Figure ND-3324.11(a)(6)-1, sketches (c) and (d)] may be shaped of elements other than those as illustrated.

(b) *Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure*

(1) The equations of (2) and (3) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle $\alpha \leq 30$ deg. In (5) below, provision is made for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ , obtained from Table ND-3324.11(b)(2)-1, using the appropriate ratio P/SE , is less than α . Interpolation may be made in the Table.

Table ND-3324.11(b)(2)-1
Values of Δ for Junctions at the Large Cylinder for $\alpha \leq 30$ deg

P/SE	0.001	0.002	0.003	0.004	0.005
Δ , deg	11	15	18	21	23
P/SE	0.006	0.007	0.008	0.009 [Note (1)]	...
Δ , deg	25	27	28.5	30	...

NOTE:

- (1) $\Delta = 30$ deg for greater values of P/SE .

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{P(R_L)^2}{2SE} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

(-b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = 4t_e \sqrt{R_L t_s}$$

(-c) Any additional area of reinforcement that is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5 \sqrt{R_L t_s}$ from the junction.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from Table ND-3324.11(b)(3)-1, using the appropriate ratio P/SE , is less than α .

Table ND-3324.11(b)(3)-1
Values of Δ for Junctions at the Small
Cylinder for $\alpha \leq 30$ deg

P/SE	0.002	0.005	0.010	0.02
Δ , deg	4	6	9	12.5
P/SE	0.04	0.08	0.10	0.125 [Note (1)]
Δ , deg	17.5	24	27	30

NOTE:

(1) $\Delta = 30$ deg for greater values of P/SE .

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_S^2}{2SE} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

(-b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = m \sqrt{R_s t} \left[t_c - (t / \cos \alpha) + (t_s - t) \right]$$

(-c) Any additional area of reinforcement that is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5 \sqrt{R_s t_s}$ from the junction.

(4) Reducers not described in (a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

- (13) (5) When the half apex angle α is greater than 30 deg, cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on stress analysis. When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values.

(-a) Membrane hoop stress plus average discontinuity hoop stress shall not be greater than $1.5SE$, where the "average discontinuity hoop stress" is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces.

(-b) Membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than $3SE$.

(-c) The angle joint between the cone and cylinder shall be designed equivalent to a double butt welded joint, and, because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

ND-3324.12 Nozzles.

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in ND-3111 plus the thickness added for corrosion allowance. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

(2) the minimum thickness⁸ of standard wall pipe plus the corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ASME B36.10M, the wall thickness of that largest size plus corrosion allowance.

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

ND-3324.13 Nozzle Piping Transitions. The stress limits of Table ND-3321-1 shall apply to all portions of nozzles that lie within the limits of reinforcement given in ND-3334, except as provided for in ND-3324.14. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

ND-3324.14 Consideration of Standard Reinforcement.

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table ND-3321-1. Under these conditions no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are specified, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3321-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit for σ_m in Table ND-3321-1 for a given condition.

ND-3324.15 Other Loadings. 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 ND-3111 other than pressure and temperature.

ND-3325 Flat Heads and Covers

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 noncircular⁹ heads and covers. Some

acceptable types of flat heads and covers are shown in [Figure ND-3325-1](#). In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

ND-3325.1 Nomenclature. The symbols used are defined as follows:

- C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in [ND-3325.3](#), dimensionless
- D = long span of noncircular heads or covers measured perpendicular to short span
- d = diameter, or short span, measured as indicated in [Figure ND-3325-1](#)
- h_G = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Table XI-3221.1-2
- L = perimeter of noncircular bolted head measured along the centers of the bolt holes
- l = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in [Figure ND-3325-1](#) sketches (a) and (c)
- m = the ratio t_r/t_s
- P = Design Pressure
- r = inside corner radius on a head formed by flanging or forging
- S = maximum allowable stress value, from Tables 1A and 1B, Section II, Part D, Subpart 1
- t = minimum required thickness of flat head or cover, exclusive of corrosion allowance
- t_f = actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in [Figure ND-3325-1](#) sketches (b-1) and (b-2)
- t_h = actual thickness of flat head or cover, exclusive of corrosion allowance
- t_p = the smallest dimension from the face of the head to the edge of the weld preparation
- t_r = required thickness of seamless shell, for pressure
- t_s = actual thickness of shell, exclusive of corrosion allowance
- t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in [Figure ND-3325-1](#) sketch (g)
- t_1 = throat dimension of the closure weld, as indicated in [Figure ND-3325-1](#) sketch (r)
- W = total bolt load, given for circular heads for Equations (3) and (4), XI-3223
- Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span ([ND-3325.2](#)), dimensionless

ND-3325.2 Thickness. The thickness of unstayed flat heads, covers, and blind flanges shall conform to one of the following four requirements.¹⁰

(a) Circular blind flanges of ferrous materials conforming to ASME B16.5 shall be acceptable for the diameters and pressure-temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in [Figure ND-3325-1](#) sketches (j) and (k).

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by [eq. \(4\)](#)

$$t = d \sqrt{CP/S} \quad (4)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [[Figure ND-3325-1](#) sketches (j) and (k)], in which case the thickness shall be calculated by [eq. \(5\)](#)

$$t = d \sqrt{CP/S + 1.27 Wh_G / Sd^3} \quad (5)$$

When using [eq. \(5\)](#), the thickness t shall be calculated for both Service Loadings and gasket seating and the greater of the two values shall be used. For Service Loadings, the value of P shall be the Design Pressure and the values of S at the Design Temperature and W from [eq. \(3\)](#) of XI-3223(c) shall be used. For gasket seating, P equals zero and the values of S at atmospheric temperature and W from [eq. \(4\)](#) of XI-3223 shall be used.

(c) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by [eqs. \(6\) and \(7\)](#)

$$t = d \sqrt{ZCP/S} \quad (6)$$

where

$$Z = 3.4 - \frac{2.4d}{D} \quad (7)$$

with the limitation that Z need not be greater than 2.5.

(d) [Equation \(c\)\(6\)](#) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [[Figure ND-3325-1](#) sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

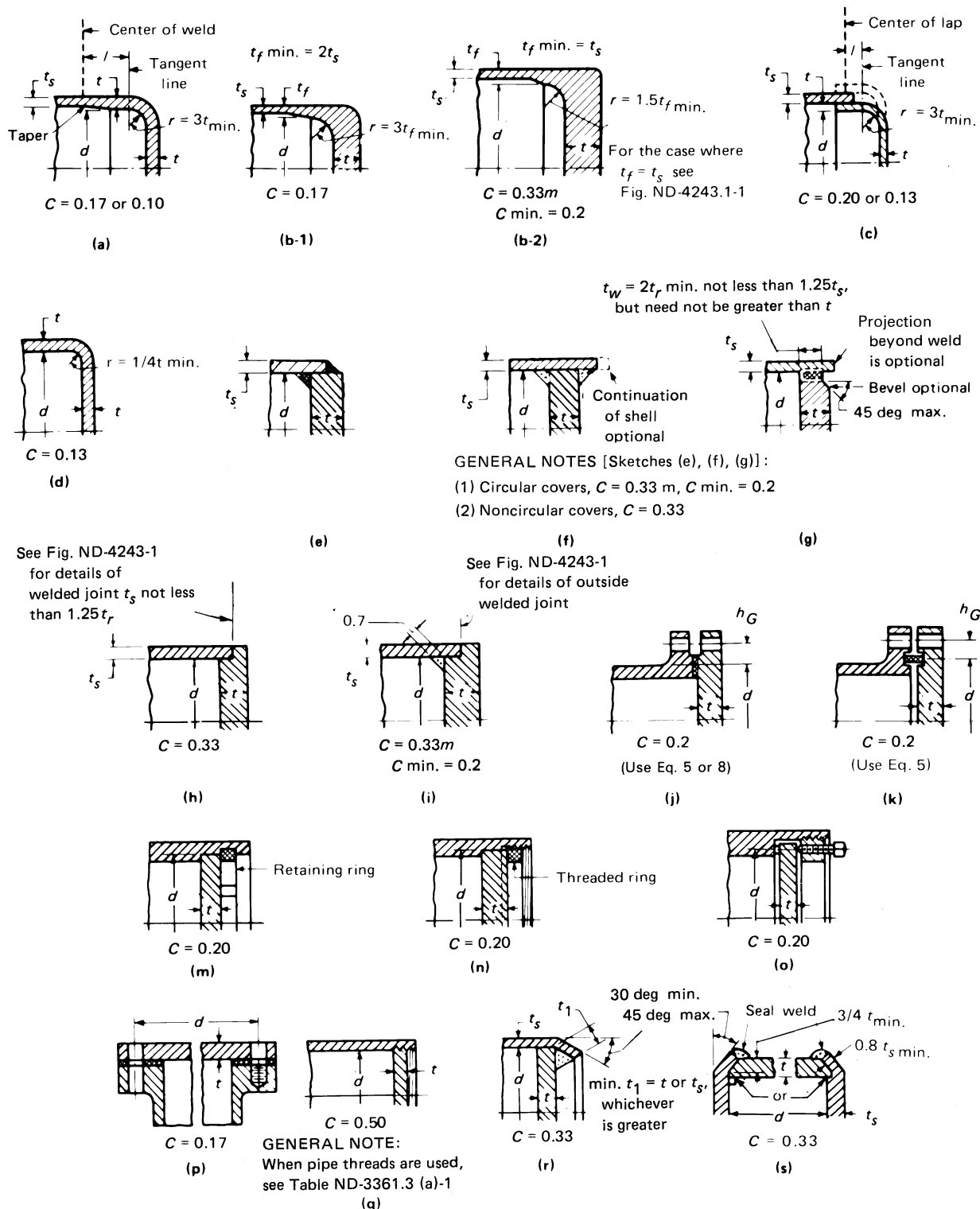
$$t = d \sqrt{ZCP/S + 4 Wh_G / SLd^2} \quad (8)$$

When using [eq. \(8\)](#), the thickness t shall be calculated in the same way as specified above for [eq. \(b\)\(5\)](#).

ND-3325.3 Values of C . For the types of construction shown in [Figure ND-3325-1](#), the minimum values of C to be used in [eqs. ND-3325.2\(b\)\(4\), ND-3325.2\(b\)\(5\), ND-3325.2\(c\)\(6\), and ND-3325.2\(d\)\(8\)](#) are given in (a) through (o) below.

(13)

Figure ND-3325-1
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: The illustrations above are diagrammatic only. Other designs that meet the requirements of ND-3325 are acceptable.

(a) In sketch (a), $C = 0.17$ for flanged circular and non-circular 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.

(1) $C = 0.10$ for circular heads, when the flange length l for heads of the above design is not less than

$$l = \left(1.1 - 0.8 \frac{t_s^2}{t_h^2} \right) \sqrt{dt_h}$$

(2) $C = 0.10$ for circular heads, when the flange length l is less than the requirement in (1) above but the shell thickness is not less than

$$t_s = 1.12t_h \sqrt{1.1 - l / \sqrt{dt_h}}$$

for a length of at least $2\sqrt{dt_s}$.

(3) When $C = 0.10$ is used, the taper shall be 1:4.

(b) In sketch (b-1), $C = 0.17$ for forged circular and non-circular 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 ND-4000.

(c) In sketch (b-2), $C = 0.33m$ but not less than 0.3 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 1.5 times the flange thickness, and the welding meets all the requirements for circumferential joints given in ND-4000. [see Figure ND-4243.1-1 sketches (a) and (b) for the special case where t_f equals t_s .]

(d) In sketch (c), $C = 0.13$ for circular heads lap-welded or brazed to the shell with corner radius not less than $3t$ and l not less than required by (a)(1) above and the requirements of ND-3358 are met.

(1) $C = 0.20$ for circular and noncircular lap-welded or brazed construction as above but with no special requirement with regard to l .

(2) $C = 0.20$ 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 a factor of safety of at least 4 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.

(e) In 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 nor 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.

(f) In sketches (e), (f), and (g), $C = 0.33m$ but not less than 0.2 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 two 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 figure.

For noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels, $C = 0.33$. 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 two 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 figure.

(g) In 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 ND-3358.3(e) and Figure ND-4243-1 sketches (a) through (g).

(h) In sketch (i), $C = 0.33m$ but not less than 0.3 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 ND-3358.3(e) and Figure ND-4243-1 sketches (a) through (g), 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 .

(i) In sketches (j) and (k), $C = 0.2$ for circular and non-circular heads and covers bolted to the vessel as indicated in the figures. Note that eq. ND-3325.2(b)(5) or eq. ND-3325.2(d)(8) shall be used because of the extra moment applied to the cover by 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

$$d \sqrt{1.27 Wh_G / Sd^3}$$

for circular heads and covers, nor less than

$$d \sqrt{4 Wh_G / SLd^2}$$

for noncircular heads and covers.

(j) In sketches (m), (n), and (o), $C = 0.2$ 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 resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(k) In sketch (p), $C = 0.17$ for circular and noncircular covers bolted with a full face gasket to shells, flanges, or side plates.

(l) In sketch (q), $C = 0.50$ 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 stresses consistent with this Subsection. If a tapered pipe thread is used, the requirements of ND-3361.3 shall also be met. Seal welding may be used, if desired.

(m) In 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.

(n) In 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 $P = S/5d$.

(o) In Figure ND-4243.1-1, $C = 0.33m$, but not less than 0.3 when the dimensional requirements of ND-3358.4 are met.

ND-3326 Spherically Dished Covers With Bolting Flanges

ND-3326.1 Nomenclature. The symbols used are defined as follows:

- A = outside diameter of flange
- B = inside diameter of flange
- C = bolt circle diameter

H_D = axial component of the membrane load in the spherical segment, acting at the inside of the flange ring
 $= 0.785B^2P$

h_D = radial distance from the bolt circle to the inside of the flange ring

H_r = radial component of the membrane load in the spherical segment $= H_D \cot \beta_1$, acting at the intersection of the inside of the flange ring with the center line of the dished cover thickness

h_r = lever arm of H_r about centroid of flange ring

L = inside spherical or crown radius

M_o = the total moment, determined as in XI-3230 for heads concave to pressure, and XI-3260 for heads convex to pressure; except that, for heads of the type shown in Figure ND-3326.1-1 sketch (d), H_D and h_D shall be as defined below, and an additional moment H_r , h_r shall be included¹¹

P = Design Pressure

r = inside knuckle radius

S = maximum allowable stress value

T = flange thickness

t = minimum required thickness of head plate after forming

β_1 = angle formed by the tangent to the center line of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover where

$$\beta_1 = \arcsin\left(\frac{B}{2L + t}\right)$$

ND-3326.2 Spherically Dished Heads With Bolting Flanges. Circular spherically dished heads with bolting flanges, both concave and convex to the pressure, and conforming to the several types illustrated in Figure ND-3326.1-1, shall be designed in accordance with the requirements of (a) through (d) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of ND-3133. The actual value of the total moment M_o may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the equations that follow, the absolute values for both P and M_o shall be used.

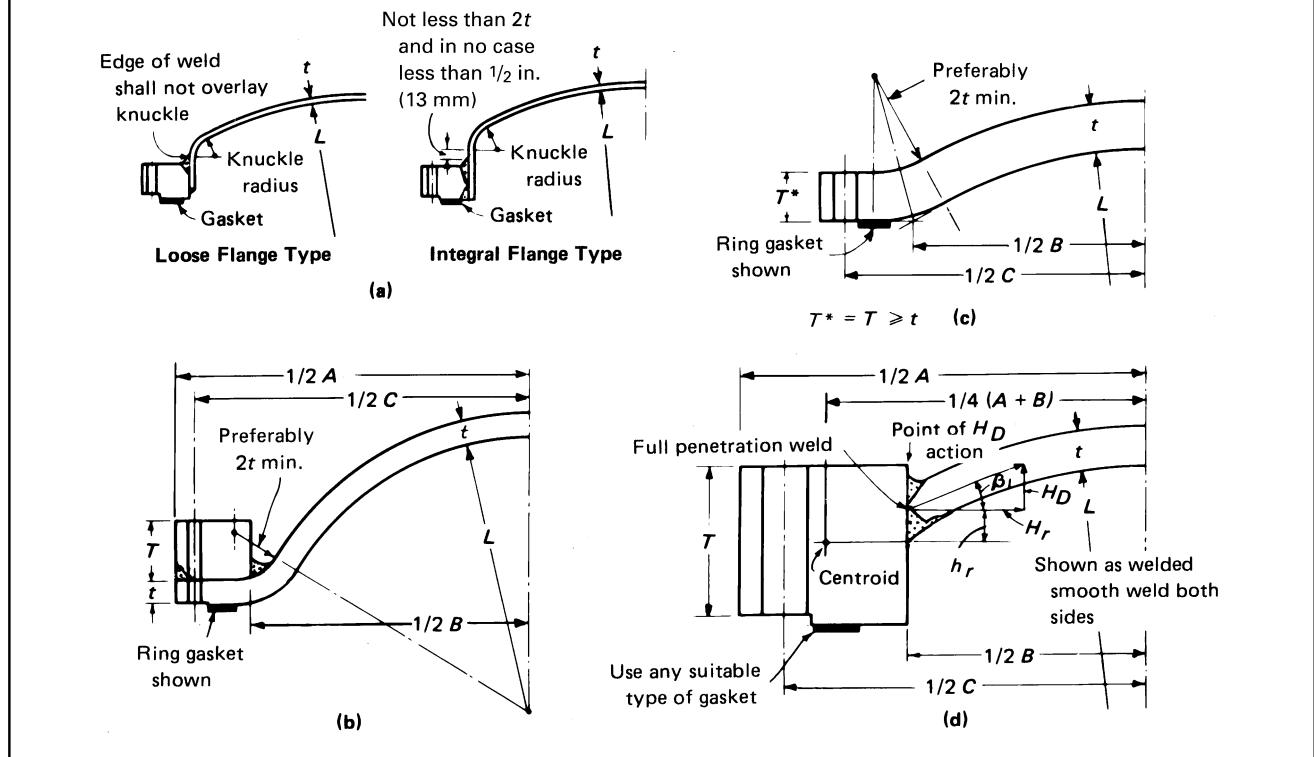
(a) Heads of the Type Shown in Figure ND-3326.1-1 Sketch (a)

(1) The thickness of the head t shall be determined by the appropriate equation in ND-3324.

(2) The head radius L or the knuckle radius r shall not exceed the limitations given in ND-3324.

(3) The flange shall comply at least with the requirements of Figure XI-3120-1 and shall be designed in accordance with the applicable provisions of Appendix XI. Within the range of ASME B16.5, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.

Figure ND-3326.1-1
Spherically Dished Covers With Bolting Flanges



(b) Heads of the Type Shown in Figure ND-3326.1-1 Sketch (b)

(1) Head thickness

$$t = \frac{5PL}{6S}$$

(2) Flange thickness T

For ring gasket

$$T = \sqrt{\frac{M_o(A+B)}{SB(A-B)}}$$

For full face gasket

$$T = 0.6 \sqrt{\frac{P}{S} \left[\frac{B(A+B)(C-B)}{(A-B)} \right]}$$

NOTE: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

Within the range of ASME B16.5, the flange facings and drillings should conform to those Standards, and the thickness specified therein shall be considered as a minimum requirement.

(c) Heads of the Type Shown in Figure ND-3326.1-1 Sketch (c)

(1) Head thickness

$$t = \frac{5PL}{6S} \quad (9)$$

(2) Flange thickness for ring gaskets shall be calculated as follows:

(-a) for heads with round bolting holes

$$T = Q + \sqrt{\frac{1.875 M_o(C+B)}{SB(7C-5B)}} \quad (10)$$

where

$$Q = \frac{PL}{4S} \left(\frac{C+B}{7C-5B} \right) \quad (11)$$

(-b) for heads with bolting holes slotted through the edge of the head

$$T = Q + \sqrt{\frac{1.875 M_o(C+B)}{SB(3C-B)}} \quad (12)$$

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{3C - B} \right) \quad (13)$$

(3) Flange thickness for full face gaskets shall be calculated by the following equation:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \quad (14)$$

The value of Q in eq. (14) is calculated by eq. (2)(-a)(11) for round bolting holes or by eq. (2)(-b)(13) for bolting holes slotted through the edge of the head [see (c)(2) above].

(4) The required flange thickness shall be T as calculated in (2) or (3) above, but in no case less than the value of t calculated in (1) above.

(d) Heads of the Type Shown in Figure ND-3326.1-1 Sketch (d)

(1) Head thickness

$$t = \frac{5PL}{6S} \quad (15)$$

(2) Flange thickness

$$T = F + \sqrt{F^2 + J} \quad (16)$$

where

$$F = \frac{PB\sqrt{4L^2 - B^2}}{8S(A - B)} \quad (17)$$

and

$$J = \left(\frac{M_o}{SB} \right) \left(\frac{A + B}{A - B} \right) \quad (18)$$

NOTE: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis that takes this into account may be used. Such a method may parallel the method of analysis and allowable stresses for flange design in Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

ND-3327 Quick Actuating Closures

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation

that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

ND-3327.1 Positive Locking Devices. Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limiting movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designated that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

ND-3327.2 Manual Operation. Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy ND-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

ND-3327.3 Pressure Indicating Device. When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

ND-3328 Combination Units

When a vessel consists of more than one independent chamber, operating at the same or different pressures and temperatures, each such chamber shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service.

ND-3329 Braced and Stayed Surfaces, Staybolts, and Ligaments**ND-3329.1 Braced and Stayed Surfaces.**

(a) The minimum thickness and maximum allowable pressure for braced and stayed flat plates and those parts which, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced shall be calculated by the following equations:

$$t = p \sqrt{\frac{P}{SC}} \quad (19)$$

$$P = \frac{t^2 SC}{p^2} \quad (20)$$

where

- C = 2.1 for welded stays or stays screwed through plates not over $\frac{7}{16}$ in. (11 mm) in thickness with ends riveted over
- = 2.2 for welded stays or stays screwed through plates over $\frac{7}{16}$ 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
- = 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
- = 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 = Design Pressure
- p = maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical, or inclined
- S = maximum allowable stress value, given in Tables 1A and 1B, Section II, Part D, Subpart 1
- t = minimum thickness of plate, exclusive of corrosion allowance

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $\frac{5}{16}$ in. (8 mm) except for welded construction (ND-3329.3).

(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 (ND-3324).

(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) The acceptable proportions for the ends of through stays with washers are indicated in Figure ND-3329.1(e)-1.

(f) The maximum pitch shall be $8\frac{1}{2}$ in. (215 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt.

(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.

ND-3329.2 Threaded 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.

ND-3329.3 Welded Stayed Construction. For welded stayed construction, the provisions of ND-4470 and ND-5260 shall be met in addition to the requirements of (a) through (d) below.

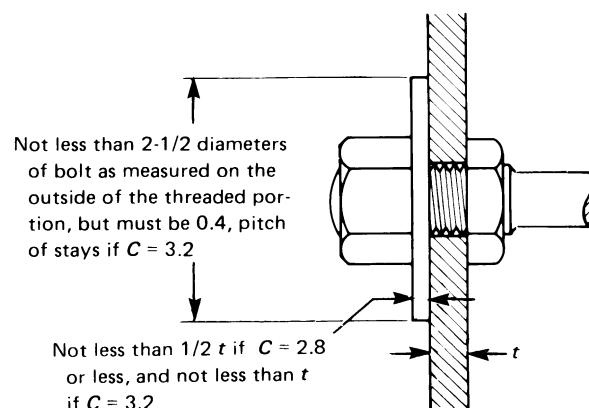
(a) Welded-in staybolts shall meet the requirements of (1) through (4) below.

(1) The arrangement shall conform to one of those illustrated in Figure ND-4470-1.

(2) The required thickness of the plate shall not exceed $1\frac{1}{2}$ in. (38 mm) but, if greater than $\frac{3}{4}$ in. (19 mm), the staybolt pitch shall not exceed 20 in. (500 mm).

(3) The provisions of ND-3329.1 and ND-3329.4 shall be met.

**Figure ND-3329.1(e)-1
Acceptable Proportions for Ends or Through Stays**



(4) The required area of the staybolt shall be determined in accordance with ND-3329.5.

(b) Welded stays, as shown in Figure ND-4470-1, may be used to stay jacketed vessels provided the requirements of (1) through (8) below are met.

(1) The pressure does not exceed 300 psi (2 MPa).

(2) The required thickness of the plate does not exceed $\frac{1}{2}$ in. (13 mm).

(3) The size of the fillet welds is not less than the plate thickness.

(4) The inside welds are properly inspected before the closing plates are attached.

(5) The allowable load on the fillet welds is computed in accordance with ND-3356(c).

(6) The maximum diameter or width of the hole in the plate does not exceed $1\frac{1}{4}$ in. (32 mm).

(7) The welders are qualified under the rules of Section IX.

(8) The maximum spacing of stays is determined by the equation in ND-3329.1(a), using

$C = 2.1$ if either plate is not over $\frac{7}{16}$ in. (11 mm) thick

$C = 2.2$ if both plates are over $\frac{7}{16}$ in. (11 mm) thick

(c) Welded stayed construction, consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used provided the requirements of (1) through (4) below are met.

(1) The pressure does not exceed 300 psi (2 MPa).

(2) The welded attachment is made by fillet welds around holes or slots as shown in Figure ND-4470-1 and is calculated in accordance with ND-4470.

(3) The maximum allowable pressure of the dimpled or embossed components is established in accordance with the requirements of ND-6900.

(4) The plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(d) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel is required to be postweld heat treated.

ND-3329.4 Location of Staybolts.

(a) The distance from the edge of a staybolt hole to the edge of a flat stayed plate shall not be greater than the pitch of the stays.

(b) 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.

ND-3329.5 Dimensions of Staybolts.

(a) The required area of a staybolt at its minimum cross section¹² and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt, computed in accordance with (b) below, and by increasing the allowable stress value by a factor of 1.10 for the material used (Tables 1A and 1B, Section II, Part D, Subpart 1).

(b) 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 pressure.

(c) Stays made of parts joined by welding shall be designed using a joint efficiency of 0.60 for the weld.

ND-3329.6 Ligaments.

(a) The symbols used in the equations and chart of this paragraph are defined as follows:

d = diameter of tube holes, in. (mm)

n = number of tube holes in length p_1

p = longitudinal pitch of tube holes, in. (mm)

p' = diagonal pitch of tube holes, in. (mm)

p_1 = unit length of ligament, in. (mm)

(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 ND-3329.6(b)-1 through ND-3329.6(b)-3, the efficiency of the ligaments between the tube holes shall be determined as follows:

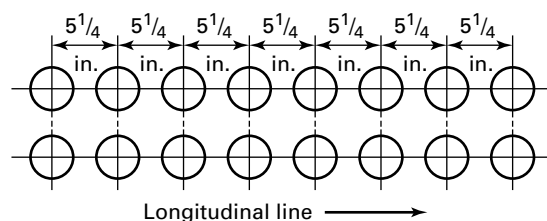
(1) when the pitch of the tube holes on every row is equal [Figure ND-3329.6(b)-1], the equation is $(p-d)/p$ = efficiency of ligament;

(2) when the pitch of tube holes on any one row is unequal [Figures ND-3329.6(b)-2 and ND-3329.6(b)-3], the equation is $(p_1 - nd)/p_1$ = efficiency of ligament.

(c) The strength of ligaments between tube holes measured circumferentially shall be at least 50% of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

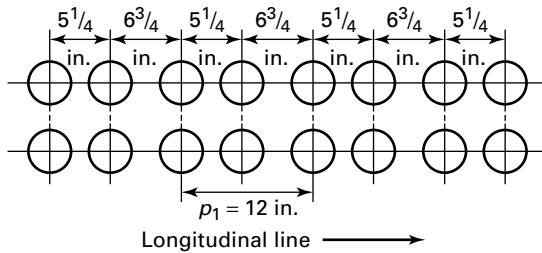
(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Figure ND-3329.6(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure ND-3329.6(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Figure ND-3329.6(d)-2, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next find in the diagram the vertical line corresponding to the

Figure ND-3329.6(b)-1
Example of Tube Spacing With Pitch of Holes
Equal in Every Row



GENERAL NOTE: $5\frac{1}{4}$ in. = 133 mm

Figure ND-3329.6(b)-2
Example of Tube Spacing With Pitch of Holes
Unequal in Every Second Row



GENERAL NOTES:

- (a) $5\frac{1}{4}$ in. = 133 mm
- (b) $6\frac{3}{4}$ in. = 171 mm
- (c) 12 in. = 300 mm

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 shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

(e) When tube holes in a cylindrical shell are arranged in symmetrical groups that 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 pressure is based.

(f) 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 (1) and (2) below.¹³

(1) For a length equal to the inside diameter of the shell for the position that gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable pressure is based. When the diameter of the shell exceeds 60 in. (1 500 mm), the length shall be taken as 60 in. (1 500 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position that gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (750 mm), the length shall be taken as 30 in. (750 mm) in applying this rule.

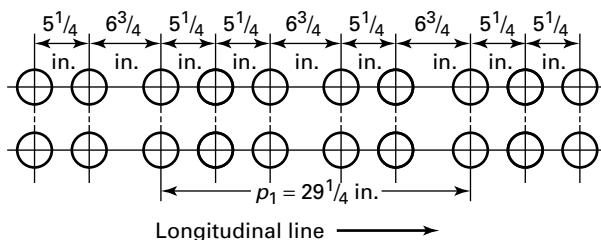
(g) For holes that are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Figure ND-3329.6(g)-1.

ND-3330 OPENINGS AND REINFORCEMENT¹⁴

ND-3331 General Requirements for Openings

(a) Openings¹⁵ in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround.¹⁶ 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.

Figure ND-3329.6(b)-3
Example of Tube Spacing With Pitch of Holes
Varying in Every Second and Third Row



GENERAL NOTES:

- (a) $5\frac{1}{4}$ in. = 133 mm
- (b) $6\frac{3}{4}$ in. = 171 mm
- (c) $29\frac{1}{4}$ in. = 743 mm

Figure ND-3329.6(d)-1
Example of Tube Spacing With Tube Holes on
Diagonal Lines

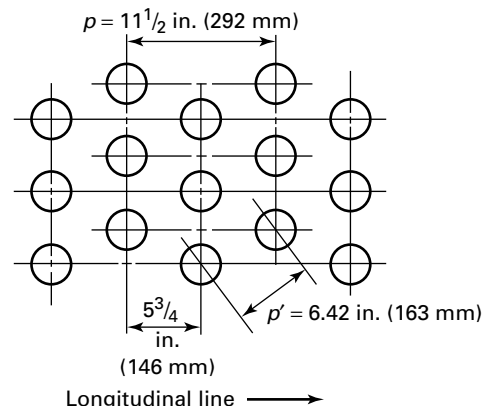


Figure ND-3329.6(d)-2
Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells

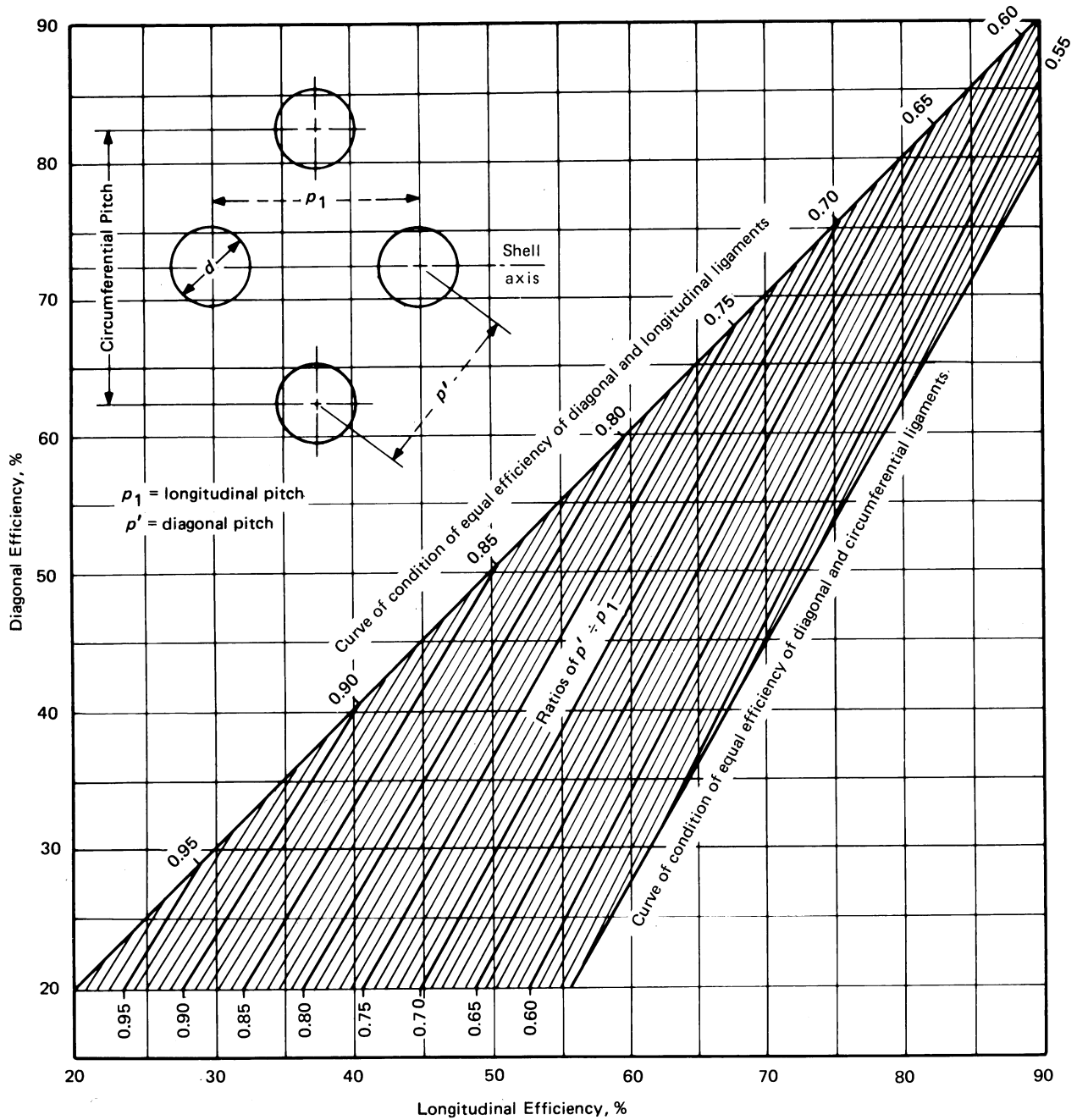
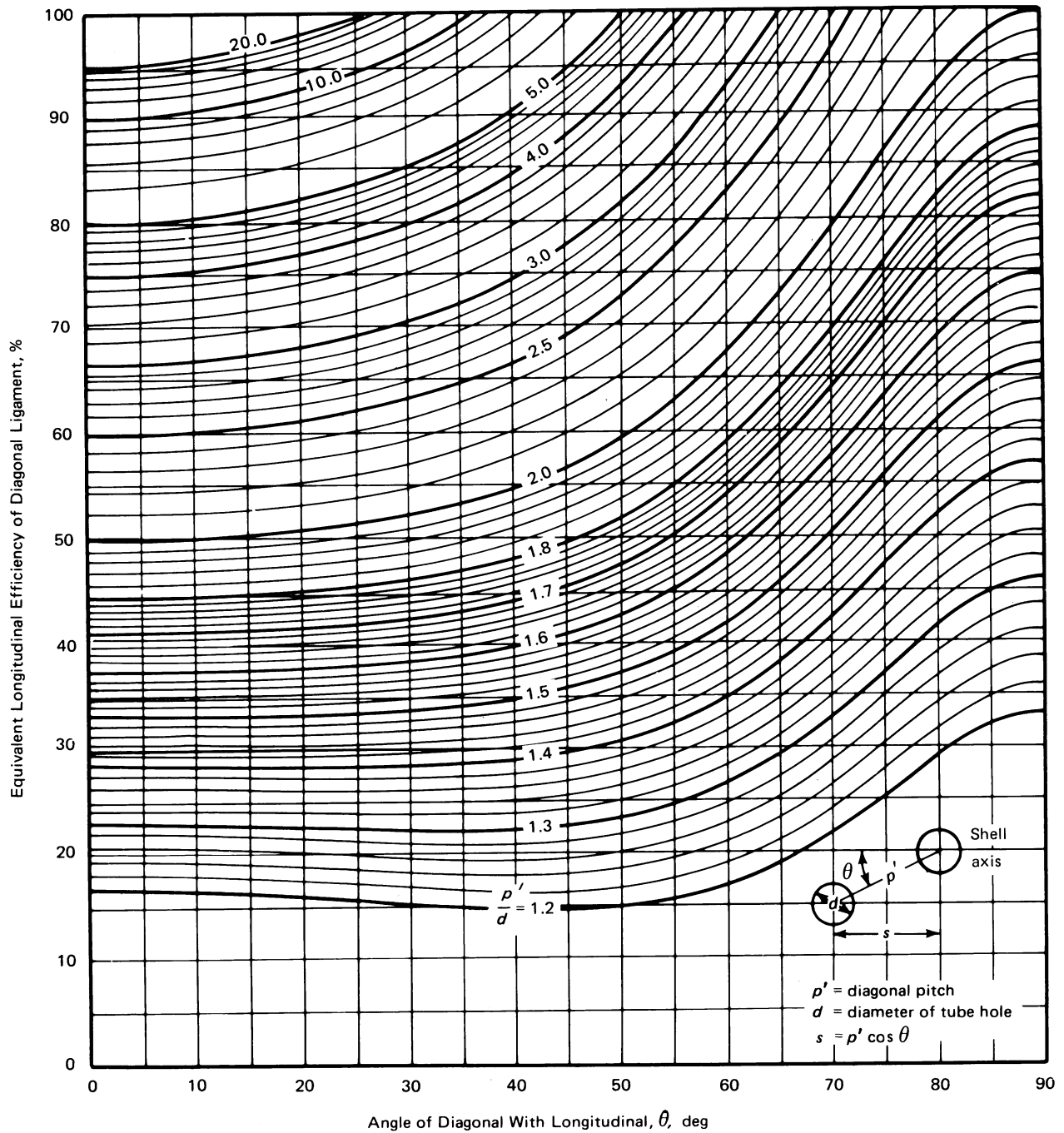


Figure ND-3329.6(g)-1
Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments



(b) Openings may be of other shapes than those given in (a) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in [ND-6900](#).

(c) See below.

(1) The rules for reinforcement of openings given in [ND-3330](#) are intended to apply to openings not exceeding the following:

(-a) for vessels 60 in. (1 500 mm) diameter and less: one-half the vessel diameter but not to exceed 20 in. (500 mm);

(-b) for vessels over 60 in. (1 500 mm) diameter: one-third the vessel diameter but not to exceed 40 in. (1 000 mm).

(2) Larger openings shall be given special attention. Two-thirds of the required reinforcement shall be within $\frac{1}{2}r$ parallel to the vessel surface and measured from the edge of the opening, where r is the radius of the finished opening. The limit normal to the vessel wall is the smaller of the limits specified in [ND-3334.2](#). Special consideration shall be given to the fabrication details used and examination employed. Reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening. Welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations.

(d) All references to dimensions in [ND-3330](#) apply to the finished dimensions, excluding material added as corrosion allowance.

(e) Any type of opening may be located in a welded joint.

ND-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

ND-3332.1 Openings Not Requiring Reinforcement.

Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than NPS 2 (DN 50).

ND-3332.2 Required Area of Reinforcement. The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall not be less than

$$A = d t_r F$$

where

d = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition

F = a correction factor which compensates for the variation in pressure stresses on different planes. A value of 1.00 shall be used for all configurations except that [Figure ND-3332.2-1](#) may be used for integrally reinforced openings in cylindrical shells and cones.

t_r = the required thickness of a shell or head computed in accordance with the rules of this Article for the Design Pressure, 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 [ND-3324.8\(b\)](#), using $E = 1$ and $M = 1$;

(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 $K_1 D$, where D is the shell diameter and K_1 is given by [Table ND-3332.2-1](#).

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

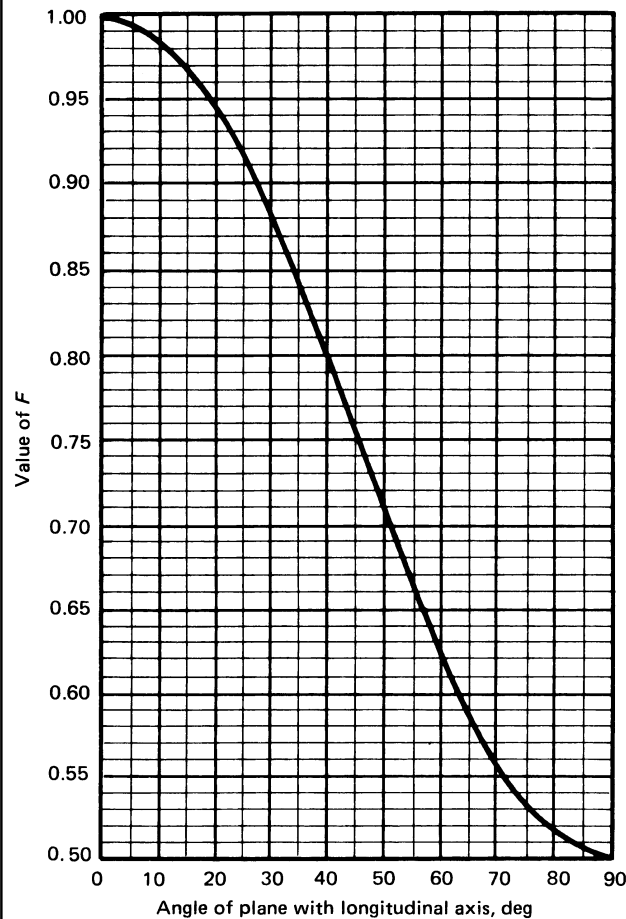
ND-3332.3 Reinforcement for External Pressure.

(a) The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the equation for area in [ND-3332.2](#) except t_r is the wall thickness required by the rules for components under external pressure.

(b) The reinforcement required for openings in each shell of a multiple walled vessel shall comply with (a) above when the shell is subject to external pressure and with [ND-3332.2](#) when the shell is subject to internal pressure.

ND-3332.4 Reinforcement for Internal and External Pressure. Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of [ND-3332.2](#) for internal pressure and of [ND-3332.3](#) for external pressure.

Figure ND-3332.2-1
Chart for Determining Value of F



ND-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation

Table ND-3332.2-1 Values of Spherical Radius Factor K_1						
$D/2h$	...	3.0	2.8	2.6	2.4	2.2
K_1	...	1.36	1.27	1.18	1.08	0.99
$D/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius = $K_1 D$; $D/2h$ = axis ratio. Interpolation is permitted for intermediate values.

$$A = 0.5 d t_r$$

where d is as defined in ND-3332.2 and t_r is the thickness, which meets the requirements of ND-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(1) in eq. ND-3325.2(b)(4), by using $2C$ or 0.75 in place of C , whichever is less;

(2) in eq. ND-3325.2(b)(5), by doubling the quantity under the square root sign.

(c) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in ND-3325.1, shall be designed as follows.

(1) When the opening is a single, circular, centrally located opening and when the shell-head juncture is integrally formed or integrally attached by a full penetration weld similar to those shown in Figure ND-3325-1 sketches (a), (b-1), (b-2), (d), or (g), the head shall be designed according to Appendix XIX and related parts of Appendix XI. The required head thickness which satisfies all the requirements of Appendix XIX also satisfies the intent of ND-3225. The opening in the head may have a nozzle that is integrally formed or integrally attached by a full penetration weld or it may be an opening without an attached nozzle or hub.

(2) When the opening is of any other type than that described in (1) above, no specific rules are given. Consequently, the requirements of ND-1100(c) shall be met.

ND-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

ND-3334.1 Limits of Reinforcement Along the Vessel Wall. The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius, in., of shell or head, t is the nominal vessel wall thickness, in., r is the radius, in., of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

ND-3334.2 Limits of Reinforcement Normal to the Vessel Wall. The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the lesser of (a) or (b) below:

(a) $2\frac{1}{2}$ times the nominal shell thickness less corrosion allowance;

(b) $2\frac{1}{2}$ times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

ND-3335 Metal Available for Reinforcement

ND-3335.1 Openings. Metal within the limits of reinforcement that may be considered to have reinforcing value shall be that given in (a) through (d) below.

(a) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by

$$A_1 = (E_1 t - F t_r) d$$

or

$$A_1 = 2(E_1 t - F t_r)(t + t_n)$$

(b) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the lesser of the values of A_2 given by

$$A_2 = (t_n - t_{rn}) 5t$$

or

$$A_2 = (t_n - t_{rn})(5t_n + 2t_e)$$

(c) all metal in the nozzle wall extending inside the vessel wall 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 where

A_1 = area in excess thickness in the vessel wall available for reinforcement, (ND-3334)

A_2 = area in excess thickness in the nozzle wall available for reinforcement, (ND-3334)

d = diameter in the plane under consideration of the finished opening in its corroded condition (ND-3332.2)

E_1 = 1 when an opening is in the plate or when the opening passes through a circumferential joint in a shell or cone exclusive of head-to-shell joints; or
= the joint efficiency obtained from ND-3352 when any part of the opening passes through any other welded joint

F = a correction factor that compensates for the variation in 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 ND-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.

t = nominal thickness of the vessel wall, less corrosion allowance

t_e = thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement, [Figure ND-3335.1(b)-1]

t_n = nominal thickness of nozzle wall, less corrosion allowance

t_r = required thickness of a seamless shell or head as defined in ND-3332.2

t_{rn} = required thickness of a seamless nozzle wall

(d) metal added as reinforcement and metal in attachment welds.

ND-3335.2 Reinforcement of Multiple Openings.

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Figure ND-3335.2-1), in accordance with ND-3330 through ND-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcements required for separate openings. No portion of the cross section is to be considered as applying to more than one opening, or to be evaluated more than once in a combined area. The following additional requirements shall also apply:

(1) When the distance between the centers of the openings is greater than $1\frac{1}{3}$ times their average diameter, the area of reinforcement between them shall be not less than 50% of the total required for these openings.

(2) When the distance between the centers of the openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

Figure ND-3335.1(b)-1
Some Representative Configurations Describing the t_e Reinforcement Dimension

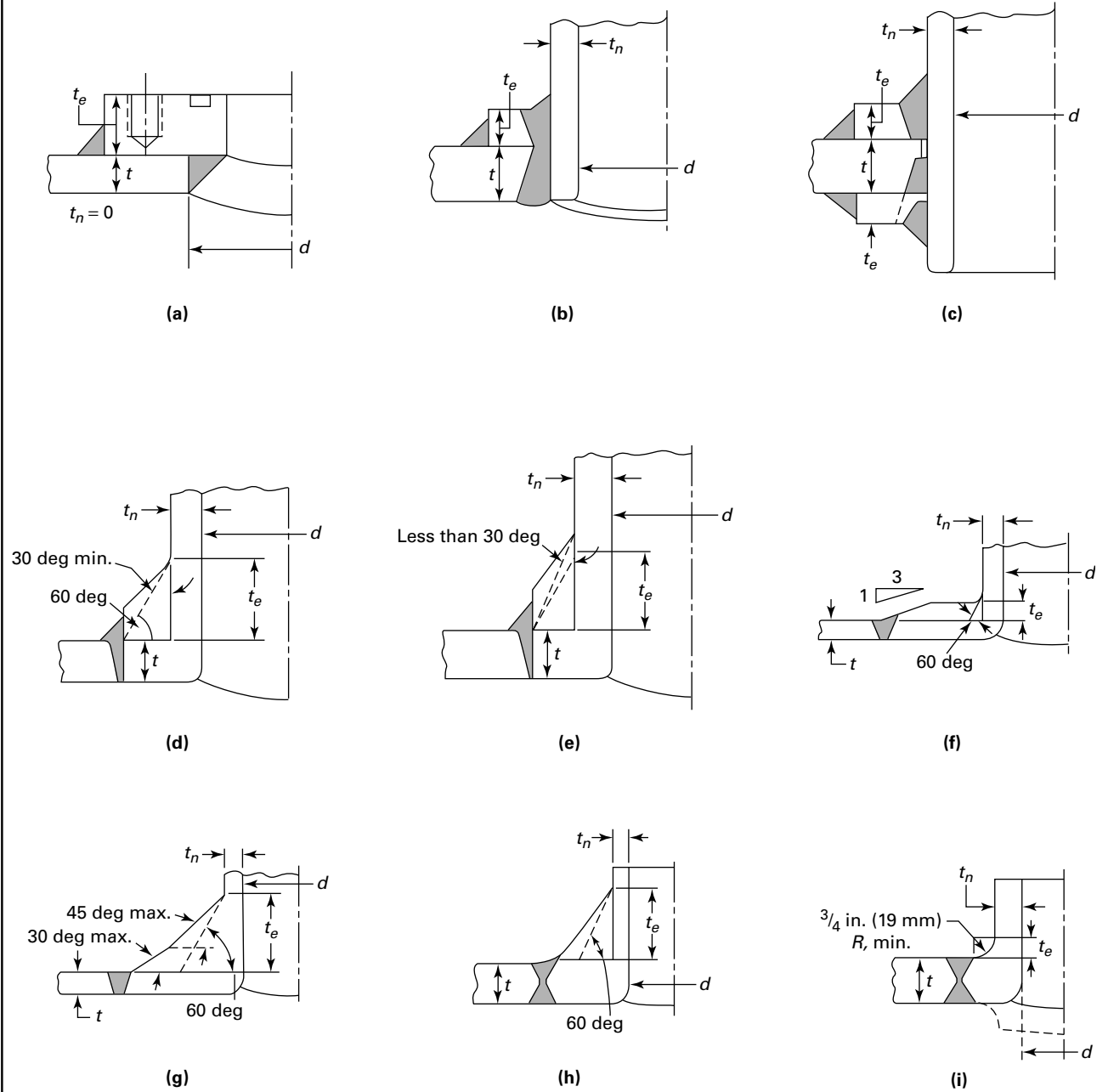
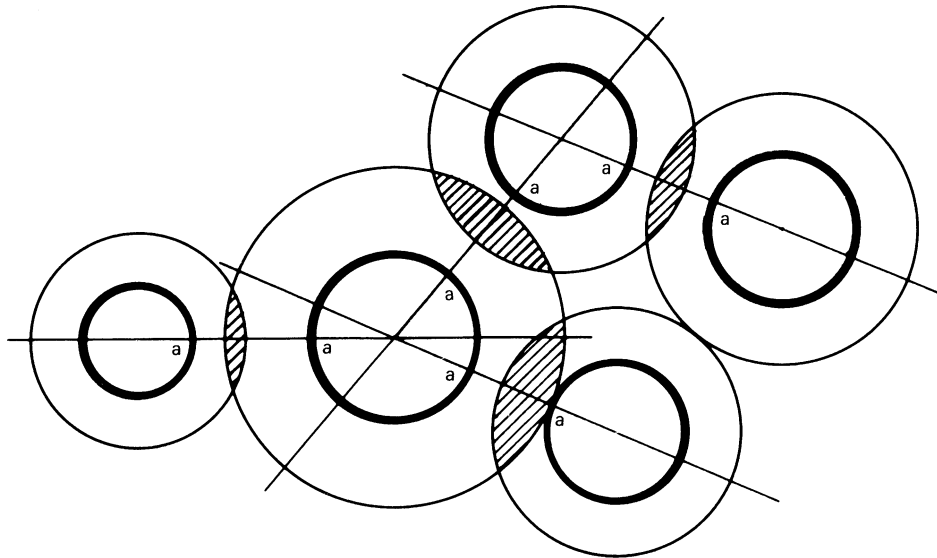


Figure ND-3335.2-1
Arrangement of Multiple Openings



GENERAL NOTES:

- (a) Hatched area represents overlapping of the reinforcement limits.
- (b) Each cross-section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
- (c) Heavy circles represent openings, and light circles represent limits of reinforcement.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:

(1) for vessels 60 in. (1 500 mm) diameter and less, one-half the vessel diameter, but not to exceed 20 in. (500 mm);

(2) for vessels over 60 in. (1 500 mm) diameter, one-third the vessel diameter, but not to exceed 40 in. (1 000 mm).

(c) 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 ND-3361.

(d) When a series of two or more openings in a pressure vessel are arranged in a regular pattern, reinforcement of the openings may be provided in accordance with the requirements of ND-3329.6.

ND-3335.3 Flued Openings in Formed Heads.

(a) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in ND-3332.

(b) The minimum depth of flange of a flued opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3 \text{ in.})$ ($t_r + 75 \text{ mm}$), whichever is less, where t_r is the required 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 straight edge to the edge of the flanged opening [Figure ND-3335.3(b)-1].

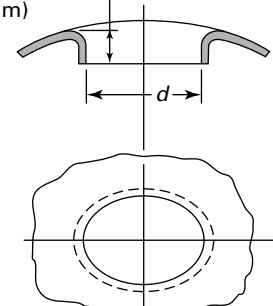
(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with ND-3363.7.

ND-3336 Strength of Reinforcement

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value S

Figure ND-3335.3(b)-1
Minimum Depth for Flange of Flued Openings

Min. depth of flange; the smaller of $3t_r$ or $t_r + 3 \text{ in. (75 mm)}$ when d exceeds 6 in. (150 mm)



than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of ND-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement material design stress value to the vessel material design stress value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress values than that of the material 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.

ND-3336.1 Strength of Weld. On each side of the plane defined in ND-3334, 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 lesser of (a) or (b) below:

(a) the strength in tension of the cross section of the element of reinforcement being considered;

(b) the strength in tension of the area defined in ND-3332 less the strength in tension of the reinforcing area that is integral in the vessel wall.

ND-3336.2 Strength of Attachment. 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 ND-3334. 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.

ND-3350 DESIGN OF WELDED CONSTRUCTION

ND-3351 Welded Joint Categories

The term *Category* defines the location of a joint in a vessel but not the type of joint. The categories are for use in specifying special requirements regarding joint type and method of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure ND-3351-1 illustrates typical joint locations included in each category.

ND-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,¹⁷ transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates¹⁸ of a flat sided vessel;

circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

ND-3351.2 Category B. Category B comprises circumferential welded joints within the main shell, communicating chambers,¹⁷ nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

ND-3351.3 Category C. Category C comprises welded joints connecting flanges, Van Stone laps, tube sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles or to communicating chambers;¹⁷ any welded joint connecting one side plate¹⁸ to another side plate of a flat sided vessel.

ND-3351.4 Category D. Category D comprises welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads or to flat sided vessels and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

ND-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure ND-3352-1 shows typical butt welds for each category joint.

ND-3352.1 Joints of Category A. All welded joints of Category A as defined in ND-3351 shall meet the fabrication requirements of ND-4241 and shall be capable of being examined in accordance with ND-5210. The joint efficiency E shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed in accordance with ND-5211.1(a), E used in the design calculations for determining the thickness of the part shall not exceed 1.00 for Type 1 butt welds and 0.90 for Type 2 butt welds.

(b) When the vessel section or part is spot radiographed in accordance with ND-5211.1(b), the value of E used in the design calculations for determining the thickness of the part shall not exceed 0.85 for Type 1 butt welds and 0.80 for Type 2 butt welds.

(c) When the vessel section or part is neither fully radiographed nor spot radiographically examined as allowed by ND-5211.1(c), the value of E used in the design calculations for determining the thickness of the part shall not exceed 0.70 for Type 1; 0.65 for Type 2; 0.60 for Type 3; 0.55 for Type 4; 0.50 for Type 5; and 0.45 for Type 6

Figure ND-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D

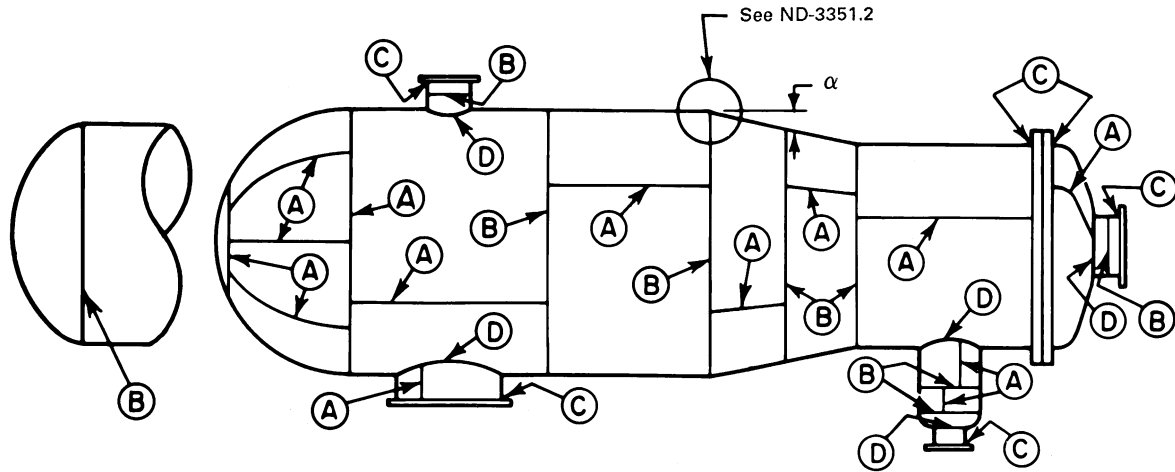
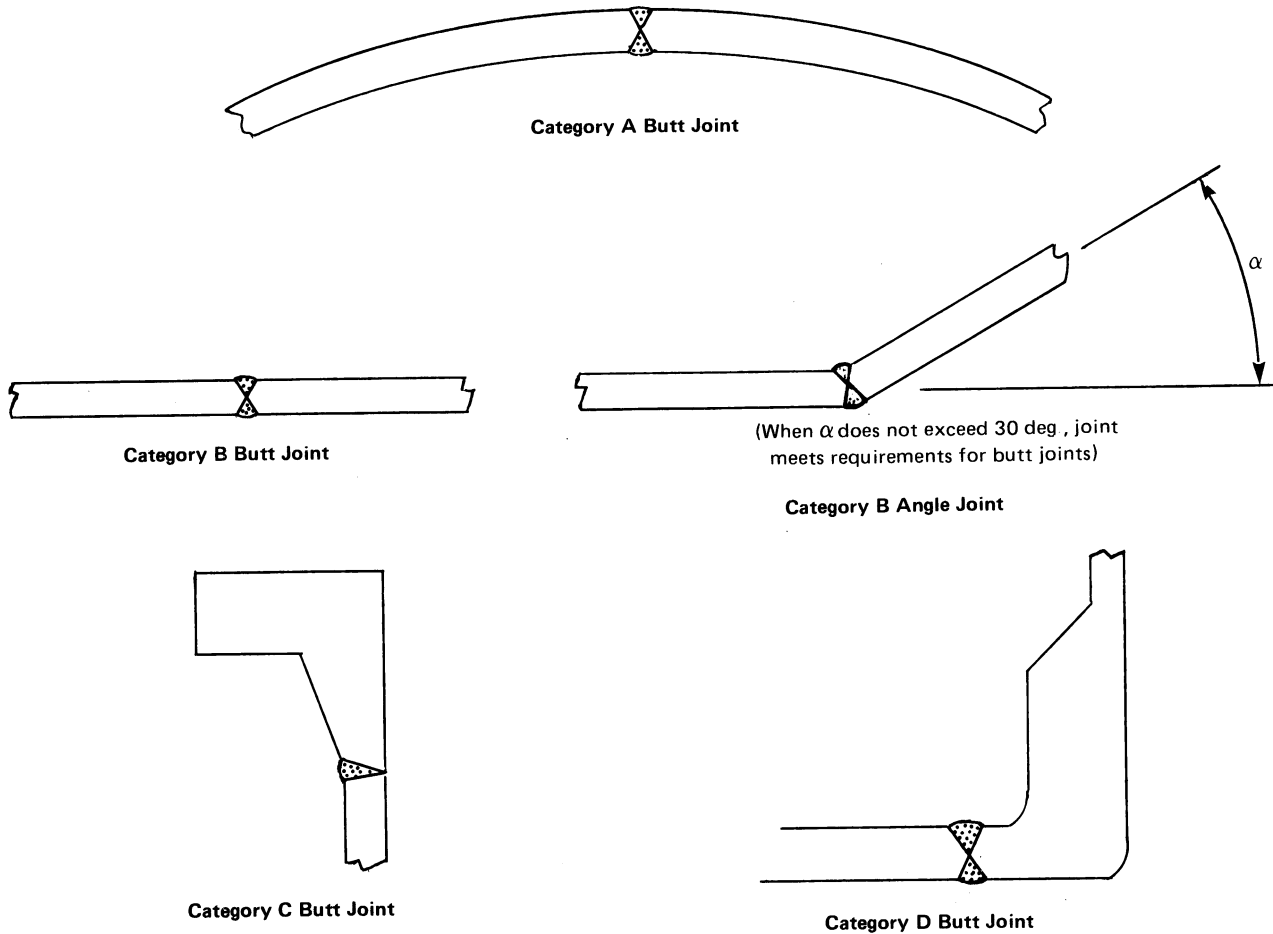


Figure ND-3352-1
Typical Butt Joints



welds. In other cases, the allowable stresses used in the design calculations shall not exceed 80% of the listed values in the stress tables. This 80% factor does not apply to allowable stresses for S_a , S_b , S_f , and S_n used in flange design and defined in XI-3130 or for calculating the thickness of braced and stayed surfaces for eqs. ND-3329.1(a)(19) and ND-3329.1(a)(20). The value of E for vessels designed for external pressure only may be taken as 1.00.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category A shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category A shall be Type 1 or Type 2.

ND-3352.2 Joints of Category B. All welded joints of Category B as defined in ND-3351 shall meet the fabrication requirements of ND-4242 and shall be capable of being examined in accordance with ND-5220. The joint efficiency E shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed, the design provisions of ND-3352.1(a) shall apply.

(b) When the butt weld is partially radiographed as allowed by ND-5221(b) or when the vessel section or part is spot radiographed in accordance with ND-5221(c), the value of E used in the longitudinal stress calculations shall be as stated in ND-3352.1(b). When seamless vessel sections or heads with Category B butt weld joints are spot radiographed, the allowable stresses used in the design calculations for determining the thickness of the vessel section or part shall not exceed 85% of the values listed in the stress tables. This factor does not apply to allowable stresses for S_a , S_b , S_f , and S_n used in flange design and defined in XI-3130 or for calculating the thickness of braced or stayed surfaces for eqs. ND-3329.1(a)(19) and ND-3329.1(a)(20).

(c) When the vessel section or part is neither fully radiographed, partially radiographed, nor spot radiographed, the design provisions of ND-3352.1(c) apply.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category B shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category B shall be Type 1 or Type 2.

ND-3352.3 Joints of Category C. All welded joints of Category C as defined in ND-3351 shall meet the fabrication requirements of ND-4243 and shall be capable of being examined in accordance with ND-5230. The design for attaching flanged heads shall meet the requirements of ND-3358. The design requirements of Category C butt welds are given in (a) through (e) below.

(a) When a Category C butt weld is fully radiographed, the design provisions of ND-3352.1(a) shall apply.

(b) When a Category C butt weld is spot radiographed, the design provisions of ND-3352.2(b) shall apply.

(c) When a Category C butt weld is not radiographed, the design provisions of ND-3352.1(c) shall apply.

(d) When a Category C corner joint is used, the design requirements of ND-3325 and the dimensional requirements of Figure ND-4243-1 specified in ND-3358.3 shall be met.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category C shall be Type 1 or Type 2 when the Design Temperature is 1,000°F (540°C) or higher.

ND-3352.4 Joints of Category D. All welded joints of Category D as defined in ND-3351 shall be in accordance with the requirements of ND-3359 and one of (a) through (h) below.

(a) *Butt Welded Attachments.* Nozzles shall meet the fabrication requirements of ND-4244(a) and shall be capable of being examined in accordance with ND-5241. The minimum dimensions and geometrical requirements of Figure ND-4244(a)-1 shall be met, where

$r_1 = \frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less

$r_2 = \frac{1}{4}$ in. (6 mm) minimum

t = nominal thickness of part penetrated

t_n = nominal thickness of penetrating part

(b) *Full Penetration Corner Welded Attachments.* Nozzles shall meet the fabrication requirements of ND-4244(b) and shall be capable of being examined as required in ND-5241. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{min}$. The minimum dimensions of Figure ND-4244(b)-1 shall be met, where

$r_1 = \frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less

$r_2 = \frac{1}{4}$ in. (6 mm) minimum

t = nominal thickness of part penetrated

$t_c = 0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less

t_e = thickness of reinforcing element

t_{min} = the lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined

t_n = nominal thickness of penetrating part

(c) *Use of Deposited Weld Metal for Openings and Attachments*

(1) Nozzles shall meet the requirements of ND-4244(c) and shall be capable of being examined in accordance with ND-5241.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Figure ND-4244(c)-1 shall be met, where

$r_1 = \frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less

t = nominal thickness of part penetrated

$t_c = 0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
 t_n = nominal thickness of penetrating part

(4) The corners of the end of each nozzle extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness t_n of the nozzle or $\frac{3}{4}$ in. (19 mm), whichever is less.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds shall meet the requirements of ND-4244(d). Typical details are shown in Figure ND-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds or a combination of fillet, single bevel, and single J-welds may be used. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{min}$. The welds attaching the nozzles to the vessel wall and to the reinforcement shall consist of one of the combinations given in (-a) through (-c) below.

(-a) A single bevel or single J-weld in the shell plate and a single bevel or single J-weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{min}$ [Figure ND-4244(d)-1].

(-b) A full penetration groove weld in the shell plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{min}$ in each reinforcement plate [Figure ND-4244(d)-1, sketch (f)].

(-c) A full penetration groove weld in each reinforcement plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{min}$ in the shell plate [Figure ND-4244(d)-1, sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of ND-5241.

(2) The minimum dimensions of Figure ND-4244(d)-1 shall be met, where

$c = \frac{1}{2}t_{min}$
 t = nominal thickness of part penetrated
 $t_c = 0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
 t_e = thickness of reinforcement element
 t_{min} = the lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined
 t_n = nominal thickness of penetrating part
 $t_w = 0.7t_n$, except $t_w = 0.7t_{min}$ for sketch (e)
 $t_1 + t_2 = \frac{1}{4}t_{min}$
 t_1 or t_2 = not less than the lesser of $\frac{1}{4}$ in. (6 mm) or $0.7t_{min}$

(e) *Attachment of Fittings With Internal Threads.*¹⁹ The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below.

(1) Except as provided for in (2) and (3) below, the provisions of ND-4244(e) shall be met. The minimum weld dimensions shall be as shown in Figure ND-4244(e)-1 where

t_{min} = lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the parts joined

$t_c = \frac{1}{4}$ in. (6 mm), minimum

Sketches (a) and (b)

$t_1 + t_2 = \frac{1}{4}t_{min}$

Sketch (c)

t_w = thickness of Sch. 160 pipe (ASME-B36.10M)

$t_1 + t_2$ = not less than the lesser of $\frac{1}{4}$ in. (6 mm) or $0.7t_{min}$

Sketch (d)

$t_w = 0.7t_{min}$

(2) Fittings shown in Figure ND-4244(e)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding NPS 3 may be attached by welds that are exempt from size requirements other than those specified in ND-3359.

(3)

(-a) When internally threaded fittings and bolting pads not exceeding NPS 3 (DN 80) are attached to vessels having a wall thickness not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Figure ND-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in ND-3332.1.

(-b) If the opening exceeds $5\frac{3}{8}$ in. (135 mm) in any direction or is greater than one-half the vessel diameter, the part of the vessel affected shall be subjected to a proof test as required in ND-6900 or the opening shall be reinforced in accordance with ND-3332 with the nozzle or other connections attached, using a suitable detail in Figure ND-4244(e)-1.

(f) *Attachment of Tubed Connections.* Nozzles or tubes recessed into thick walled vessels or headers, welded from only one side, shall have a welding groove in the vessel wall not deeper than t_n on the longitudinal axis of the opening. A recess $\frac{1}{16}$ in. (1.5 mm) deep shall be provided at the bottom of the groove in which to center the nozzle. The dimension t_w of the attachment weld shall not be less than t_n nor less than $\frac{1}{4}$ in. (6 mm). The minimum dimension for t_c shall be $\frac{1}{4}$ in. (6 mm) [Figure ND-4244(f)-1, sketches (a) and (b)].

(g) *Nozzles With Integral Reinforcing.* Nozzles and other connections having integral reinforcement in the form of extended nozzles or saddle type pads shall have the throat dimension of the outer weld not less than $\frac{1}{2}t_{min}$ [Figure ND-4244(g)-1]. The dimension t_w of the inner weld shall be not less than $0.7t_{min}$, where

$c = \frac{1}{2}t_{min}$

t = nominal thickness of shell
 $t_c = 0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
 t_e = thickness of reinforcement element
 t_{min} = lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined
 t_n = nominal thickness of neck
 $t_w = 0.7t_{min}$

(h) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category D shall be Type 1 or Type 2 when the Design Temperature is 1,000°F (540°C) or higher.

ND-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of ND-4430.

ND-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in ND-4000, is acceptable as proof that the welding groove is satisfactory.

ND-3356 Fillet Welds, Lap Joints, and Plug Welds

ND-3356.1 Fillet Welds.

(a) Fillet welds may be used as strength welds within the limitations given in ND-3352 and Figure ND-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for lugs or clips.

(c) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimensions, the allowable stress value in tension of the material being welded, and a joint efficiency of 0.55.

ND-3356.2 Lap Joints. For lap joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in ND-3358 and for tanks in ND-4246.

ND-3356.3 Plug Welds.

(a) Plug welds may be used in lap joints, in reinforcements around openings, and in structural attachments. Plug welds shall be properly spaced to carry no more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than $t + \frac{1}{4}$ in. (6 mm) and not more than $2t + \frac{1}{4}$ in. (6 mm), where t is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate or attached part in which the weld is made is $\frac{5}{16}$ in. (8 mm) or less; for thicker plates or attached parts, the holes shall be filled to a

depth of at least half the plate thickness or $\frac{5}{16}$ of the hole diameter, whichever is larger, but in no case less than $\frac{5}{16}$ in. (8 mm).

(d) The allowable load on a plug weld in either shear or tension shall be computed by the following equation:

(U.S. Customary Units)

$$P = 0.63S(d - 1/4)^2$$

(SI Units)

$$P = 0.63S(d - 6)^2$$

where

d = the bottom diameter of the hole in which the weld is made, in. (mm)

P = total allowable load on the plug weld

S = maximum allowable stress (Tables 1A and 1B, Section II, Part D, Subpart 1)

ND-3357 Welded Joints Subject to Bending Stresses

Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. Corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds [ND-3356.1(b)].

ND-3358 Design Requirements for Head Attachments

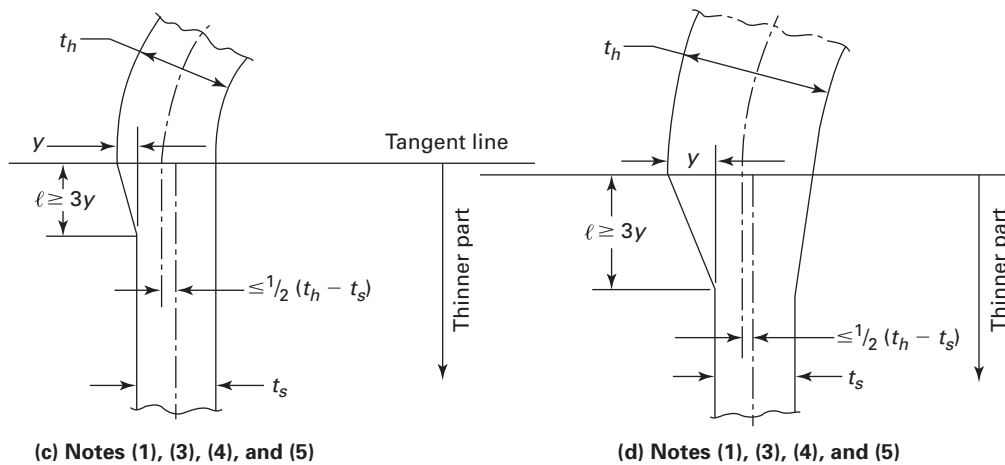
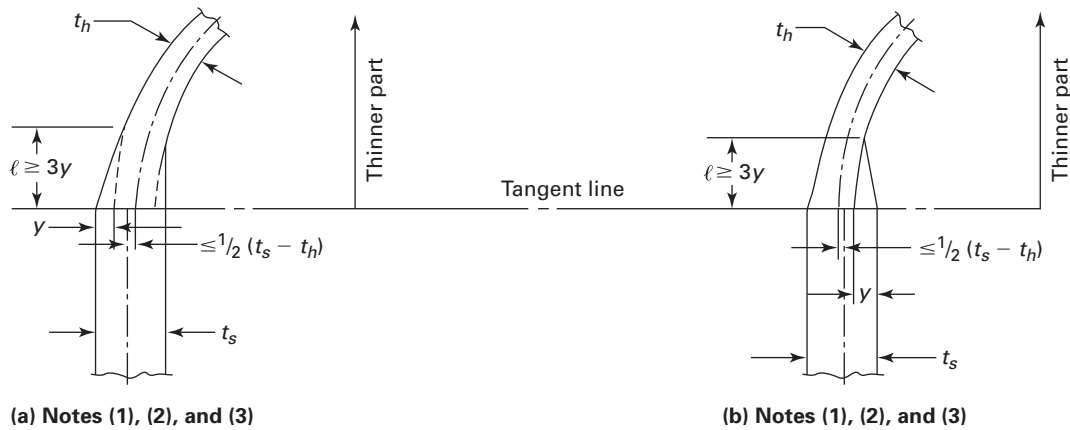
ND-3358.1 Skirt Length of Formed Heads.

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure ND-3358.1(a)-1. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure ND-3358.1(a)-1 shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Figure ND-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(c) 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 diameter.

Figure ND-3358.1(a)-1
Heads Attached to Shells



NOTES:

- (1) Length of required taper ℓ may include the width of the weld.
- (2) In all cases, the projected length of taper ℓ shall be not less than $3y$.
- (3) The shell plate center line may be on either side of the head plate center line.
- (4) In all cases, ℓ shall be not less than 3 times y when t_h exceeds $1.25t_s$; minimum length of skirt is $3t_h$, but need not exceed $1\frac{1}{2}$ in. (38 mm) except when necessary to provide required length of taper.
- (5) When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.

ND-3358.2 Unstayed Flat Heads Welded to Shells.

The requirements for the attachment of unstayed flat heads welded to shells are given in [ND-3325](#), [ND-3358.3](#), and [ND-3358.6](#).

ND-3358.3 Head Attachments Using Corner Joints.

When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in [Figure ND-4243-1](#), the joint shall meet the requirements of (a) through (f) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b , respectively.

(b) For flange rings of bolted flanged connections and for flat heads and unsupported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure part.

(c) For supported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. A supported tubesheet is defined as one in which not less than 80% of the pressure load on the tubesheet is carried by tubes, stays, or braces.

(d) For other components, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection having holes for a bolted connection and the side plates of a rectangular vessel.

(e) Other dimensions at the joint shall be in accordance with details as shown in [Figure ND-4243-1](#)

(1) sketch (a)

$a + b$ not less than $2t_s$, ($b = 0$)

t_w not less than t_s

t_s = actual thickness of shell

(2) sketch (b)

$a + b$ not less than $2t_s$

t_w not less than t_s

t_p not less than t_s

t_s = actual thickness of shell

(3) sketch (c)

$a + b$ not less than $2t_s$

a not less than t_s

t_p not less than t_s

t_s = actual thickness of shell

(4) sketch (d)

$a + b$ not less than $2t_s$

a not less than t_s

t_p not less than t_s

t_s = actual thickness of shell

(5) sketch (e)

$a + b$ not less than $2t_s$, ($b = 0$)

t_s = actual thickness of shell

(6) sketch (f)

$a + b$ not less than $2t_s$

t_s = actual thickness of shell

(7) sketch (g)

$a + b$ not less than $2t_s$

a_1 not less than $0.5a_2$ nor greater than $2a_2$

$a_1 + a_2 = a$

t_s = actual thickness of shell

(8) sketches (h) through (j)

t_r = required thickness of shell

$c = 0.7t_s$

$t_w = 2t_r$ but not less than $1.25t_s$

t_w need not be greater than t

t_s = actual thickness of shell

(9) sketches (k) through (o)

(-a) for supported tubesheets

$a + b$ not less than $2t_s$

c not less than $0.7t_s$ or $1.4t_r$, whichever is less

a_1 not less than $0.5a_2$

t_s = actual thickness of shell

(-b) for flange rings, flat heads, and unsupported tubesheets

$a + b$ not less than $3t_s$

c not less than t_s or $2t_r$, whichever is less

a_1 not less than $0.5a_2$

t_s = actual thickness of shell

(10) sketch (p)

a not less than $3t_n$, ($b = 0$)

c not less than t_n or t_D ,²⁰ whichever is less

(11) sketch (q)

$a + b$ not less than $3t_n$

c not less than t_n or t_D ,²⁰ whichever is less

(f) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide eccentric attachment, are not permissible [[Figure ND-4243-1](#) sketches (r), (s), and (t)].

ND-3358.4 Intermediate Heads.

(a) Intermediate heads of the type shown in [Figure ND-4245-1](#) sketch (f), without limit to thickness, may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

(b) The butt weld and fillet weld shall be designed to take shear based on 1.5 times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material, and the allowable value for the fillet weld shall be 55% of the stress value for the vessel material. The area of the fillet weld is the minimum leg dimension times the length of the weld. The area of the butt weld in shear is the smaller of the width at the root of the weld or the thickness of the vessel shell to which it is attached times the length of the weld.

(c) This construction may also be used for end closures when the thickness of the shell section of the vessel does not exceed $\frac{5}{8}$ in. (16 mm).

ND-3358.5 Heads Concave to Pressure. Heads concave to pressure may be attached to shells using a butt weld with one plate offset as shown in [Figure ND-4245-1](#) sketch (k). The offset shall be smooth and symmetrical, and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld.

ND-3358.6 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in [Figure ND-4243.1-1](#), shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical.

In [Figure ND-4243.1-1](#), the minimum dimensions are as follows:

- (a) sketch (a)
 r not less than $1.5t_s$
- (b) sketch (b)
 r not less than $1.5t_s$
 e not less than t_s
- (c) sketch (c)
 h not less than $1.5t_s$
- (d) sketch (d)
 t_f not less than $2t_s$
 r not less than $3t_f$
- (e) sketch (e)
 t_f not less than $2t_s$
 r not less than $3t_f$
 e not less than t_f

ND-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of [ND-3352.4](#), the minimum design requirements for nozzle attachment welds are given in (a) and (b) below.

(a) *Required Weld Strength.* Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as required in [ND-3336](#), through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear, computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required when full penetration welds are used.

(b) *Allowable Stress Values for Welds.* The allowable stress values for groove and fillet welds and for shear in nozzles, in percentage of stress values for the vessel material, are as follows:

- (1) Nozzle wall shear, 70%

- (2) Groove weld tension, 74%
- (3) Groove weld shear, 60%
- (4) Fillet weld shear, 49%

ND-3360 SPECIAL VESSEL REQUIREMENTS

ND-3361 Tapered Transitions, Staggered Welds, and Threaded Connections

ND-3361.1 Tapered Transitions. A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections ([Figure ND-3361.1-1](#)) shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential butt welded joints connecting formed heads to main shells are contained in [ND-3358.1\(b\)](#).

ND-3361.2 Staggered Welds. Except when radiographed 4 in. (100 mm) each side of each welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

ND-3361.3 Threaded Connections.

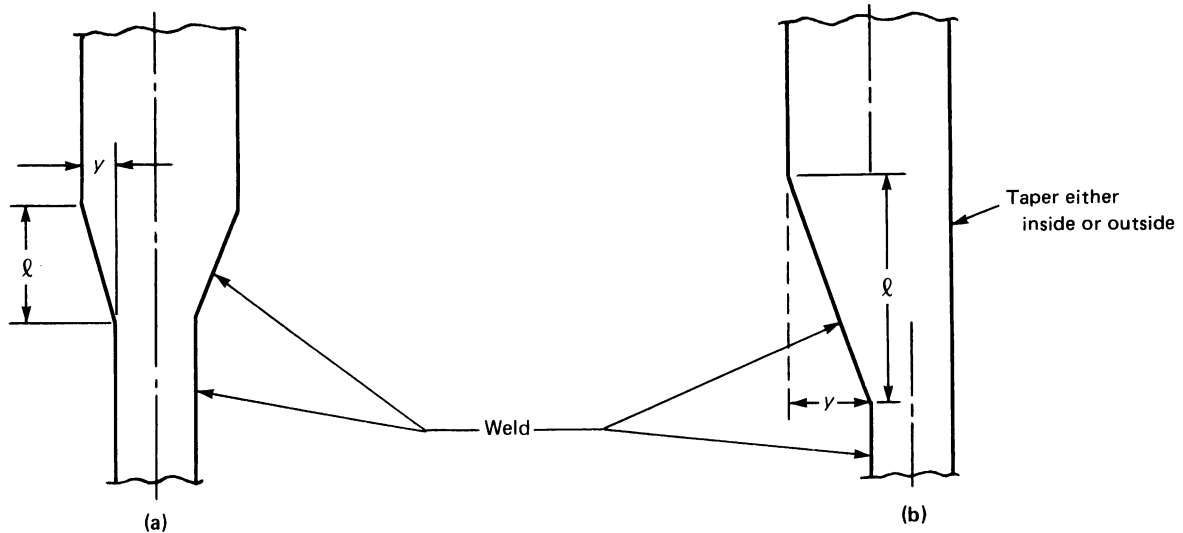
(a) Pipes, tubes, and other threaded connections that conform to ANSI/ASME B1.20.1, Pipe Threads, General Purpose, may be screwed into a threaded hole in a vessel wall provided the pipe engages the minimum number of threads specified in [Table ND-3361.3\(a\)-1](#) after allowance has been made for curvature of the vessel wall. 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 ND-3361.3\(a\)-1](#), or to furnish reinforcement when required.

(b) Threaded connections larger than NPS 3 (DN 80) shall not be used when the maximum allowable pressure exceeds 125 psi (860 kPa), except that this NPS 3 (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes.

ND-3362 Bolted Flange and Studded Connections (13)

(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ASME Standard B16.5, Pipe Flanges and Flanged Fittings; ANSI B16.24, Cast Copper Alloy Pipe Flanges and Flanged Fittings; or to ASME B16.47, Large Diameter Steel Flanges. Such flanges and flanged fittings may be used for the pressure-temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards are acceptable provided they have been

Figure ND-3361.1-1
Butt Welding of Plates of Unequal Thicknesses



GENERAL NOTES:

- (a) In all cases l shall be not less than $3y$.
 (b) $l \geq 3y$, where l is required length of taper and y is the offset between the adjacent surfaces of abutting sections.
 (c) Length of required taper l may include the width of the weld.

designed in accordance with the rules of Appendix XI for the vessel design loadings and are used within the pressure-temperature ratings so determined.

(b) 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 diameter of the stud. The thread engagement need not exceed $1\frac{1}{2}d_s$.

Table ND-3361.3(a)-1
Minimum Number of Pipe Threads for Connections

Size of Pipe Connections, in. (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
$\frac{1}{2}$, $\frac{3}{4}$ (15, 20)	6	0.43 (11)
1, $1\frac{1}{4}$, $1\frac{1}{2}$ (25, 32, 40)	7	0.61 (16)
2 (50)	8	0.70 (18)
$2\frac{1}{2}$, 3 (65, 80)	8	1.0 (25)
4-6 (100-150)	10	1.25 (32)
8 (200)	12	1.5 (38)
10 (250)	13	1.62 (41)
12 (300)	14	1.75 (45)

ND-3363 Access or Inspection Openings²¹

ND-3363.1 General Requirements.

(a) All vessels for use with compressed air, except as otherwise permitted, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (ND-3121), shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Vessels over 12 in. (300 mm) inside diameter under air pressure which also contain other substances that will prevent corrosion need not have openings for inspection only, providing the vessel contains suitable openings through which inspection can be made conveniently and providing such openings are equivalent in size and number to the requirements for inspection openings in ND-3363.3.

(c) Compressed air is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of -50°F (-45°C) or less. The Certificate Holder's Data Report shall include a statement for "noncorrosive service" when inspection openings are not provided.

(d) When provided with telltale holes complying with the provisions of (e) below, inspection openings as required in ND-3363 may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(e) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided they shall be at least $\frac{3}{16}$ in. (5 mm) in diameter 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 surface opposite to that where deterioration is expected.

ND-3363.2 Requirements for Vessels 12 in. (300 mm) Inside Diameter and Smaller. For vessels 12 in. (300 mm) or less inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $\frac{3}{4}$ (DN 20).

ND-3363.3 Requirements for Vessels Over 12 in. (300 mm), but Not Over 16 in. (400 mm) Inside Diameter. Vessels over 12 in. (300 mm), but not over 16 in. (400 mm) inside diameter, that are to be installed so that they may be disconnected from an assembly to permit inspection, need not be provided with openings for inspection only, if there are at least two removable pipe connections not less than NPS $1\frac{1}{2}$ (DN 40).

ND-3363.4 Equipment of Vessels Requiring Access or Inspection Openings. Vessels that require access or inspection openings shall be equipped as required in (a) through (f) below.

(a) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS $1\frac{1}{2}$ (DN 40).

(b) All vessels 18 in. to 36 in. (450 mm to 900 mm), inclusive, inside diameter shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than NPS 2 (DN 50).

(c) All vessels over 36 in. (900 mm) inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. \times 6 in. (100 mm \times 150 mm) or two equal openings of equivalent areas.

(d) 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.

(e) 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.

(f) 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.

ND-3363.5 Size and Type of Access and Inspection Openings. When inspection or access openings are required, they shall comply at least with the requirements of (a) and (b) below.

(a) An elliptical or obround manhole shall be not less than 11 in. \times 15 in. (275 mm \times 375 mm) or 10 in. \times 16 in. (250 mm \times 400 mm). A circular manhole shall be not less than 15 in. (375 mm) inside diameter.

(b) A handhole opening shall be not less than 2 in. \times 3 in. (50 mm \times 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

ND-3363.6 Design of Access and Inspection Openings in Shells and Heads. All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules for openings.

ND-3363.7 Minimum Gasket Bearing Width for Manhole Cover Plates. 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 $\frac{11}{16}$ in. (17 mm).

ND-3363.8 Threaded Openings. 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 for that material. The thread shall be a standard taper pipe thread, except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

ND-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of ND-3135.

ND-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged or attached to the vessel wall in such a way as to withstand the maximum imposed loads (ND-3111 and Subsection NF).

ND-3366 Bellows Expansion Joints

Expansion joints of the bellows type may be used to provide flexibility for vessels. Expansion joints in piping portions of vessels shall meet the requirements of ND-3649. The design, material, fabrication, examination, and testing of expansion joints which are constructed as a part or appurtenance of a vessel shall conform with the requirements of (a) through (i) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by either or both pressure or the bellows spring force shall be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.

(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connecting parts that are not properly aligned unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. (150 mm) in diameter when flow velocities exceed the following values:

(1) air, steam, and other gases — 25 ft/sec (7.6 m/s);

(2) water and other liquids — 10 ft/sec (3.0 m/s).

(g) Pressure retaining material in the expansion joint shall comply with the requirements of ND-2000.

(h) All welded joints shall comply with the requirements of ND-4400.

(i) Design of bellows-type expansion joints shall comply with the requirements of ND-3649.4.

ND-3400 PUMP DESIGN

ND-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

ND-3411 Scope

ND-3411.1 Applicability. The rules of ND-3400 apply to (a) through (j) below:

- (a) pump casings;
- (b) pump inlets and outlets;
- (c) pump covers;
- (d) clamping rings;
- (e) seal housings, seal glands, and packing glands;
- (f) related bolting;
- (g) pump internal heat exchanger piping;
- (h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections, excluding the connecting weld;

(i) piping identified with the pump and external to and forming part of the pressure retaining boundary, and supplied with the pump;

(j) external and internal integral attachments to the pressure retaining boundary;

Hydrostatic test of seal glands and packing glands is not required.

ND-3411.2 Exemptions. The rules of ND-3400 do not apply to (a) through (c) below:

(a) pump shafts and impellers; shafts may be designed in accordance with Appendix S

(b) nonstructural internals

(c) seal packages

ND-3412 Acceptability

The requirements for the design of pumps are given in (a) and (b) below.

(a) The design shall be such that the requirements of ND-3100 are satisfied.

(b) The rules of this Subarticle shall be met.

ND-3413 Design Specifications

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, dead weight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

ND-3414 Design and Service Loadings

The general design considerations, including definitions, of ND-3100 plus the requirements of ND-3320, ND-3330, ND-3361, and ND-3362, are applicable to pumps. The pump shall conform to the requirements of ND-3400. The stress limits listed in ND-3416 shall be used for the specified Design and Service Conditions. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory may be used.

ND-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

ND-3416 Stress and Pressure Limits for Design and Service Loadings

Stress⁷ limits for Design and Service Loadings are specified in Table ND-3416-1. The symbols used in Table ND-3416-1 are defined as follows:

S = allowable stress, given in Tables 1A and 1B, Section II, Part D, Subpart 1. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.

σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress. This stress is the same as σ_m , except that it includes the effect of discontinuities.

σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

ND-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

ND-3418 Corrosion

The requirements of ND-3121 apply.

ND-3419 Cladding

Cladding design dimensions used in the design of pumps shall be as required in ND-3122.

ND-3420 DEFINITIONS

ND-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

ND-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

ND-3423 Single and Double Volute Casings

Figures ND-3423-1 and ND-3423-2 show typical single and double volute casings, respectively.

ND-3424 Seal Housing

A seal housing is defined as that portion of the pump cover or casing assembly that contains the seal and forms a part of the primary pressure boundary.

ND-3425 Typical Examples of Pump Types

Figures ND-3441.1-1 through ND-3441.9-2 are intended to be typical examples to aid in the determination of a pump type and are not to be considered as limiting.

ND-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

ND-3431 Design of Welded Construction

(a) The design of welded construction shall be in accordance with ND-3350.

(b) Partial penetration welds, as shown in Figure ND-4244(e)-1 sketch (c-3) and Figure ND-4244(f)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

Table ND-3416-1 Stress and Pressure Limits for Design and Service Loadings		
Service Limits	Stress Limits [Note (1)]	P_{max} [Note (2)]
Design and Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5 S$	1.0
Level B	$\sigma_m \leq 1.1 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$	1.1
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$	1.2
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$	1.5
NOTES:		
(1) These requirements for acceptability of pump design are not intended to assure the operability of the pump.		
(2) The maximum pressure shall not exceed the tabulated factors listed under P_{max} times the Design Pressure.		

Figure ND-3423-1
Typical Single Volute Casing

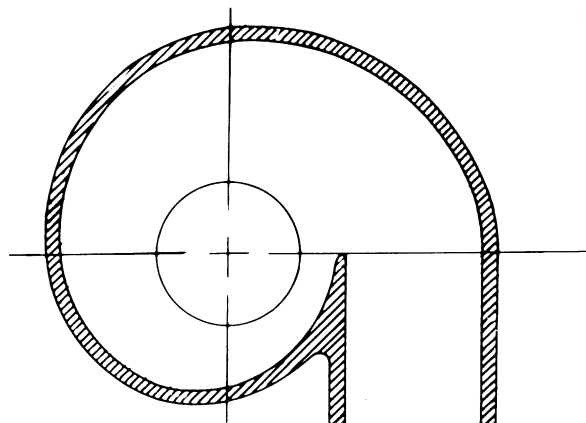
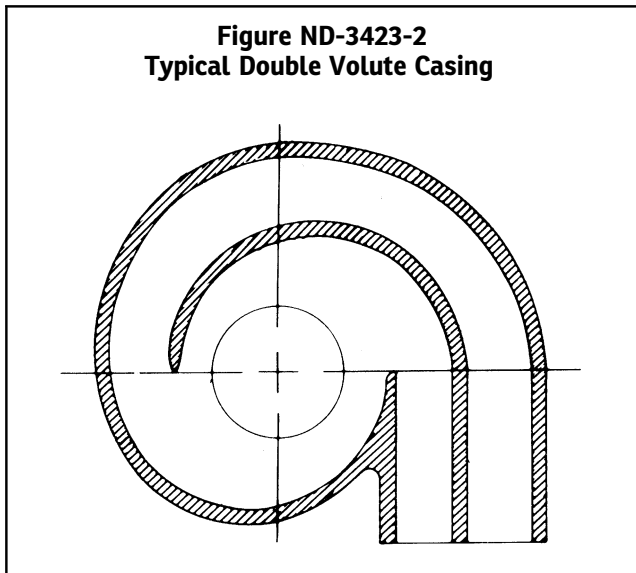


Figure ND-3423-2
Typical Double Volute Casing



ND-3432 Flanged Connections

ND-3432.1 Pressure Design.

(a) Pumps with flanged connections that are cast integrally with the casing and meet all dimensional requirements (including tolerances) of flanged fittings (as shown in Table NCA-7100-1) with regard to the flange dimensions and required wall thicknesses, shall be considered to meet the pressure design requirements of this subarticle and are suitable for use within the pressure-temperature range shown in Appendix I for the material utilized.

(b) Flanged connections not meeting the requirements of (a) shall be designed in accordance with XI-3000 or L-3000.

(c) Pump flanges meeting all requirements of Table NCA-7100-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle, provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of ND-1130.

ND-3432.2 External Loads. When external nozzle loads interact with pumps, it is very likely that operability will dictate the maximum allowable loads. The major areas of concern are distortion of the casing and misalignment of driver and driven equipment. The casing shall be capable of withstanding the external loading plus the design pressure, provided in the Design Specification, without distortion that would impair the operation of the pump. In addition, the pump supports shall be capable of accommodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

(a) Flanged connections meeting the requirements of ND-3432.1 do not require further analysis when all requirements of ND-3658.2 or ND-3658.3 are met. All other flanged connections shall all meet the requirements of (b) below.

(b) Flanged connections shall meet the requirements of ND-3658.1.

ND-3433 Reinforcement of Pump Casing Inlets and Outlets

ND-3433.1 Axially Oriented Inlets and Outlets.

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in ND-3330.

(b) To avoid stress concentrations, the outside radius r_2 of Figures ND-3441.1(a)-1 and ND-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

ND-3433.2 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets is required. The applicable portions of ND-3330 shall apply.

ND-3433.3 Tangential Inlets and Outlets. Except as modified in ND-3433.4, any design method that has been demonstrated to be satisfactory for the specified Design Loadings may be used.

ND-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses. In Figure ND-3433.4-1, the value of l , in. (mm), shall be determined from the relationship

$$l = 0.5 \sqrt{r_m t_m}$$

where

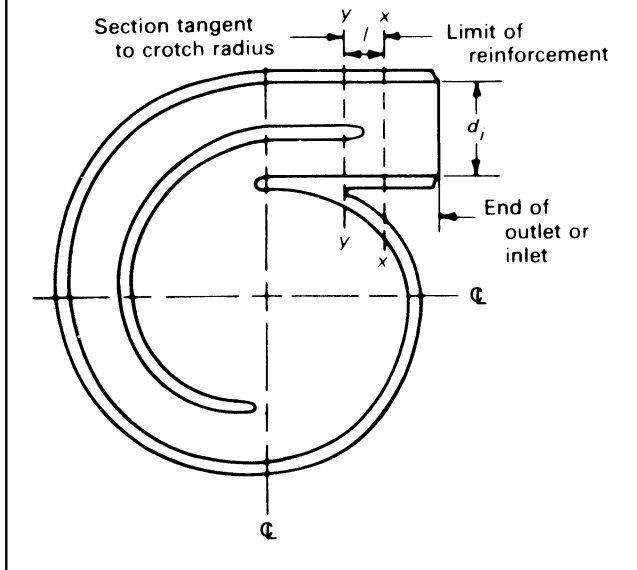
r_i = maximum inlet or outlet inside radius, in. (mm)
 $= d_i/2$
 $r_m = r_i + 0.5t_m$, in. (mm)
 t_m = mean inlet or outlet wall thickness, in. (mm), taken between section x-x and a parallel section y-y tangent to crotch radius

The wall thicknesses of the inlet and outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Figure ND-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Figure ND-4250-1.

ND-3434 Bolting

ND-3434.1 Radially Split Configurations. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI. Bolting requirements for Type K pumps are given in ND-3441.9(a)(3) and ND-3441.9(b)(1) and for Type L pumps in ND-3441.10(b) and ND-3441.10(c).

Figure ND-3433.4-1
Minimum Tangential Inlet and Outlet Wall Thicknesses



ND-3434.2 Axially Split Configurations. Bolting in axially split configurations shall be designed in accordance with the procedure given in [ND-3441.7](#) for Type G pumps.

ND-3435 Piping

ND-3435.1 Piping Under External Pressure. Piping located within the pressure retaining boundary of the pump shall be designed in accordance with [ND-3640](#).

ND-3435.2 Piping Under Internal Pressure. Piping identified with the pump and external to or forming a part of the pressure retaining boundary, such as auxiliary water connections, shall be designed in accordance with [ND-3640](#).

ND-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump [[Figure ND-3436\(c\)-1](#)]. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of [ND-3135](#).

ND-3437 Pump Covers

Pump covers shall be designed in accordance with [ND-3325](#) or [ND-3326](#). Covers for which specific design rules are not given in [ND-3325](#) or [ND-3326](#) shall be designed by any method shown by analysis or experience to be satisfactory.

ND-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of [ND-3411.1\(j\)](#).

ND-3440 DESIGN OF SPECIFIC PUMP TYPES

ND-3441 Standard Pump Types

ND-3441.1 Design of Type A Pumps. Type A pumps are those having single volutes and radially split casings with a single suction as illustrated in [Figure ND-3441.1-1](#) and [ND-3441.1-2](#). Pumps with nozzle sizes NPS 4 (DN 100) discharge and smaller shall be constructed in accordance with (a) through (e). Larger pumps are permitted as stipulated in (f).

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t in. (mm), which is determined as follows:

$$t = (PA) / S$$

or 0.25 in. (6 mm), whichever is greater, where

A = scroll dimension, in. (mm), inside casing as shown in [Figure ND-3441.1\(a\)-1](#). If the value of dimension A exceeds 20 in. (500 mm), the equation shall not be used and (f) below applies.

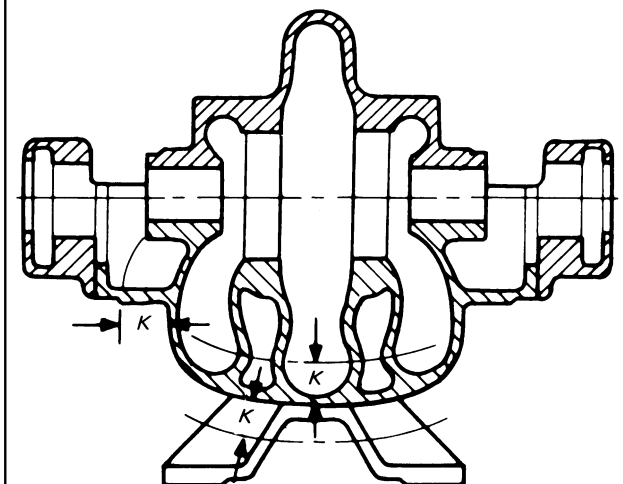
P = Design Pressure, psig (MPa gage)

S = allowable stress, including casting factor, psi (MPa) ([ND-2571](#) and Tables 1A and 1B, Section II, Part D, Subpart 1)

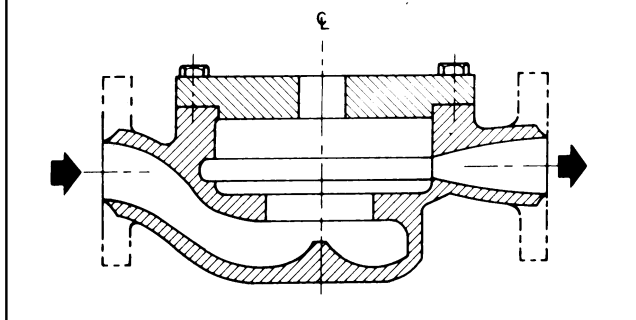
t = minimum allowable wall thickness, in. (mm)

(b) *Cutwater Tip.* The cutwater tip radius shall not be less than $0.05t$.

Figure ND-3436(c)-1
External and Internal Attachments



**Figure ND-3441.1-1
Type A Pump**



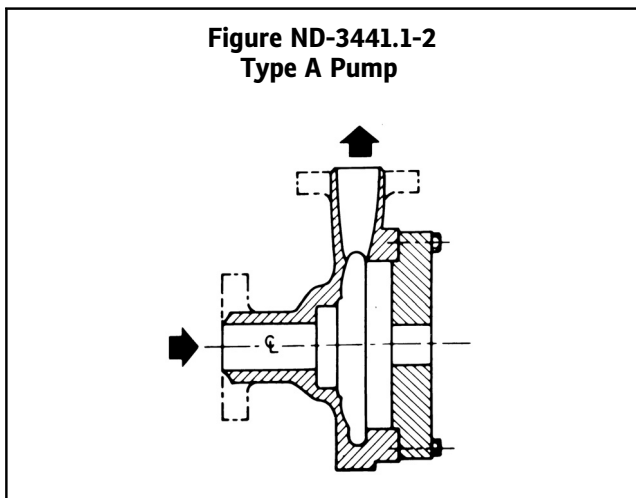
(c) *Cutwater Fillets.* All cutwater fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.1t$ or 0.25 in. (6 mm), whichever is greater.

(d) *Crotch Radius [Figure ND-3441.1(a)-1].* The crotch radius shall not be less than $0.3t$.

(e) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Figure ND-3441.1(a)-1 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness the greater of t from (a) or t_b . The value of t_b shall be determined by methods of ND-3300 or Appendix A using the appropriate equations for the casing shape.

(f) Pumps with an "A" dimension greater than 20 in. (500 mm) or nozzles larger than NPS 4 (DN 100) discharge are permitted. Design of these larger pumps must be performed in accordance with Appendix II, Experimental Stress Analysis, or ND-3414. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3551.1.

**Figure ND-3441.1-2
Type A Pump**



ND-3441.2 Design of Type B Pumps. Type B pumps are those having single volutes and radially split casings with double suction as illustrated in Figure ND-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

ND-3441.3 Design of Type C Pumps. Type C pumps are those having double volutes and radially split casings with a single suction as illustrated in Figures ND-3441.3-1 and ND-3441.3-2. The splitter is considered a structural part of the casing. Casing design shall be in accordance with the requirements of this Subarticle and with those given in (a) through (e) below.

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

$$t = (0.5PA) / S$$

where

A = scroll dimension, in. (mm), inside casing as shown in Figure ND-3441.3-2

P = Design Pressure, psig (MPa gage)

S = allowable stress, including casting factor, psi (MPa) (ND-2571 and Tables 1A and 1B, Section II, Part D, Subpart 1)

t = minimum allowable wall thickness, in.

(b) *Splitter Wall Thickness*

(1) The splitter, which is considered a structural part of the casing, shall have a minimum wall thickness of $0.7t$ as determined above for the casing wall and shall extend from point B in Figure ND-3441.3-2 sketch (a) through a minimum angle of 135° to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

(2) Cutwater tip and splitter tip radii shall not be less than $0.05t$.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.1t$ or 0.25 in. (6 mm), whichever is greater.

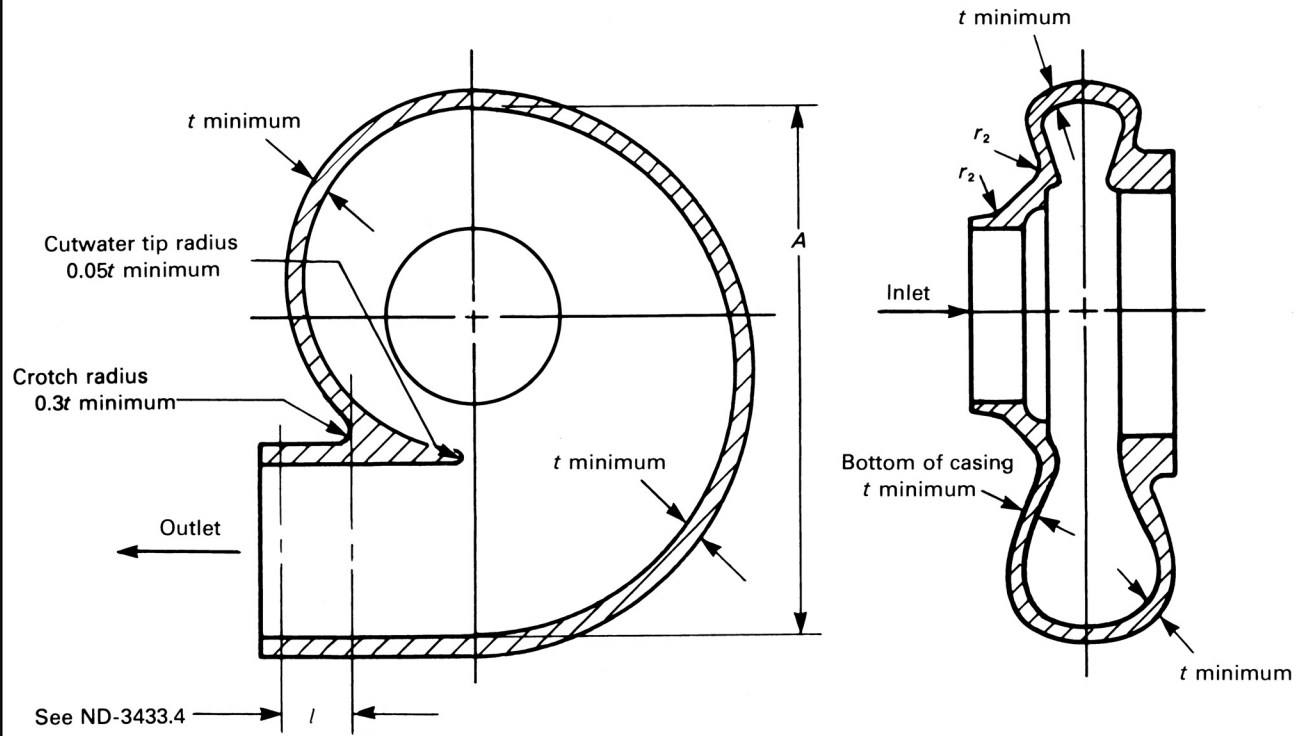
(c) *Crotch Radius (Figure ND-3441.3-2).* The crotch radius shall not be less than $0.3t$.

(d) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Figure ND-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness no less than the value of t determined in (a) above.

(e) *Alternative Rules for Casing Wall Thickness and Splitter Wall Thickness.* As an alternative to (a) and (b) above, it is permissible to use a smaller casing wall thickness and a larger splitter wall thickness when requirements of (1) through (3) below are met.

(1) The casing wall thickness, as determined by (a) above, shall be maintained at a minimum t , in., between the tangent point of the crotch radius to a point D radially

**Figure ND-3441.1(a)-1
Type A Pump**



opposite the splitter tip [Figure ND-3441.3-2 sketch (b)]. The casing wall shall be decreased uniformly to point E from which point a minimum thickness of $0.7t$ shall be continued around the casing wall to a point on the discharge nozzle a distance l , in. (mm), from the crotch, where l is defined in Figure ND-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness of t , in. (mm), instead of $0.7t$.

(3) The requirements of (b)(2) and (b)(3) above shall apply.

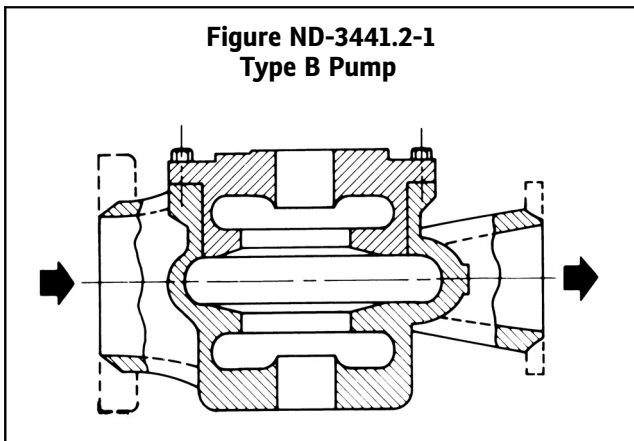
ND-3441.4 Design of Type D Pumps.

(a) Type D pumps are those having double volutes and radially split casings, with double suction as illustrated in Figure ND-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of ND-3400.

(b) The requirements of ND-3441.3(a), ND-3441.3(b), and ND-3441.3(c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

**Figure ND-3441.2-1
Type B Pump**



**Figure ND-3441.3-1
Type C Pump**

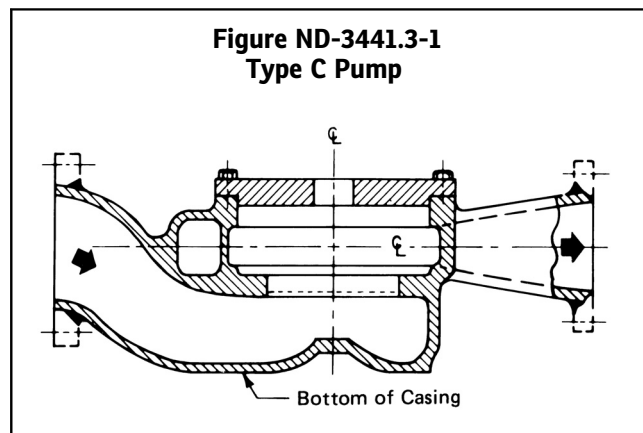
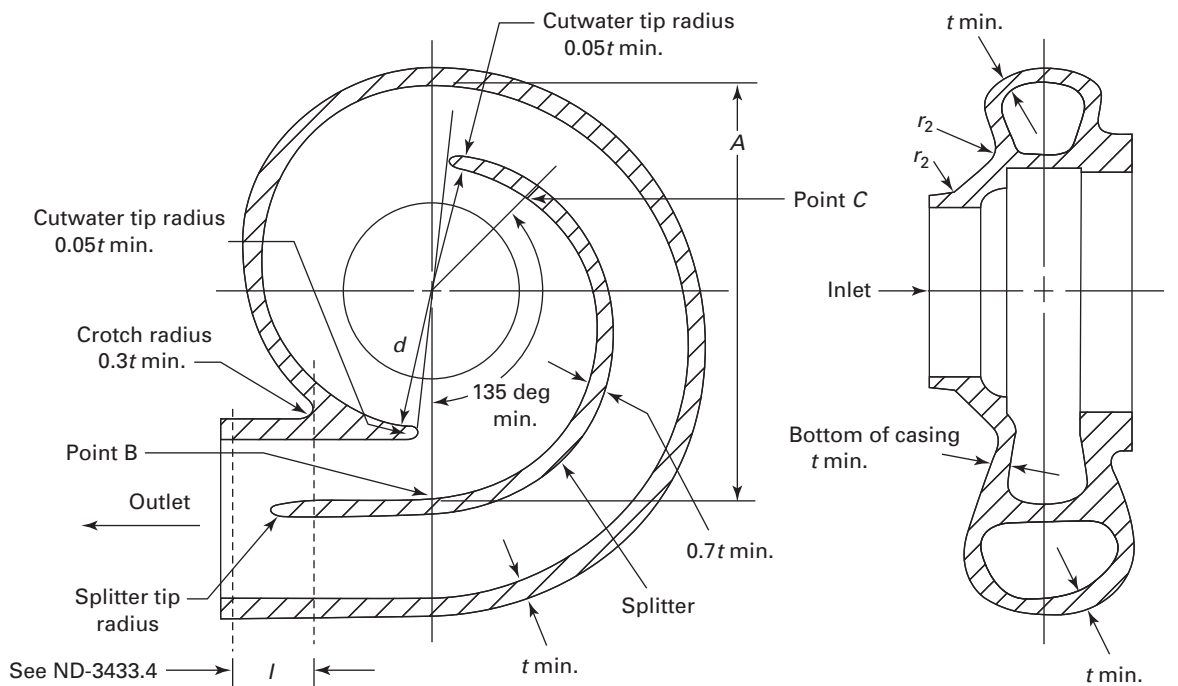
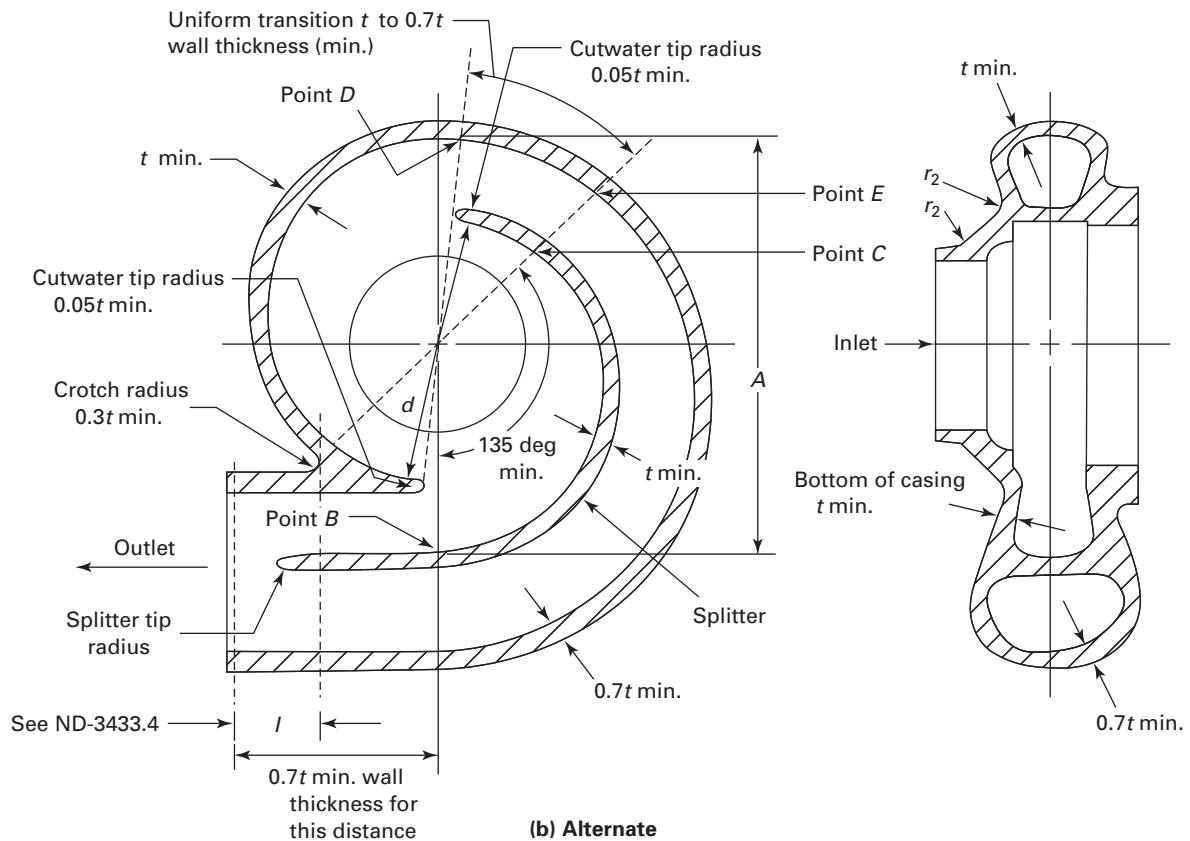


Figure ND-3441.3-2
Type C Pump

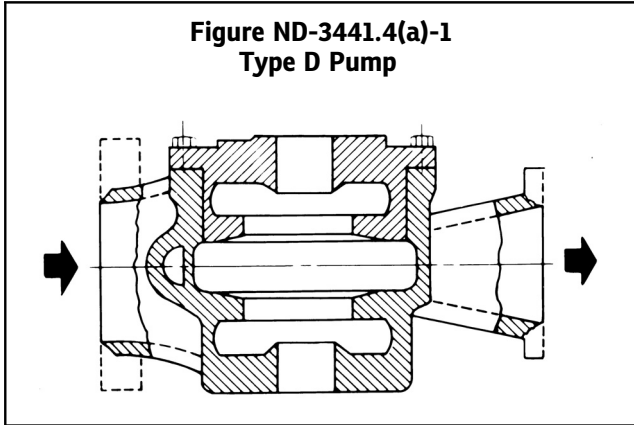


(a) Standard



(b) Alternate

**Figure ND-3441.4(a)-1
Type D Pump**



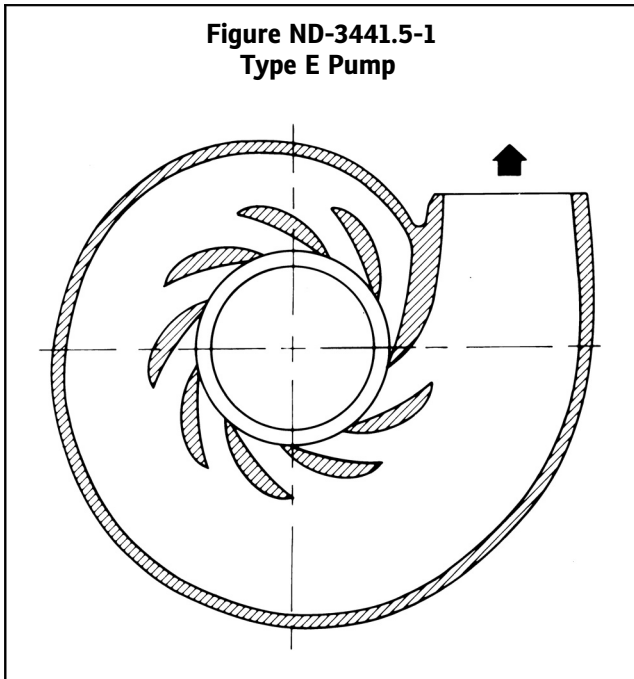
ND-3441.5 Design of Type E Pumps. Type E pumps are those having volute type radially split casings and multivane diffusers which form a structural part of the casing as illustrated in Figure ND-3441.5-1. The design shall be in accordance with the applicable requirements of ND-3400.

ND-3441.6 Design of Type F Pumps.

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Figure ND-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

(b) The design of Type F pumps shall be in accordance with the applicable requirements of ND-3400.

**Figure ND-3441.5-1
Type E Pump**



ND-3441.7 Design of Type G Pumps.²²

(a) Type G pumps are those having axially split, single or double volute casings [Figures ND-3441.7(a)-1 and ND-3441.7(a)-2].

(b) Manufacturers proposing this design should thoroughly review nondestructive examination requirements for compatibility.

(c) An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which more than one bolt falls within a given section [Figure ND-3441.7(c)-1, Section B – B].

(1) The following assumptions are made:

(-a) assign one bolt to Section X, assign one-half bolt to Section Y and one-half bolt to Section Z, Section Z is identical to Section Y;

(-b) the flange and bolts act together in bending;

(-c) the maximum moment occurs at the bolt;

(-d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

(2) Typical sections are shown in Figures ND-3441.7(c)(2)-1, ND-3441.7(c)(2)-2, and ND-3441.7(c)(2)-3. The procedure for the calculation is given in (-a) through (-o) below.

(-a) Establish Design Pressure P , psi (MPa). Establish dimensions A , B , C , F , R , t_c , t_f , w , and b from Figure ND-3441.7(c)(2)-1, Figure ND-3441.7(c)(2)-2, or Figure ND-3441.7(c)(2)-3 and determine the following:

A_b = bolt root area, in.² (mm²)

A_g = effective gasket area, in.² (mm²)

D = diameter of bolt hole, in. (mm)

d = bolt root diameter, in. (mm)

DTF = Design Temperature, °F (°C)

**Figure ND-3441.6(a)-1
Type F Pump**

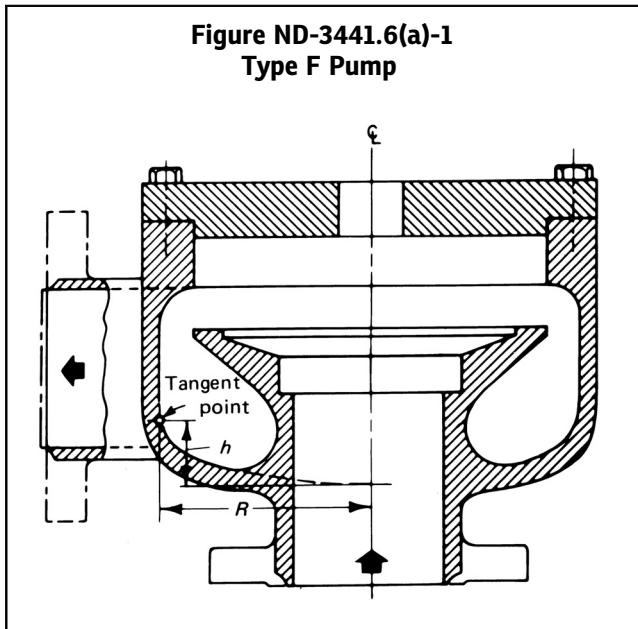
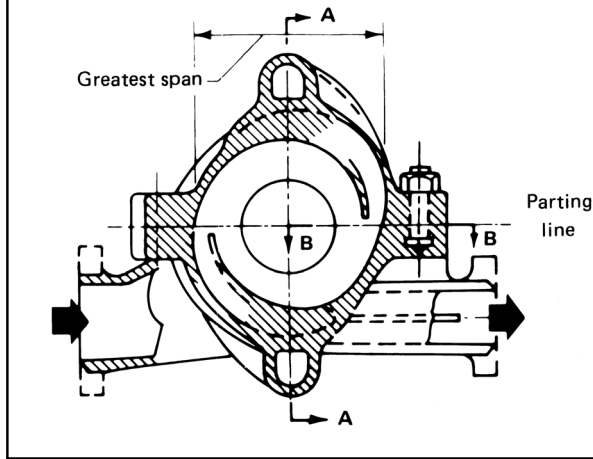


Figure ND-3441.7(a)-1
Axially Split Casing, Volute Pump, Type G



E = modulus of elasticity of bolt at service temperature, psi (MPa)

e = unit thermal elongation of bolt, in./in. (mm/mm)

$G = B + 0.5t_c$, in. (mm)

m = gasket factor (Table XI-3221.1-1)

$R = C - (B + t_c)$, in. (mm)

S_b = allowable stress, bolt, psi (MPa)

S_c = allowable stress, case, psi (MPa)

W = load used in calculating preliminary bolt stress, lb (N)

= W_x, W_y, W_z

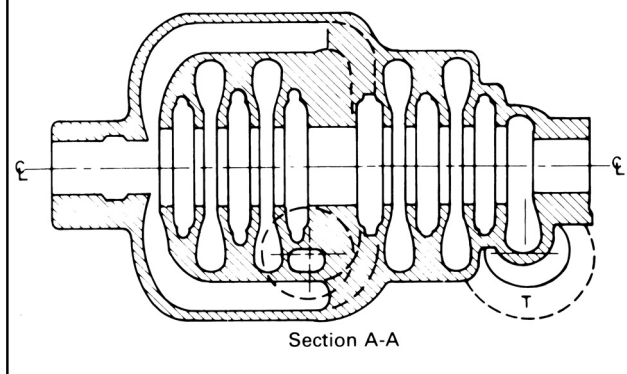
w = section width, in. (mm)

y = gasket design seating stress, psi (MPa) (Table XI-3221.1-1)

(-b) Determine the effective gasket area A_G , in.² (mm²), for Sections X and Y

$$A_G = \left[(A - F)w - (\pi D^2 / 4) \right] \times K$$

Figure ND-3441.7(a)-2
Axially Split Casing, Volute Pump, Type G



For the factor K , use 0.20 if case face is crowned for greatest contact pressure at inner edge; for flat surfaces, use 0.50.

(-c) Determine bolt load, lb (N), and preliminary bolt stress σ_{PRE} , psi (MPa)

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5 A_G y$$

$$W = \text{greater of } W_{m1} \text{ or } W_{m2}$$

$$\sigma_{PRE} = W / A_b$$

(-d) Determine the total load H_o , lb (N)

$$H_D = B \times w \times P$$

$$H_G = H_p$$

$$H_T = H - H_D$$

$$H_o = H_D + H_G + H_T$$

(-e) Determine the lever arms h_D , h_G , and h_T , in. (mm)

$$h_D = R + 0.5t_c$$

$$h_G = h_D$$

$$h_T = 0.5(R + t_c + h_G)$$

(-f) Determine the total moment M_o , in.-lb (N·mm):

$$M_D = H_D h_D$$

$$M_G = H_G h_G$$

$$M_T = H_T h_T$$

$$M_o = M_D + M_G + M_T$$

Figure ND-3441.7(c)-1
Axially Split Casing, Volute Pump, Type G
Section B – B Typical Highly Stressed Sections of Pump Case

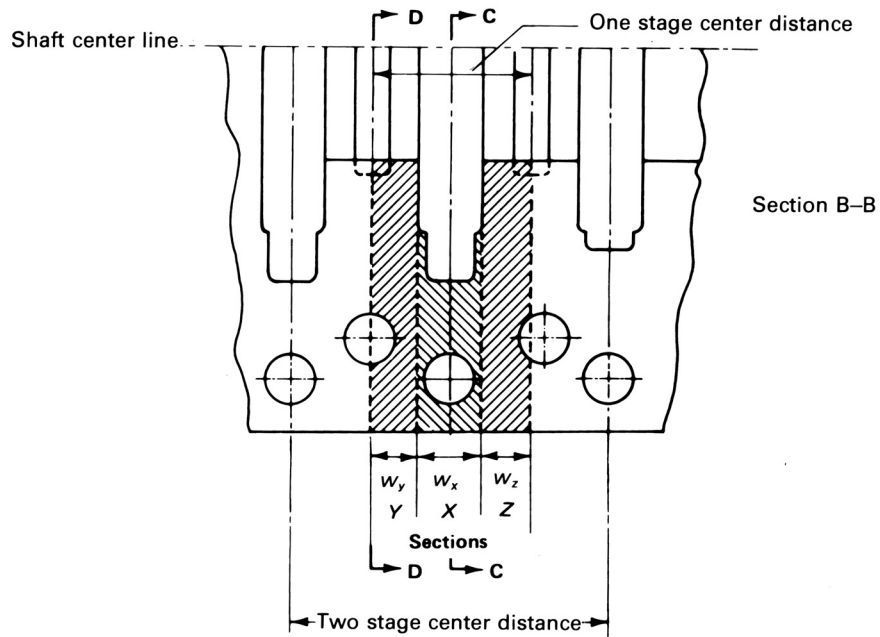


Figure ND-3441.7(c)(2)-1
Typical Section of Type G Pump

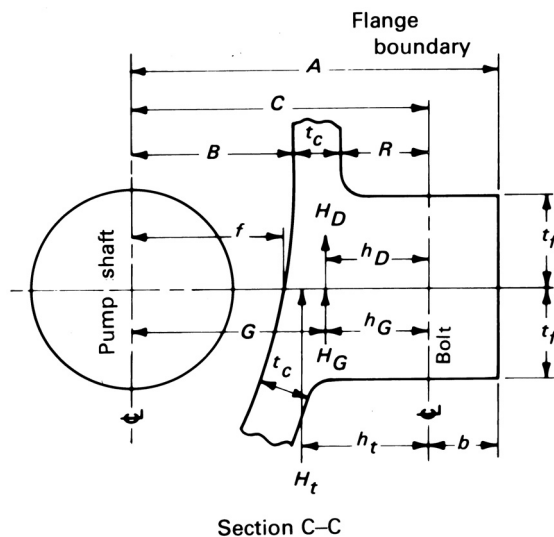
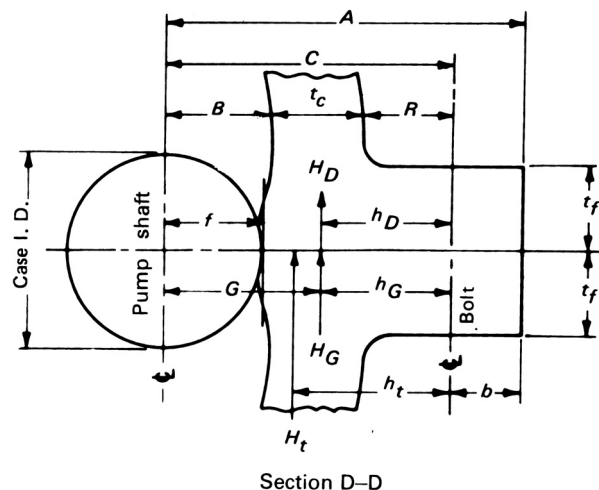
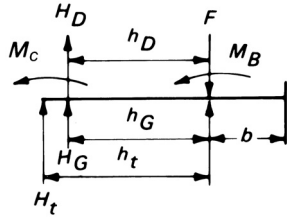


Figure ND-3441.7(c)(2)-2
Typical Section of Type G Pump



**Figure ND-3441.7(c)(2)-3
Typical Loads on Type G Pump**



(-g) Determine the moments of inertia, in.⁴ (mm⁴), I_F (flange), I_B (bolt), I_C (case), and I_T (total)

$$I_F = \left[w(t_f)^3 / 12 \right] - \left[D(t_f)^3 / 12 \right]$$

$$I_B = 0.049d^4$$

$$I_C = w(t_c)^3 / 12$$

$$I_T = I_F + I_B + I_C$$

(-h) Determine the moments, in.-lb (N·mm), carried M_F (flange), M_B (bolt), and M_C (case)

$$M_F = (M_o I_F) / I_T$$

$$M_B = (M_o I_B) / I_T$$

$$M_C = (M_o I_C) / I_T$$

(-i) Determine the resultant bolt load F_R , lb (N)

$$F_R = \left[H_D(b + h_D) + H_G(b + h_G) + H_T(b + h_T) - M_C - M_B \right] / b$$

or

$$F_R = H_o + \left[(M_o - M_C - M_B) / b \right]$$

(-j) Determine resultant bolt stresses, psi (MPa)

$$\sigma_{\text{Load}} = F_R / A_b$$

$$\sigma_{\text{Temp}} = eE$$

$$\sigma_{\text{Tensile}} = \sigma_{\text{Load}} + \sigma_{\text{Temp}}$$

$$\sigma_{\text{Bending}} = M_B d / 2I_B$$

(-k) Determine the shear and bending flange stresses σ'_s , psi (MPa), and σ'_b , psi (MPa), respectively

$$\sigma'_s = H_o / wt_f$$

$$\sigma'_b = M_F t_f / 2I_F$$

(-l) Determine the tensile and bending case stresses σ''_t , psi (MPa), and σ''_b , psi (MPa), respectively

$$\sigma''_t = H_D / wt_c$$

$$\sigma''_b = M_C t_c / 2I_C$$

(-m) Use the following method for combining stresses in combined section:

$$F_X = \text{load on section X, lb (N)}$$

$$F_Y = \text{load on section Y, etc., lb (N)}$$

$$S_X = \text{stress in section X, psi (MPa)}$$

$$S_Y = \text{stress in section Y, etc., psi (MPa)}$$

The combined stress S_{COMB} is as follows:

$$S_{\text{COMB}} = (F_X + F_Y) / [(F_X / S_X) + (F_Y / S_Y)], \text{ etc.}$$

(-n) Determine the maximum stresses using (-1) through (-4) below.

(-1) To determine the preliminary bolt stress, establish the load W and stress σ_{PRE} for Section X and for Section (Y + Z)

$$\sigma_{\text{PRECOMB}} = \frac{\frac{W_X}{\sigma_{\text{PREX}}} + \frac{W_{(Y+Z)}}{\sigma_{\text{PRE}(Y+Z)}}}{\frac{W_X}{\sigma_{\text{PREX}}} + \frac{W_{(Y+Z)}}{\sigma_{\text{PRE}(Y+Z)}}}$$

The allowable limit for this stress is S_b .

(-2) To determine the resultant bolt stress, establish the load F_R and the stresses σ_t and σ_b for Section X and for Section (Y + Z)

$$\sigma_{t\text{COMB}} = \frac{\frac{F_{RX}}{\sigma_{tX}} + \frac{F_{R(Y+Z)}}{\sigma_{t(Y+Z)}}}{\frac{F_{RX}}{\sigma_{tX}} + \frac{F_{R(Y+Z)}}{\sigma_{t(Y+Z)}}}$$

The allowable limit for $\sigma_{t\text{COMB}}$ is $2S_b$.

$$\sigma_{b\text{COMB}} = \frac{\frac{F_{RX}}{\sigma_{bX}} + \frac{F_{R(Y+Z)}}{\sigma_{b(Y+Z)}}}{\frac{F_{RX}}{\sigma_{bX}} + \frac{F_{R(Y+Z)}}{\sigma_{b(Y+Z)}}}$$

The allowable limit for $\sigma_{b\text{COMB}}$ is $3S_b$.

(-3) To determine the flange stresses, establish the load H_o , the shear stress σ'_s , and the bending stress σ'_b for Section X and for Section $(Y + Z)$

$$\sigma'_{s\text{COMB}} = \frac{H_{oX} + H_{o(Y+Z)}}{\frac{H_{oX}}{\sigma'_{sX}} + \frac{H_{o(Y+Z)}}{\sigma'_{s(Y+Z)}}} \sigma'_{b\text{COMB}} = \frac{H_{oX} + H_{o(Y+Z)}}{\frac{H_{oX}}{\sigma'_{bX}} + \frac{H_{o(Y+Z)}}{\sigma'_{b(Y+Z)}}}$$

$$\sigma'_{s\text{max}} = \left[\left(\sigma'_{s\text{COMB}} \right)^2 + \left(\sigma'_{b\text{COMB}} / 2 \right)^2 \right]^{1/2}$$

$$\sigma'_{n\text{max}} = \sigma'_{s\text{max}} + \left(\sigma'_{b\text{COMB}} / 2 \right)$$

where $\sigma'_{n\text{max}}$ is the maximum normal stress. The allowable limit for $\sigma'_{s\text{max}}$ is S_c and the allowable limit for $\sigma'_{n\text{max}}$ is $1.5S_c$.

(-4) To determine the case stresses, establish the load H_D , the tensile stress σ''_t , and the bending stress σ''_b for Section X and for Section $(Y + Z)$

$$\sigma''_{t\text{COMB}} = \frac{H_{DX} + H_{D(Y+Z)}}{\frac{H_{DX}}{\sigma''_{tX}} + \frac{H_{D(Y+Z)}}{\sigma''_{t(Y+Z)}}}$$

$$\sigma''_{b\text{COMB}} = \frac{H_{DX} + H_{D(Y+Z)}}{\frac{H_{DX}}{\sigma''_{bX}} + \frac{H_{D(Y+Z)}}{\sigma''_{b(Y+Z)}}}$$

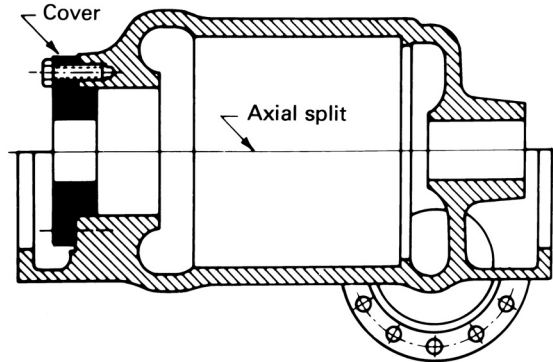
The allowable limit for $\sigma''_{t\text{COMB}}$ is S_c . The total stress is $\sigma''_{t\text{COMB}} + \sigma''_{b\text{COMB}}$. The allowable limit for total stress is $1.5S_c$.

(-o) The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

ND-3441.8 Design of Type H Pumps. Type H pumps are those having axially split, barrel type casings (Figures ND-3441.8-1 and ND-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of ND-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of ND-3437.

ND-3441.9 Design of Type K Pumps. Type K pumps are vertical pumps having a radially split casing with one or more internal pump stages, as illustrated in Figures ND-3441.9-1 and ND-3441.9-2. The basic configuration is a casing that forms the pressure boundary and consists of

**Figure ND-3441.8-1
Longitudinal Section Through Type H Pump**

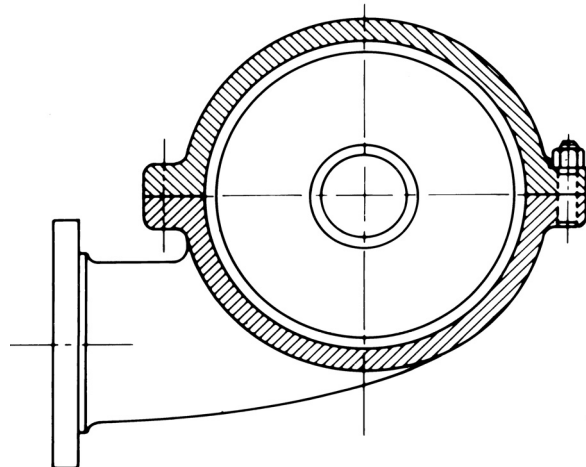


a barrel and a head joined by bolted flanges. There is an inner assembly consisting of internal chambers of the head, one or more bowls, column sections, and a suction bell, all joined by bolted flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column(s) and with or without lateral restraints between the inner assembly and outer casing.

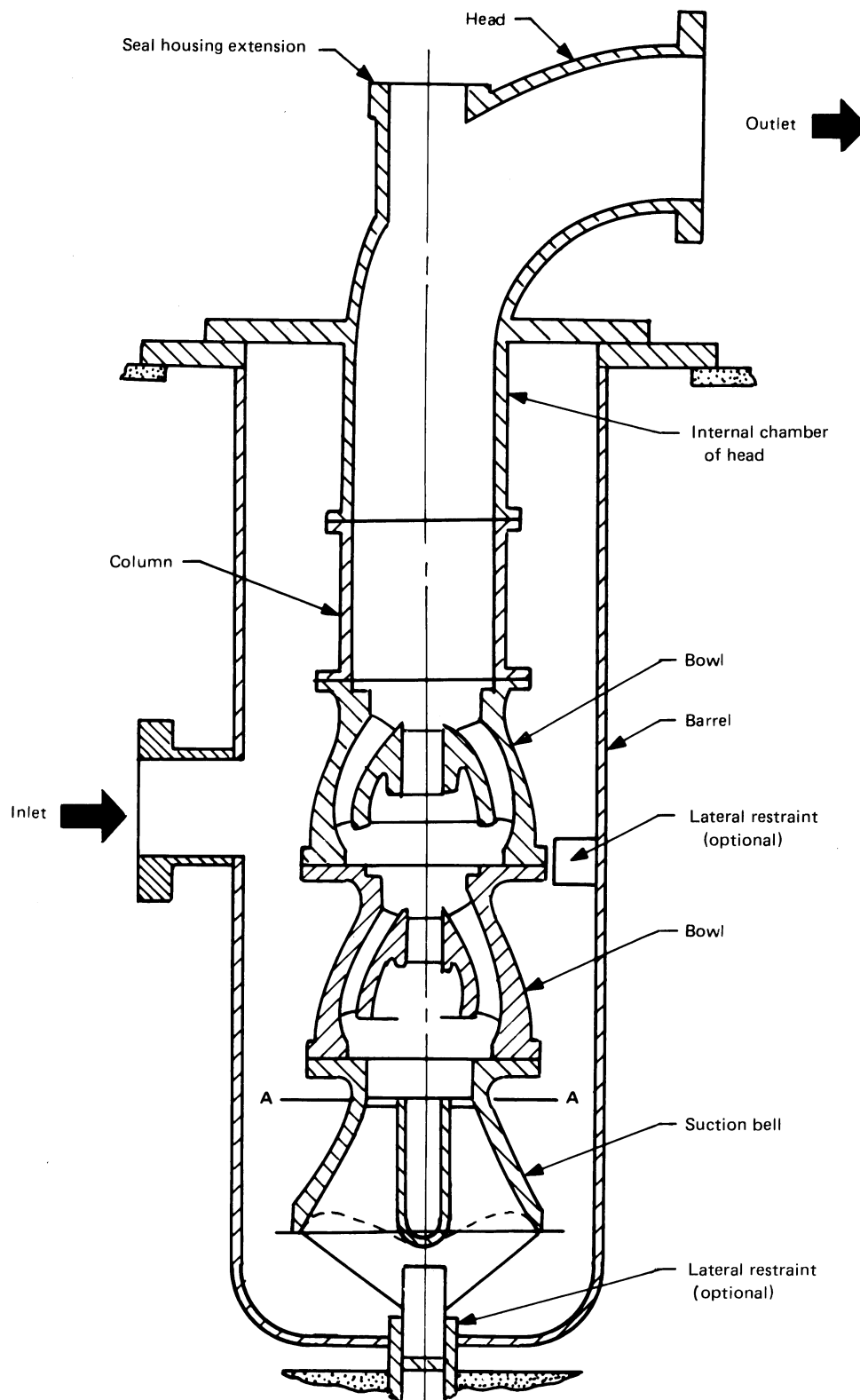
(a) *Flanged Joints.* Except for flanged joints conforming to (5), flanged joints may be analyzed and the stresses evaluated by using methods given in Appendix XI if of the "RF" type and in accordance with Appendix L if of the "FF" type, as modified by (1) through (4) below or by (5) below.

(1) The Design Pressure to be used for the calculation of H in Appendix XI or Appendix L shall be replaced by the flange design pressure

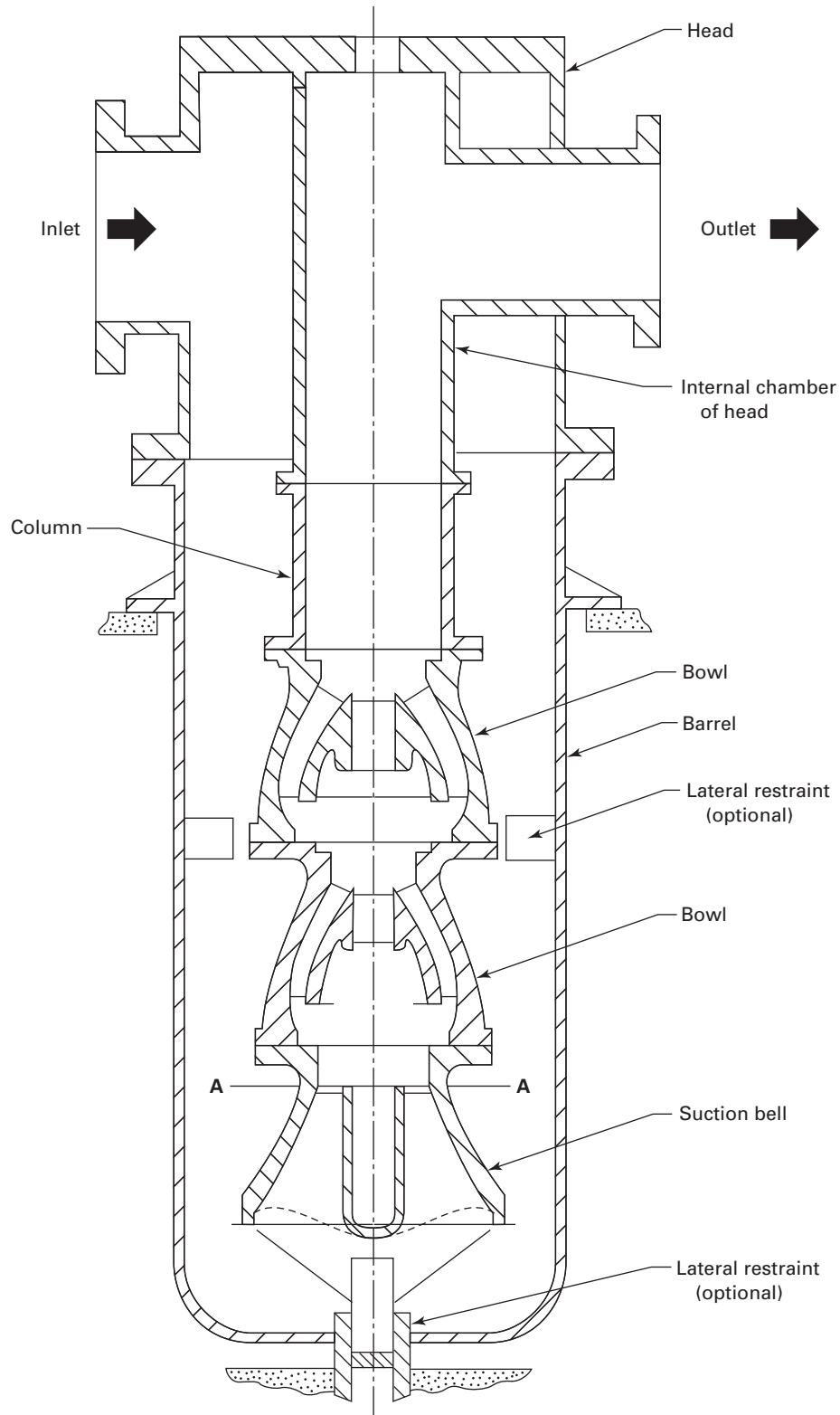
**Figure ND-3441.8-2
Transverse Section Through Type H Pump**



**Figure ND-3441.9-1
Type K Pump**



**Figure ND-3441.9-2
Type K Pump**



$$P_{FD} = P + P_{eq} \quad (1)$$

where

P = design or Service Condition Pressure as defined in NCA-2140, psi (MPa)

P_{eq} = equivalent pressure to account for the axial force and moments applied to the flange joint, psi (MPa)

The equivalent pressure, P_{eq} , shall be determined from the seismic and external loads acting on the flanged joint using the equation

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{4F}{\pi G^2} \quad (2)$$

where

F = the axial load at the flange, lbf (N)

G = the diameter at the location of the gasket load reaction, in. (mm)

K = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

M_f = the resultant bending moment on the flange as taken from paragraph ND-3658, in.-lbf (N·mm)

(2) Equations (3) and (4) in Section III Appendices, Mandatory Appendix XI, XI-3223 or Section III Appendices, Nonmandatory Appendix L, L-3221 shall be used to establish minimum bolt area required using allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

(3) Equation (6) in Section III Appendices, Mandatory Appendix XI, XI-3240 for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1^2B} + \frac{PB}{4g_o} \quad (3)$$

where P is the Design or Service Pressure as defined in NCA-2140, psi (MPa). Other terms are defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(4) The allowable stress limits S_H , S_R , and S_T shall not be greater than $1.5S$.

(5) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1 and if each P_{FD} as calculated by eq. (1)(1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) *Casing*. The barrel and head of the casing shall be designed in accordance with the requirements of ND-3400 and with those given in (1) and (2) below.

(1) *Barrel*. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be

less than the maximum pressure at the pump inlet under any Service Condition. The static pressure head shall be considered in the selection of the Design Pressure.

The inlet nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2), as applied to the inlet geometry.

The barrel shall be designed in accordance with the requirements of ND-3320 for pressure vessels.

(2) Head

(-a) The external walls of the head, which form the pressure boundary shall be designed for the pressures specified in (-b) and (-c) below. The Design Pressure for the internal chambers shall be as specified under the inner assembly rules.

(-b) The Design Pressure P for the portions of the head that form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

The minimum thickness of the head waterway required for Design Pressure and for temperatures not exceeding those for various materials in Tables 1A and 1B, Section II, Part D, Subpart 1 shall be not less than that determined by the equation

$$t_m = \frac{P D_o}{2(SE + Py)} + A \quad (4)$$

where

A = corrosion or erosion allowance as specified by the Design Specification, in. (mm). If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.

D_o = the outside diameter of the head waterway, in. (mm)

d = inside diameter of the head waterway, in. (mm)

E = the joint efficiency for the type of longitudinal joint used, as given in ND-3350 or casting quality factor as given in the notes to Tables 1A and 1B, Section II, Part D, Subpart 1

S = the allowable stress for the material at the design temperature (Tables 1A and 1B, Section II, Part D, Subpart 1), psi (MPa)

t_m = minimum required wall thickness of the head waterway in its finished form, in. (mm)

$y = 0.4$ for D_o/t_m greater or equal to 6.0

$= \frac{d}{d + D_o}$ for D_o/t_m less than 6.0

The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

The discharge nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2), as applied to the head geometry.

(-c) The Design Pressure for the portions of the head that form the pressure-containing boundary between the inlet pressure and the atmosphere shall be the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition.

This portion of the head shall be designed in accordance with ND-3320 for pressure vessels.

(c) *Inner Assembly.* The inner assembly consists of those elements of the pump subjected to differential pressure within the pump. This assembly comprises the internal chambers of the head, the bowls and columns, and the upper flange of the suction bell.

Because of the installation and operation, pumped fluids within the inner assembly may transfer through the flanged connections back to the inlet fluid source. This fluid transfer does not effect the integrity of the overall pressure boundary but may result in a higher Design Pressure for the barrel and portions of the head and shall be considered in the determination of the barrel Design Pressure.

The Inner Assembly of Type K pumps shall be designed in accordance with the requirements of ND-3400 and with those given in (1) through (3) below. Alternatively, the configuration may be designed in accordance with Appendix II, Design by Experimental Stress Analysis, or Appendix XIII, Design by Stress Analysis.

(1) *Columns.* The Design Pressure for columns, P_c psi (MPa), shall include the piping moments and axial loads. It shall be not less than the maximum differential pressure that can be developed across the wall of that column under any Service Condition. The weight of the pump bowls and impeller thrust shall be taken into consideration. P_c shall be determined using eqs. (a)(1)(1) and (a)(1)(2) but with "G" equal to the average column shell diameter.

The minimum thickness of the column shall be not less than that determined by the equation

$$t_m = \frac{P_c D_o}{2(SE + P_y)} + A \quad (5)$$

where the terms are as defined in (b)(2)(-b), but as applied to the column geometry and material.

(2) *Column Flanges.* Flanged joints in the column shall be designed in accordance with (a) except that the design pressure shall be P_c . The equivalent pressure shall be determined using eq. (a)(1)(1) as applied to the column geometry and shall be not less than the maximum differential pressure that can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(3) *Bowls.* The Design Pressure for the bowl(s), P_b , shall include the piping moments. The equivalent pressure shall be determined using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2), as applied to the bowl geometry and shall be determined as the maximum differential pressure to which the bowl may be subjected under any Service Condition.

The design of the bowls shall be completed in accordance with (-a) through (-c) below for unribbed bowl geometries. For those bowl geometries which use external ribs to increase bowl and flange stiffness the design shall be completed using methods which have been proven in actual service. Unless special provisions are made to insure that interchangeability between bowls is prevented all bowls shall be designed to the same requirements.

(-a) *Bowl Minimum Thickness.* The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by

$$t_m = \frac{P_b D_o}{2(SE + P_{by})} + A \quad (6)$$

where the terms are as defined in (b)(2)(-b) but as applied to the bowl geometry and material and

D_o = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly, (Figure ND-3441.10-2), in. (mm)

The above minimum bowl thickness is applicable only to a location within the bowl which is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (-b) and (-c) below.

(-b) *Vane/Shell Interaction.* Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below

$$F_D = \frac{2(2 - \mu)P_b A_D^2}{\frac{16 l_D t_D}{t_v} + \frac{t_D (\pi A_D)^3}{(n_v t_D)^3}} \quad (7)$$

where

A_D = the mean diameter of the vaned portion of the bowl as defined in Figure ND-3441.10-2, in. (mm)

F_D = vane load/unit length, lbf/in. (N/mm)

l_D = the radial mean vane length as defined in Figure ND-3441.10-2, in. (mm)

n_v = the number of vanes in the bowl waterway

P_b = the maximum internal bowl differential pressure, psi (MPa)

t_D = the shell thickness at the vane-shell intersection as defined in Figure ND-3441.10-2, in. (mm)

t_v = the mean vane thickness, in. (mm)

μ = Poisson's ratio

The local shell bending stress, σ_B , shall be less than 1.5SE. Its value is determined by the equation

$$\sigma_B = \frac{3 F_D \pi A_D}{n_v t_D^2} \quad (8)$$

The vane membrane stress, σ_v , shall be less than SE as determined by the equation

$$\sigma_v = \frac{F_D}{t_v} \quad (9)$$

(-c) *Bowl Flanges.* The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Appendix XI. This may not be true for ribbed flanges or the last stage bowl that attaches to the column assembly. If any of these joints have sufficient rigidity to support the prying action it shall be analyzed as an Appendix L flange. The analysis shall be in accordance with (a) using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2). The definition of the outlet flange geometry for the analysis is shown in Figure ND-3441.10-2.

The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbet fit shall be equal to or greater than one bolt diameter.

(4) *Suction Bell.* The Design Pressure for the suction bell, P_{sb} , shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2). The suction bell pressure, P_{sb} , is applied only to the suction bell flange. Below the suction bell flange (the section above line A-A in Figures ND-3441.9-1 and ND-3441.9-2), the remaining portions of the bell are not considered subject to a differential pressure.

ND-3441.10 Design of Type L Pumps. Type L pumps are vertical pumps of one or more stages, having a radially split casing as illustrated in Figure ND-3441.10-1. The basic configuration consists of a head with an attached support plate, one or more bowls and column sections, and a suction bell, all joined by flanges. These pumps may be furnished with or without column. External restraint may be provided at various locations to restrain vibratory motions and resist external loads.

The configuration is such that the external surfaces of those parts above the support plate are subjected to atmospheric pressure. The parts below the support plate may be subjected to atmospheric pressure, or atmospheric pressure plus submerged head pressures. Because of the installation and operation, pumped fluids within the bowl and column assemblies may transfer through the flanged

connections back to the fluid source. This fluid transfer does not effect the integrity of the overall pressure boundary.

Type L pumps shall be designed in accordance with the requirements of ND-3400 and with those given in (a) through (e) below. Alternatively, the configuration may be designed in accordance with Appendix II, Design by Experimental Stress Analysis, or Appendix XIII, Design by Stress Analysis.

(a) *Flanged Joints.* Except for flanged joints conforming to (5) below, flanged joints may be analyzed and the stresses evaluated by using methods given in Appendix XI if of the "RF" type and in accordance with Appendix L if of the "FF" type, as modified by (1) through (4) below.

(1) The Design Pressure to be used for the calculation of H in Appendix XI or Appendix L shall be replaced by the flange design pressure

$$P_{FD} = P + P_{eq} \quad (1)$$

where

P = Design or Service Condition Pressure as defined in NCA-2140, psi (MPa)

P_{eq} = equivalent pressure to account for the moments applied to the flange joint, psi (MPa)

The equivalent pressure P_{eq} , shall be determined from the seismic and external loads acting on the flanged joint using the equation

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{PB}{\pi G^2} \quad (2)$$

where

F = the axial load at the flange, lb (N)

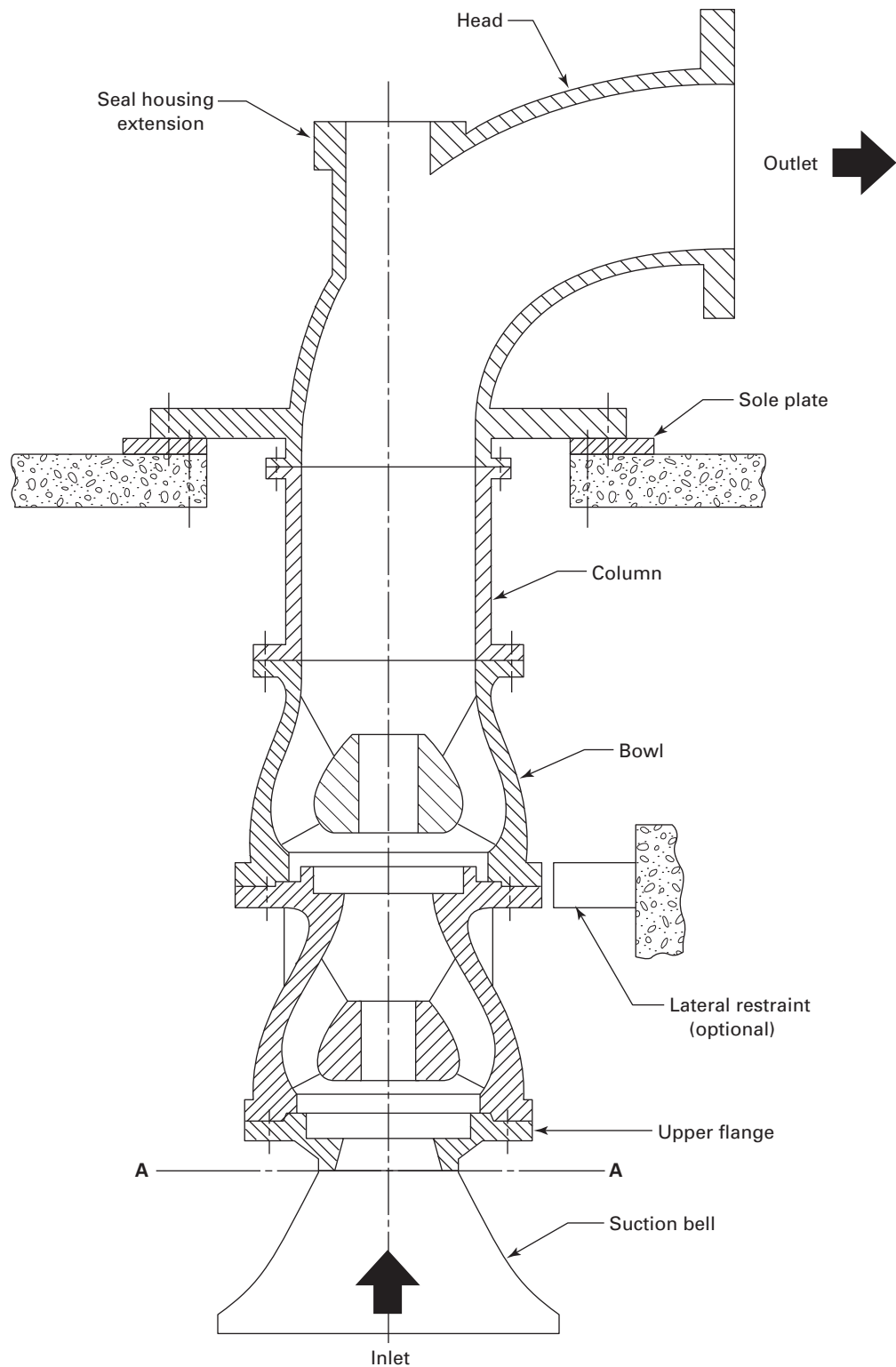
G = the diameter at the location of the gasket load reaction, in. (mm)

K = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

M_f = the resultant bending moment on the flange as taken from ND-3658, in.-lbf (N·mm)

(2) Equations (3) and (4) in Section III Appendices, XI-3223 or Section III Appendices, Nonmandatory Appendix L, shall be used to establish minimum bolt area required using allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

**Figure ND-3441.10-1
Type L Pump**



(3) Equation (6) in Section III Appendices, Mandatory Appendix XI, XI-3240 for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1^2B} + \frac{PB}{4g_o} \quad (3)$$

where P is the Design or Service Pressure as defined in NCA-2140, [psi (MPa)]. Other terms are defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(4) The allowable stress limits S_H , S_R , and S_T shall not be greater than $1.5S$.

(5) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1 and if each P_{FD} as calculated by eq. ND-3441.9(a)(1)(1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) *Head Waterway*. The Design Pressure P for portions of the head which form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification. In no case shall it be less than the maximum pressure at the pump outlet under any Service Condition. The minimum thickness of the head waterway required for Design Pressure and for temperatures not exceeding those for various materials in Tables 1A and 1B, Section II, Part D, Subpart 1 shall be not less than that determined by the equation

$$t_m = \frac{PD_o}{2(SE + Py)} + A \quad (4)$$

where

- A = corrosion or erosion allowance as specified by the Design Specification, in (mm). If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.
- D_o = the outside diameter of the head waterway, in. (mm)
- d = inside diameter of the head waterway, in. (mm)
- E = the joint efficiency for the type of longitudinal joint used, as given in ND-3350 or casting quality factor as given in the notes to Tables 1A and 1B, Section II, Part D, Subpart 1
- S = the allowable stress for the material at the design temperature (Tables 1A and 1B, Section II, Part D, Subpart 1), psi (MPa)
- t_m = minimum required wall thickness of the head waterway in its finished form, in. (mm)
- y = 0.4 for $D_o/t_m \geq 6.0$
- = $\frac{d}{d + D_o}$ for $D_o/t_m < 6.0$

The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

(c) *Column*. The Design Pressure for the column P_c shall include the effects of the piping moments and axial loads. It shall be not less than the maximum differential pressure that can be developed across the wall of that column under any Service Condition. The weight of the pump bowls and impeller thrust shall be taken into consideration. P_c shall be determined using eqs. (a)(1)(1) and (a)(1)(2) but with "G" equal to the average column shell diameter.

(1) *Column Thickness*. The minimum thickness of the column shall be not less than that determined by the equation

$$t_m = \frac{P_c D_o}{2(SE + Py)} + A \quad (5)$$

where the terms are as defined in (b) above, except as applied to the column geometry and material.

(2) *Column Flanges*. Flanged joints in the column shall be designed in accordance with (a) except that the design pressure shall be P_c . The equivalent pressure shall be determined using eq. (a)(1)(1) as applied to the column geometry and shall be not less than the maximum differential pressure which can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(d) *Bowls*. The Design Pressure for the bowl(s) P_b shall be determined as the maximum differential pressure to which the bowl may be subjected under any service condition.

The design of the bowls shall be completed in accordance with (1) through (3) below for unribbed bowl geometries. For those bowl geometries that use external ribs to increase bowl and flange stiffness, the design shall be completed using methods that have been proven in actual service. In both cases, the pump bowl experiencing the largest load shall be used in the design. Unless special provisions are made to insure that interchangeability between bowls is prevented, all bowls shall be designed to the same requirements.

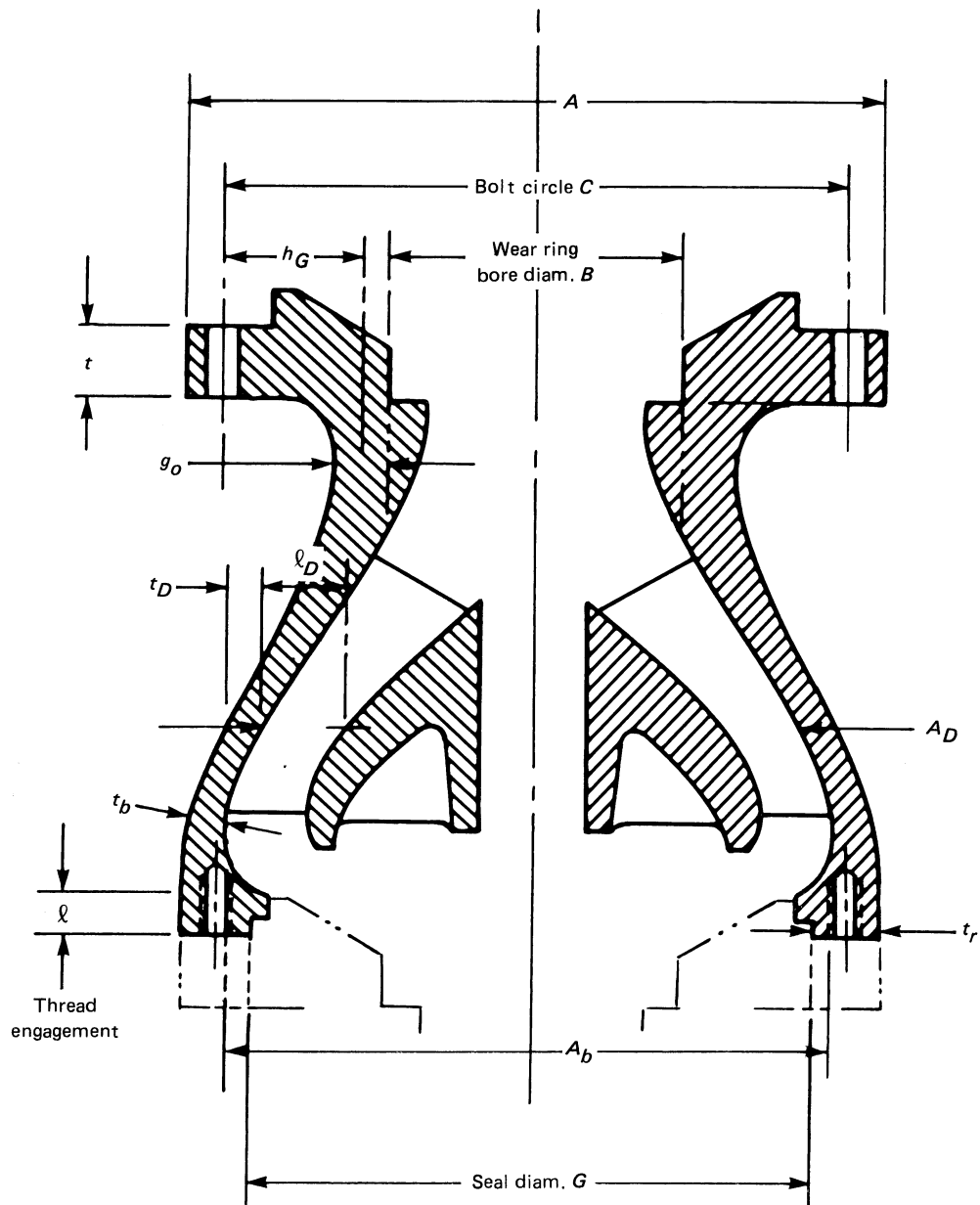
(1) *Bowl Minimum Thickness*. The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by

$$t_m = \frac{P_b D_o}{2(SE + Py)} + A \quad (6)$$

where

D_o = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly (Figure ND-3441.10-2), in. (mm)

Figure ND-3441.10-2
Type L Pump Bowl



The above minimum bowl thickness is applicable only to a location within the bowl that is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (2) and (3) below.

(2) *Vane/Shell Interaction*. Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below.

$$F_D = \frac{2(2 - \mu) P_b A_D^2}{\frac{16 I_D t_D}{t_v} + \frac{t_D (\pi A_D)^3}{(n_v t_d)^3}} \quad (7)$$

where

A_D = the mean diameter of the vaned portion of the bowl as defined in Figure ND-3441.10-2, in. (mm). The section shall be taken at a portion of the bowl where the hub can be considered essentially solid.

F_D = vane load/unit length, lbf/in. (N·mm)

I_D = the radial mean vane length as defined in Figure ND-3441.10-2, in. (mm)

n_v = the number of vanes in the bowl waterway

P_b = the maximum internal bowl differential pressure, psi (MPa)

t_D = the shell thickness at the vane-shell intersection as defined in Figure ND-3441.10-2, in. (mm)

t_v = the mean vane thickness, in. (mm)

μ = Poisson's ratio

The local shell bending stress σ_v shall be less than 1.5SE. Its value is determined by the equation

$$\sigma_v = \frac{F_D}{t_v} \quad (8)$$

(3) *Bowl Flanges*. Flanged joints in the bowls shall be designed in accordance with (a) except that the design pressure shall be P_b . The equivalent pressure shall be determined using eq. (a)(1)(1), as applied to the bowl geometry and shall be not less than the maximum differential pressure that can be developed across the wall of that bowl under any Service Condition. Unpacked flange joints are permitted. The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Appendix XI. This may not be true for ribbed flanges or the last stage bowl that attaches to the column assembly. The definition of the outlet flange geometry for the analysis is shown in Figure ND-3441.10-2.

The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbet fit shall be equal to or greater than one bolt nominal diameter.

(e) *Suction Bell*. The Design Pressure for the suction bell P_{sb} shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using eq. (a)(1)(1), with $F = 0$ in eq. (a)(1)(2), except using the geometry of the suction bell. The suction bell pressure, P_{sb} , is applied only to the suction bell flange. Below the suction bell flange (Section A-A of Figure ND-3441.10-1), the remaining portion of the bell and any strainer basket that may be attached thereto are not considered subject to a differential pressure load.

ND-3442 Special Pump Types

ND-3442.1 Design of Type J Pumps (Centrifugal).

(a) Type J pumps are those that cannot logically be classified with any of the preceding types of centrifugal pumps.

(b) It is not planned to establish rules for Type J pumps, and any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

ND-3442.2 Design of Reciprocating Pumps. See ND-3450.

ND-3450 DESIGN OF CLASS 3 RECIPROCATING PUMPS

ND-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Figure ND-3451(a)-1], whose failure would violate the pressure boundary. Such parts include

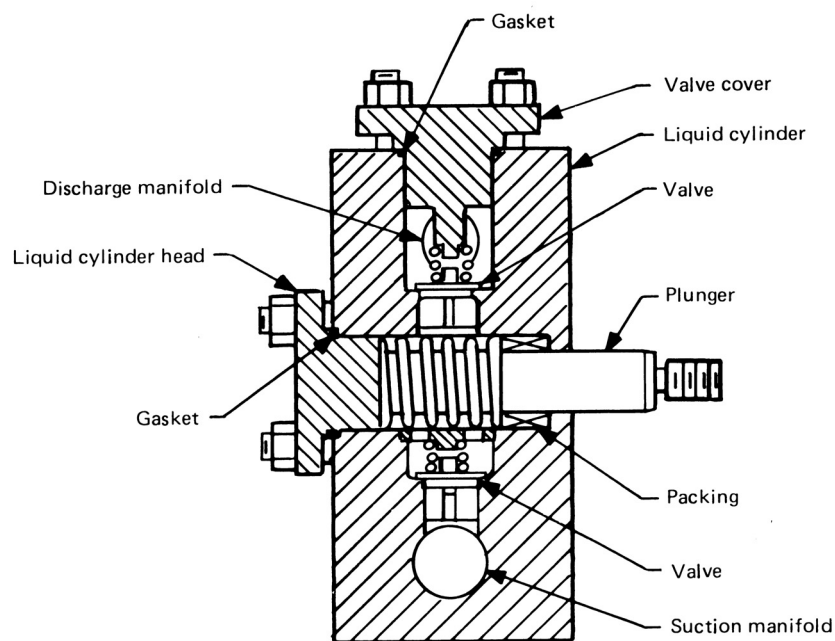
- (1) liquid cylinder and valve chambers
- (2) valve covers
- (3) liquid cylinder heads
- (4) stuffing boxes
- (5) packing glands
- (6) manifolds
- (7) piping and nozzles normally identified with the pump furnished by the pump supplier
- (8) related bolting
- (9) external and internal integral attachments to the pressure retaining boundary

(b) These rules do not apply to the plunger or piston, nonstructural internals, including valves, valve seats, gaskets, packing, and cylinder mounting bolting. Hydrostatic testing of packing glands is not required.

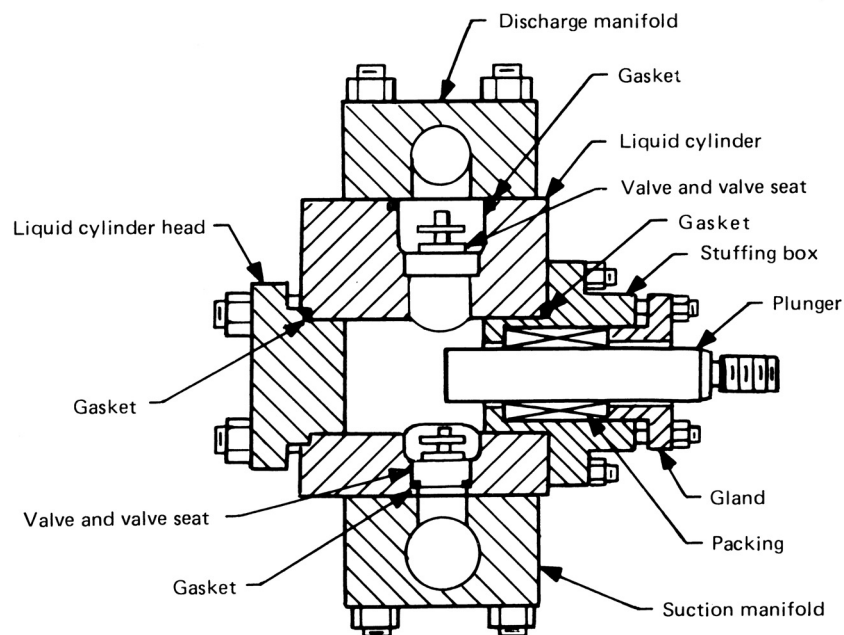
ND-3452 Acceptability

The pressure boundary parts shall be capable of withstanding the specified Design Pressures, and the design shall be such that the requirements of ND-3100 are satisfied in addition to these rules.

Figure ND-3451(a)-1
Horizontal Single-Acting Power Pump Liquid Ends



(a)



(b)

ND-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of ND-2000.

ND-3454 Design Requirements**ND-3454.1 Design of Welded Construction.**

(a) Design of welded construction shall be in accordance with ND-3350.

(b) Partial penetration welds, as shown in Figure ND-4244(e)-1 sketch (c-3) and Figure ND-4244(f)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

ND-3454.2 Piping. Piping located within the pressure retaining boundary of the pump, and identified with the pump, shall be designed in accordance with ND-3600.

ND-3454.3 Liquid End. Any design method that has been demonstrated to be satisfactory for the specified design may be used.

ND-3454.4 Fatigue. The liquid cylinder and pressure retaining bolting are exposed to significant fatigue loadings that shall be considered in the design. Any design method that has been demonstrated to be satisfactory for the specified design may be used.

ND-3454.5 Earthquake Loadings. The effects of earthquake shall be considered in the design of pumps. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

ND-3454.6 Corrosion. In designs where corrosion of material is a factor, allowances shall be made.

ND-3454.7 Bolting. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI.

ND-3500 VALVE DESIGN**ND-3510 GENERAL REQUIREMENTS****ND-3511 Design Specification**

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). The requirements of NCA-3254(a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of ND-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3254(b) for specifying the boundary conditions are not applicable to valve end connections.

CAUTION: Certain types of double-seated valves have the capability of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or his designee to provide, or require to be provided, protection against harmful overpressure in such valves.

ND-3512 Standard Design Rules**ND-3512.1 Flanged and Butt Welded End Valves. (13)**

The design of valves with flanged and butt welded ends shall conform to the applicable requirements for Standard Class category valves of ASME B16.34 except as provided in (a) and (b) below.

(a) Valves with flanged and butt welding ends may be designated as Class 75 in sizes larger than NPS 24 (DN 600), provided that the following additional requirements are met.

(1) The maximum rated pressure shall be 75 psi (520 kPa) for fluid temperatures from -20°F to 350°F (-30°C to 175°C).

(2) The minimum valve body wall thickness, exclusive of corrosion allowance, shall be in accordance with the following:

$$t_m = 0.4t_o + 0.2 \text{ for } d \leq 50 \text{ in. (1 250 mm)}$$

or

$$t_m = 0.008d + 0.2 \text{ for } d > 50 \text{ in. (1 250 mm)}$$

where

d = inside diameter, in. (mm)

t_m = minimum body wall thickness, in. (mm)

t_o = minimum body wall thickness as tabulated in ASME B16.34 for Class 150, in. (mm)

(3) Flanges shall be designed in accordance with the requirements of Section III Appendices, Mandatory Appendix XI, ANSI/AWWA C207 Class E (275 psi) or ASME B16.47.

(4) The minimum hydrostatic shell test pressure shall be 125 psi (860 kPa) and shall be maintained for a minimum of 10 min.

(5) The minimum valve closure test pressure shall be 85 psi (590 kPa) and shall be maintained for a minimum of 10 min.

(b) Valves with flanged ends in sizes larger than NPS 24 (DN 600) may be used, provided that the following additional requirements are met.

(1) For ASME B16.47, the Pressure Class shall be limited to Class 150 and Class 300.

(2) The operating temperatures shall be limited to the range of -20°F to 650°F (-30°C to 345°C).

(3) Flanges are designed in accordance with the requirements of Section III Appendices, Mandatory Appendix XI or ASME B16.47.

ND-3512.2 Socket Welded End and Nonwelded End Valves. The design of valves with socket welded end connections and nonwelded piping end connections other than ASME B16.5 flanges shall conform to the applicable requirements for Standard Class category butt welding valves of ASME B16.34 except that the end connections shall conform to the applicable requirements of ND-3661 or ND-3671.

ND-3512.3 Wafer or Flangeless Valves. The design of valves that can be bolted between flanges (i.e., butterfly valves) shall conform to the applicable requirements of Standard Class category valves of ASME B16.34 and the requirements of (a) through (e) below.

(a) The design shall provide for bolt-up using all of the bolt holes and the bolt circle of the specified flange.

(b) Bolt holes parallel to the body run may be either threaded or unthreaded. Threaded holes may be blind holes suitable for use with bolt studs.

(c) The required minimum valve body wall thickness shall be measured from the valve inside circumference to either the valve outside circumference or the circumference of a circle inscribed about the inner tangents to the bolt holes, whichever is smaller.

(d) The inner ligament of either a through hole or a blind threaded hole in the vicinity of a stem penetration shall not be less than 25% of the required body neck thickness.

(e) The inner ligament for singular holes parallel to the body run shall not be less than 25% of the required valve body wall thickness. Such holes shall not be larger than $\frac{3}{8}$ in. (10 mm) diameter.

ND-3512.4 Design and Service Loadings. The design requirements of ND-3512.1 and ND-3512.2 include pressure-temperature ratings for Design Loadings and Service Loadings for which Level A Limits are designated. When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of ND-3520 shall be met.

ND-3512.5 Openings for Auxiliary Connections. Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ASME B16.34 and the applicable requirements of ND-3330.

ND-3513 Alternative Design Rules

For butt welding end valves and for socket welding end valves whose end connections conform to the requirements of ND-3661, the design requirements for Special Class category valves of ASME B16.34 may be used in place of ND-3512 when permitted by the Design Specification, provided that the following requirements are met.

(a) The nondestructive examination requirements of ASME B16.34, Special Class, shall be met for all sizes of butt welding and socket welding end valves in accordance with the examination methods and acceptance standards of ND-2500.

(b) When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of ND-3520 shall be met.

(c) Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ASME B16.34 and the applicable reinforcement requirements of ND-3330.

ND-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this Subarticle, based on the assumption that the bellows or diaphragms do not retain pressure and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

ND-3516 Acceptability of Elastomer Diaphragm Valves

Valves using elastomer diaphragms, wherein the diaphragm performs the function of a disc or plug, shall be constructed in accordance with ND-3500. This is based on the assumptions that the diaphragms do not retain pressure, design pressure is imposed on the backup stem seal, and the following additional requirements are met.

(a) Design temperature shall not exceed 350°F (175°C).

(b) Valve size and Pressure Class shall not exceed NPS 12 (DN 300) for Class 150 and NPS 4 (DN 100) for Class 300.

(c) A backup stem seal shall be provided.

(d) Diaphragms shall meet the requirements of MSS SP-100.

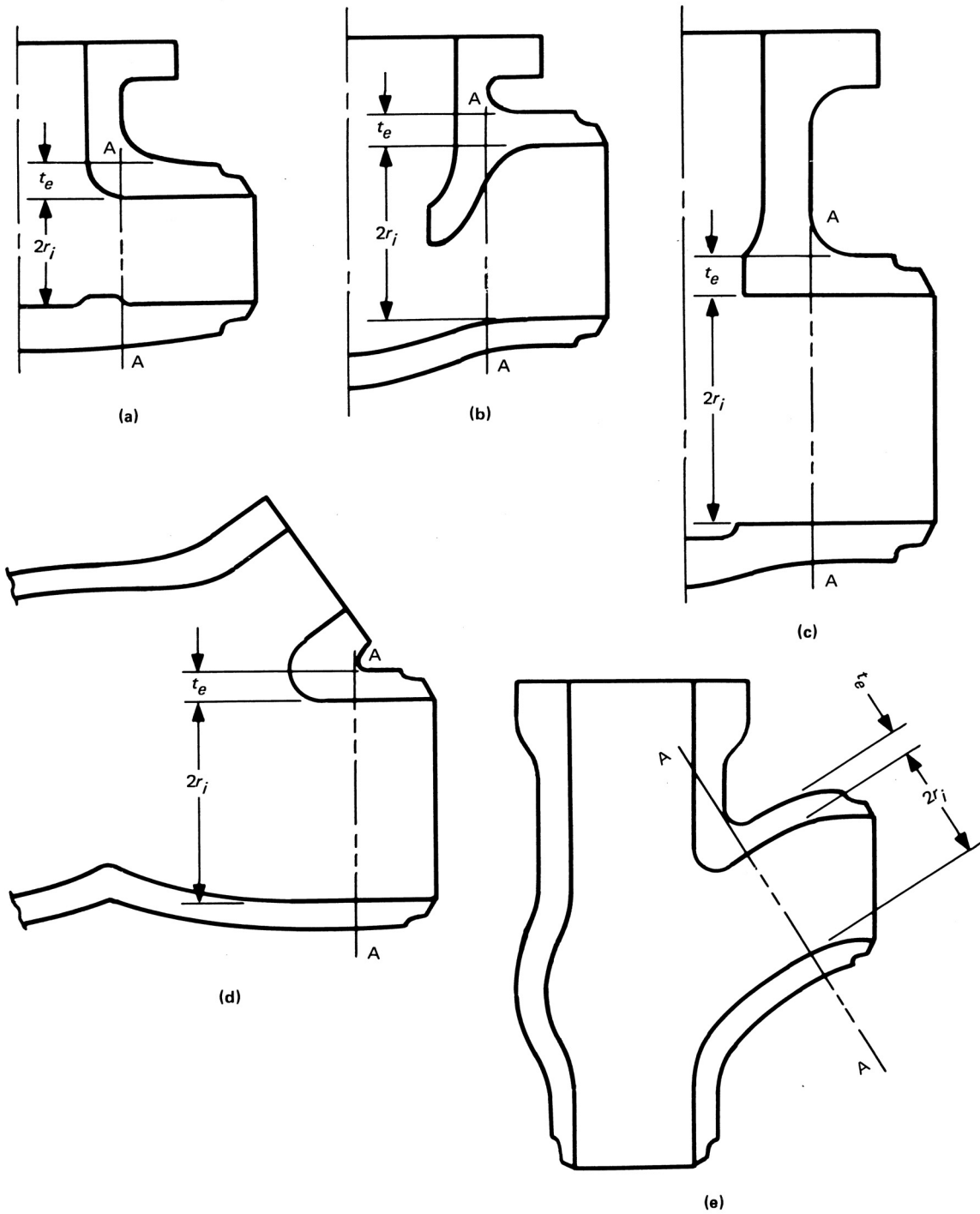
ND-3520 LEVELS B, C, AND D SERVICE LIMITS

ND-3521 Design Requirements

(a) When the piping system in which the valve is located is designed to the requirements of ND-3600, the valve body is considered adequate to withstand piping end loads provided that conditions (1) and (2) below are satisfied. In lieu of (1) and (2), the design procedure of NB-3545.2 is acceptable.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve body crotch, that is, in the plane A-A of Figure ND-3521-1, shall be not less than 110% of the section modulus and metal area of the piping connected to the valve body inlet and outlet nozzles.

Figure ND-3521-1
Typical Sections of Valve Bodies



(2) The allowable stress for valve body material is equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connected piping multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The maximum internal pressure resulting from Service Loadings for which Level B, Level C, or Level D Limits are designated shall not exceed the tabulated factors in Table ND-3521-1 times the Design Pressure or the rated pressure at the applicable service temperature. If these pressure limits are met, loadings for the stress limits in Table ND-3521-1 are considered to be satisfied. Conversely, if the stress limits in Table ND-3521-1 are met, the factored pressure limit, P_{max} need not be met.

(c) Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. The valve bodies shall conform to the stress limits listed in ND-3522. Classical bending and direct stress

equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

ND-3522 Stress and Pressure Limits

Level B, C, and D Service Limits are specified in Table ND-3521-1. The symbols used in Table ND-3521-1 are defined as follows:

S = allowable stress value given in Tables 1A and 1B, Section II, Part D, Subpart 1, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m , except that it includes the effect of discontinuities.

σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

ND-3530 GENERAL RULES

ND-3531 Hydrostatic Tests

The following requirements apply to valves designated to either ND-3512 or ND-3513.

ND-3531.1 Shell Hydrostatic Test. A shell hydrostatic test shall be made using either water or air in accordance with the requirements of ASME B16.34. Stem seal leakage during this test is permissible. Hydrostatic tests for metal bellows of metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions as defined in ASME B16.34 in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

ND-3531.2 Valve Closure Test. After the shell hydrostatic test, a valve closure test shall be performed in accordance with ASME B16.34 except that all valve sizes shall be subjected to a test differential pressure across the valve disk not less than 110% of the 100°F (38°C) pressure rating. During this test, seat leakage value is defined by the Design Specification.

ND-3531.3 Time at Pressure. The duration of the shell hydrostatic test shall meet the requirements of ND-6223. The duration of the valve closure test shall be

Table ND-3521-1
Level A, Level B, Level C, and Level D Service Limits

Service Limit	Stress [Note (1)] Limits [Note (2)]- [Note (5)]	P_{max} [Note (6)]
Level A	$\sigma_m \leq 1.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5 S$	1.0
Level B	$\sigma_m \leq 1.1 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$	1.1
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$	1.2
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$	1.5

NOTES:

- (1) Stress means the maximum normal stress.
- (2) A casting quality factor of 1 shall be assumed in satisfying these stress limits.
- (3) These requirements for the acceptability of valve design are not intended to assure the functional adequacy of the valve.
- (4) Design requirements listed in this table are not applicable to valve disks, stems, seat rings, or other parts of the valves which are contained within the confines of the body and bonnet.
- (5) These rules do not apply to safety relief valves.
- (6) The maximum pressure shall not exceed the tabulated factors listed under P_{max} times the Design Pressure or times the rated pressure at the applicable service temperature.

the greater of either 1 min/in. (2.5 sec/mm) of minimum wall thickness t_m or the testing time requirement of ASME B16.34 but not less than 1 min.

ND-3531.4 Exemptions to the Valve Closure Test.

(a) For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F (40°C) pressure rating, or that have closure members or actuating devices (direct, mechanical, fluid, or electrical) that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve nameplate and the N Certificate Holder's Data Report Form.

(b) For valves designed for nonisolation service, the primary function of which is to modulate flow, and which by their design are prevented from providing full closure, the valve closure test defined in ND-3531.2 above is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

ND-3590 PRESSURE RELIEF VALVE DESIGN

ND-3591 Acceptability

ND-3591.1 General Requirements. The rules of this Subsubarticle constitute the requirements for the design acceptability of spring-loaded pressure relief valves. The design rules for pilot operated and power actuated pressure relief valves are covered by ND-3500. The rules of this Subsubarticle cover the pressure retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this Subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure adjusting screw. The rules of this Subsubarticle do not apply to guides, control rings, bearings, set screws, and other nonpressure-retaining items. Figures ND-3591.1-1 and ND-3591.1-2 are illustrations of typical pressure relief valves.

ND-3591.2 Definitions. The definitions for pressure relief valve terms used in this Subsubarticle are given in the American National Standard ANSI B95.1-1977, Terminology for Pressure Relief Devices, and also in ND-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary pressure zone and a secondary pressure zone as illustrated by Figures ND-3591.1-1 and ND-3591.1-2.

ND-3591.3 Acceptability of Small Pressure Relief Valves. Pressure relief valves having inlet piping connections NPS 2 (DN 50) and under shall comply with the wall thickness requirements of ND-3595.1. Other elements of the valve shall be designed to ensure pressure integrity,

in accordance with appropriate design practices based on successful experience in comparable service conditions.

ND-3591.4 Acceptability of Large Pressure Relief Valves. The design shall be such that the requirements of this Subsubarticle are met.

ND-3592 Design Considerations

ND-3592.1 Design Conditions. The general design requirements of ND-3100 are applicable with consideration for the design conditions of the primary and secondary pressure zones. In case of conflict between ND-3100 and ND-3590, the requirements of ND-3590 shall apply. Mechanical loads for both the closed and open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of ND-7000 shall be met.

ND-3592.2 Stress Limits for Specified Service Loadings.

(a) *Level A Service Loadings.* Stress limits for Level A service loadings for the valve shall be as follows:

(1) The general membrane stress shall not exceed S .

(2) The general membrane stress plus bending stress shall not exceed $1.5S$.

(3) Substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required.

(4) The values of S shall be in accordance with Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) *Levels B, C, and D Service Loadings.* Stress limits for Levels B, C, and D service loadings are specified in Table ND-3592.2(b)-1. The symbols used in Table ND-3592.2(b)-1 are defined in ND-3522.

ND-3593 Special Rules

ND-3593.1 Hydrostatic Test. Pressure relief valve shell hydrostatic tests shall be made in accordance with ND-3531.1 and ND-3531.3 except that the inlet (primary pressure containing) portion of the pressure relief valve shall be shell tested at a pressure at least equal to 1.5 times the set pressure marked on the valve. For closed system application, the outlet portion of the pressure relief valve shall be shell tested to 1.5 times the design secondary pressure (ND-7111).

ND-3593.2 Marking. In addition to marking required by NCA-8220 and ND-7000, the secondary design pressure shall be marked on the valve or valve nameplate.

ND-3594 Design Requirements for Levels B, C, and D Service Loadings

(a) When the piping system in which the valve is located is designed to the requirements of ND-3600, the valve body may be considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied.

Figure ND-3591.1-1
Typical Pressure Relief Devices

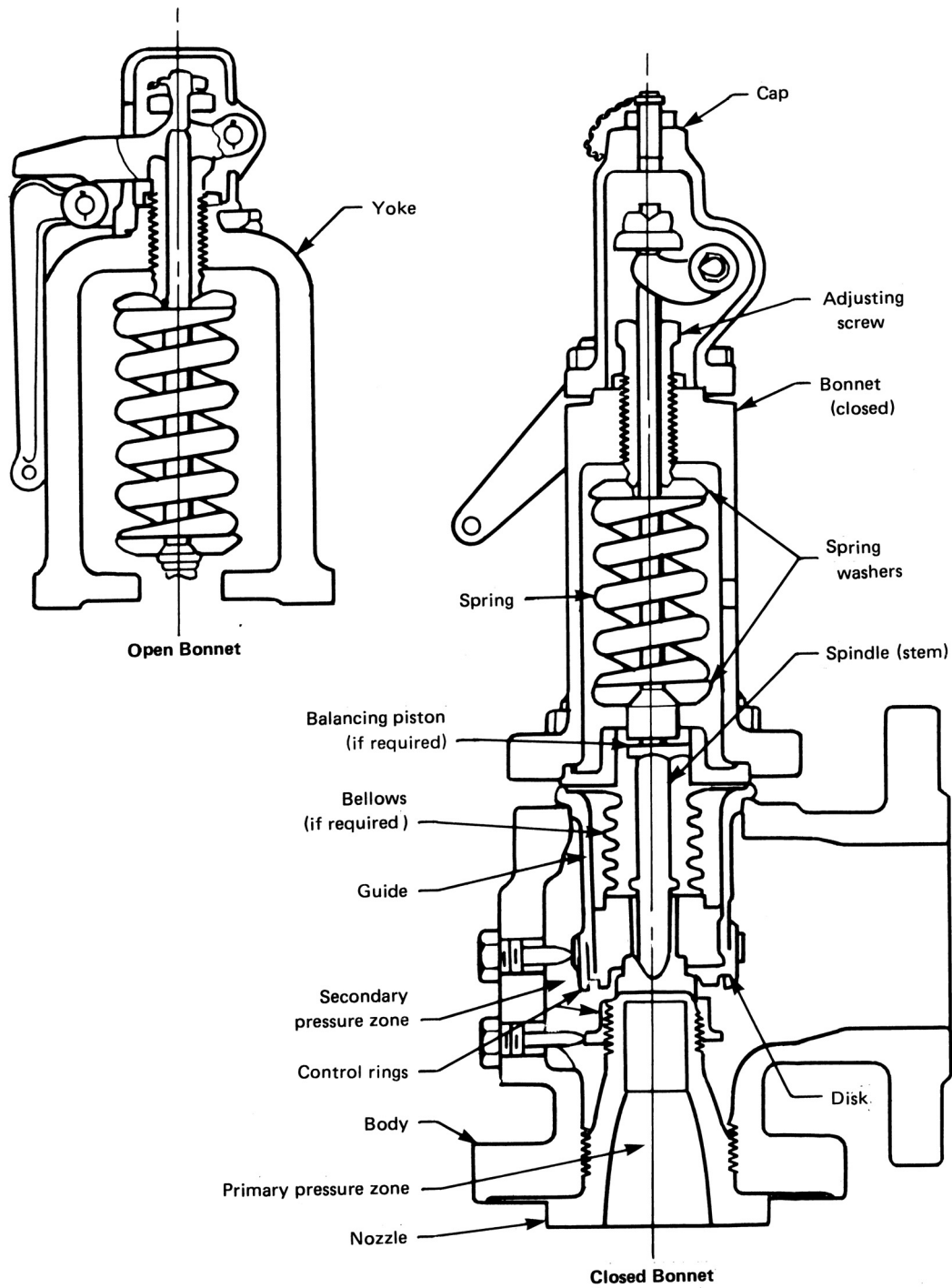


Figure ND-3591.1-2
Typical Pressure Relief Devices

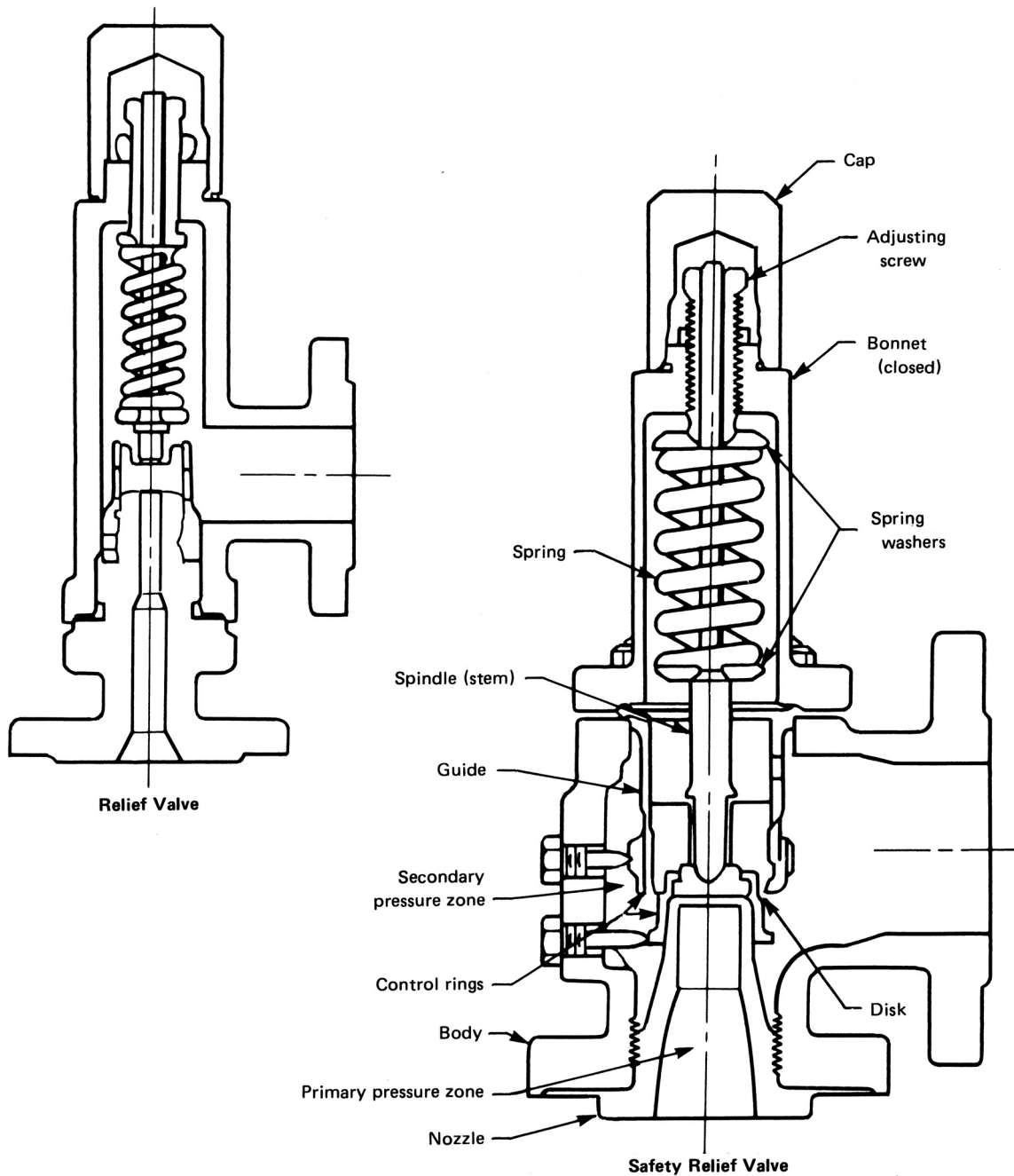


Table ND-3592.2(b)-1
Class 3 Pressure Relief Devices: Level B, C,
and D Service Loadings

Service Loadings	Stress Limits
Level B	$\sigma_m \leq 1.1 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

GENERAL NOTES:

(a) A casting quality factor is not required to satisfy these limits.

(b) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the designer is cautioned that the requirements of [ND-7000](#) relative to set pressure, lift, blowdown, and closure shall be met.

(c) Design requirements listed in this Table are applicable to those portions of the valves that are pressure retaining or affect pressure retaining items of these valves.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve inlet and outlet ([Figures ND-3591.1-1](#) and [ND-3591.1-2](#)) shall be not less than 110% of the section modulus and metal area of the piping connected (or joined) to the valve inlet and outlet.

(2) The allowable stress for valve body material shall be equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connecting pipe multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The pressure retaining portions of pressure relief valves shall conform to the stress limits listed in [Table ND-3592.2\(b\)-1](#) for those service loadings stipulated as Level B, C, or D.

(c) Pressure relief valves have extended structures, and these structures are essential to maintaining pressure integrity. An analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

ND-3595 Design of Pressure Relief Valve Parts

ND-3595.1 Body. Minimum wall thicknesses of valve bodies shall conform to the applicable requirements for Standard Class category valves of ASME B16.34, taking

into account the dimensional and pressure conditions of the primary and secondary zones. Minimum wall thickness adjacent to the inlet nozzle and for a distance equal to that minimum wall thickness from the plane of the back face of the inlet flange shall be that required for Standard Class category valves of ASME B16.34 for the inlet flange size and pressure class. Minimum wall thicknesses elsewhere in the secondary zone shall be determined by the requirements for Standard Class category valves of ASME B16.34 for the outlet flange size and pressure class, including such other rules and considerations of ASME B16.34 as may be applicable. In valve design where the outlet flange is an extension of the bonnet, the bonnet design shall conform to these rules. Where the inlet flange geometry involves inside contours encroaching on the metal section boundary represented by dimension B in Tables 9, 12, 15, 18, 21, 24, or 27 in ASME B16.5, adequacy of the design shall be proven by stress calculation in accordance with [ND-3658](#). Additional metal thickness needed for operating stresses, shapes other than circular, stress concentrations, and adequate structural strength of the crotch area(s) of the neck(s) of the valve for bending stresses and installation stress that may be imposed on the valve must be determined by the manufacturer.

ND-3595.2 Bonnet (Yoke). The bonnet (yoke) may be analyzed using classic bending and direct stress equations, with appropriate free body diagrams. The general membrane stress and the general membrane stress plus bending stress shall not exceed the stress limits of [ND-3592.2](#).

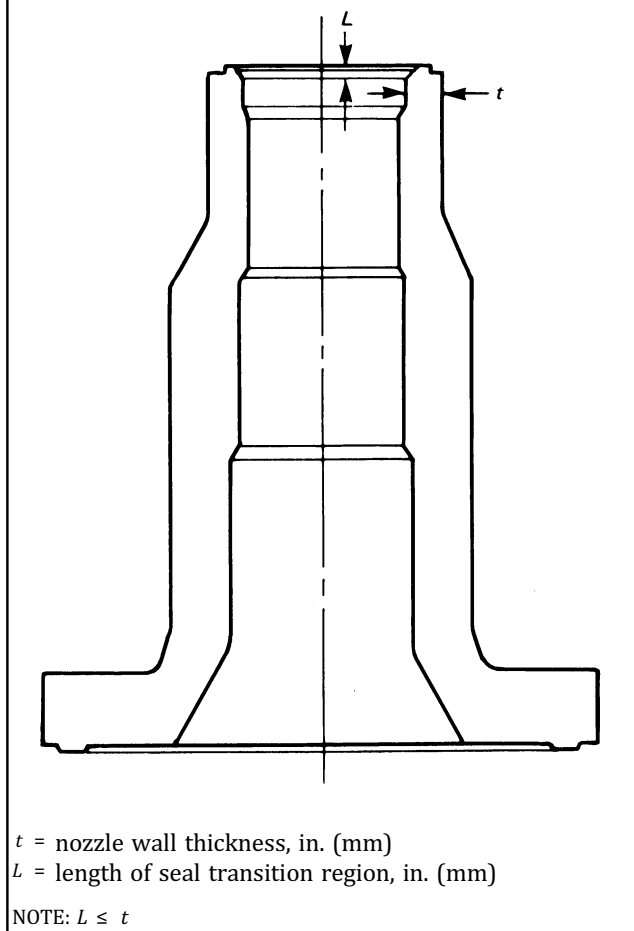
ND-3595.3 Nozzle. The minimum wall thickness of the nozzle shall be determined from the limit on general membrane stress. Alternatively, the rules of NB-3594.3 may be used. These requirements are not applicable to the transition region to the seat contacting area of the nozzle defined by L in [Figure ND-3595.3-1](#), provided the dimension L is less than the nominal wall thickness t .

ND-3595.4 Body-to-Bonnet Joint. For valves having inlet piping connections NPS 2 (DN 50) and less, body-to-bonnet connections may be threaded. The thread shear stress, considering all loadings, shall not exceed 0.6 times the allowable stress S . The body-to-bonnet bolting shall be designed to resist the hydrostatic end force of the rated maximum secondary Design Pressure combined with the total spring load to full lift, and to maintain sufficient compression for a tight joint on the gasket or joint contact surface. The bolt stresses for these loadings shall not exceed the allowable stress values of Table 3, Section II, Part D, Subpart 1.

ND-3595.5 Disk. The stress evaluation shall be made for the condition that results in the maximum stress in the disk. The bending stress shall not exceed the stress limits of [ND-3592.2](#).

ND-3595.6 Spring Washer. The shear stress shall not exceed $0.6S$. The bending stress shall not exceed the stress limits of [ND-3592.2](#).

**Figure ND-3595.3-1
Valve Nozzle**



ND-3595.7 Spindle (Stem). The general membrane stress shall not exceed the stress limits of [ND-3592.2](#).

ND-3595.8 Adjusting Screw. The adjusting screw shall be analyzed for thread stress in accordance with the method of ASME B1.1 and this stress shall not exceed $0.6S$. The general membrane stress of the adjusting screw shall not exceed the stress limits of [ND-3592.2](#), based on the root diameter of the thread.

ND-3595.9 Spring. The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and the height measured a minimum of 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 1.0% of the free height.

ND-3596 Design Reports

ND-3596.1 General Requirements. The manufacturer shall certify compliance with the requirements of this Subsubarticle in accordance with the provisions of NCA-3570.

ND-3600 PIPING DESIGN

ND-3610 GENERAL REQUIREMENTS

ND-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

ND-3611.1 Allowable Stress Values. Allowable stress values to be used for the design of piping systems are given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

ND-3611.2 Stress Limits.

(13)

(a) *Design and Service.* Loadings shall be specified in the Design Specification.

(b) *Design Loadings.* The sum of stresses due to design internal pressure, weight, and other sustained loads shall meet the requirements of [eq. ND-3652\(8\)](#)

(c) *Service Loadings.* The following Service Limits shall apply to Service Loadings as designated in the Design Specification.

(1) *Level A and B Service Limits.* For Service Loadings for which Level A and B Service Limits are designated in the Design Specification, the requirements of [ND-3653](#) shall be met. When Level B Limits apply, the peak pressure P_{max} alone shall not exceed 1.1 times the pressure P_a calculated in accordance with [eq. ND-3641.1\(5\)](#). The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

(2) *Level C Service Limits.* For Service Loadings for which Level C Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of [ND-3654](#).

(3) *Level D Service Limits.* For Service Loadings for which Level D Service Limits are designated in the Design Specification, the sum of stresses due to internal pressure, live and dead load, and those due to occasional loads shall meet the requirements of [ND-3655](#).

(4) *Test Conditions.* Testing shall be in accordance with [ND-6000](#). Occasional loads shall not be considered as acting at time of test.

(d) *External Pressure Stress.* Piping subject to external pressure shall meet the requirements of [ND-3641.2](#).

(e) *Allowable Stress Range for Expansion Stresses.* The allowable stress range S_A is given by [eq. \(1\)](#)

$$S_A = f(1.25 S_c + 0.25 S_h) \quad (1)$$

where

f = stress range reduction factor for cyclic conditions for total number N of full temperature cycles over total number of years during which system is expected to be in service, from Table ND-3611.2(e)-1

S_c = basic material allowable stress at minimum (cold) temperature, psi (MPa)

S_h = basic material allowable stress at maximum (hot) temperature, psi (MPa)

(1) In determining the basic material allowable stresses S_c and S_h , joint efficiencies need not be applied.

(2) Stress reduction factors apply essentially to non-corrosive service and to corrosion resistant materials, where employed to minimize the reduction in cyclic life caused by corrosive action.

(3) If the range of temperature change varies, equivalent full temperature cycles may be computed as follows:

$$N = N_E + r_1^5 N_1 + r_2^5 N_2 + \dots + r_n^5 N_n \quad (2)$$

where

N_E = number of cycles at full temperature change ΔT_E for which expansion stress S_E has been calculated

N_1, N_2, \dots, N_n = number of cycles at lesser temperature changes, $\Delta T_1, \Delta T_2, \dots, \Delta T_n$

$r_1, r_2, \dots, r_n = (\Delta T_1)/(\Delta T_E), (\Delta T_2)/(\Delta T_E), \dots, (\Delta T_n)/(\Delta T_E)$
the ratio of any lesser temperature cycles for which the expansion stress S_E has been calculated

(f) *Allowable Stress for Nonrepeated Stresses.* The allowable stress due to any single nonrepeated anchor movement (such as predicted building settlement) calculated in accordance with eq. ND-3653.2(b)(10b) shall be $3.0S_c$.

ND-3611.3 Alternative Analysis Methods. The specific design requirements of ND-3600 are based on a simplified engineering approach. A more rigorous analysis such as described in NB-3600 or NB-3200 may be used to calculate the stresses required to satisfy these requirements.

**Table ND-3611.2(e)-1
Stress Range Reduction Factors**

Number of Equivalent Full Temperature Cycles, N	f
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

These calculated stresses must be compared to the allowable stresses in this Subsection. In such cases, the designer shall include appropriate justification for the approach taken in the Certified Design Report.

ND-3612 Pressure-Temperature Ratings for Piping Products

ND-3612.1 Piping Products Having Specific Ratings.

(a) Pressure-temperature ratings for certain piping products have been established and are contained in some of the standards listed in Table NCA-7100-1. The pressure ratings at the corresponding temperatures given in the standards listed in Table NCA-7100-1 shall not be exceeded, and piping products shall not be used at temperatures in excess of those given in Tables 1A and 1B, Section II, Part D, Subpart 1 for the materials of which the products are made.

(b) Where piping products have established pressure-temperature ratings that do not extend to the upper material temperature limits permitted by this Subsection, the pressure-temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Subsection.

ND-3612.2 Piping Products Not Having Specific Ratings. Should it be desired to use methods of manufacture or design of piping products not covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of ND-3640 and ND-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.

ND-3612.4 Considerations for Local Conditions and Transients.

(a) Where piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirements of the higher pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with ND-7311 and ND-7321.

(3) Assure compliance with all the conditions of (-a) through (-e) below.

(-a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(-b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed that will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the low pressure system.

(-c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(-d) Means shall be provided to assure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the low pressure system.

(-e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with ND-7311 and ND-7321, on the basis of the interconnecting valve being closed but leaking at a specified rate, when (-a) through (-e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of ND-7000 shall be met.

(b) Where pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time, the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size, unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same

pressure as the trap inlet piping, unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel Pressure, psi (MPa)	Design Pressure, psi (MPa)	Design Temperature, °F (°C)
600 (4.0) and below	250 (1.7)	410 (210)
601 to 900 (4.1 to 6.0)	400 (3.0)	450 (230)
901 to 1,500 (6.1 to 10.0)	600 (4.0)	490 (255)
1,501 (10.1) and above	900 (6.0)	535 (280)

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. Where pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) When a fluid passes through heat exchangers in series, the Design Temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

ND-3613 Allowances

ND-3613.1 Corrosion or Erosion. When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

ND-3613.2 Threading and Grooving. The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

ND-3613.3 Mechanical Strength. When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

ND-3613.4 Pressure Design Weld Joint Efficiency for Butt Welds. Longitudinal weld joint efficiency factors for pressure design for butt welds as listed in

Table ND-3613.4-1 shall be applied to the allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

ND-3613.5 Steel Casting Quality Factors. The quality factors for castings required in Tables 1A and 1B, Section II, Part D, Subpart 1 apply to castings that are designed using the stresses contained in this Subsection. The minimum examination required for these castings is that stipulated in the applicable material specification and in ND-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

ND-3620 DESIGN CONSIDERATIONS

ND-3621 Design and Service Loadings

The provisions of ND-3110 shall apply, except as modified in this Subarticle.

ND-3621.1 Cooling Effects on Pressure. When the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

ND-3621.2 Fluid Expansion Effects. When the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

ND-3622 Dynamic Effects

ND-3622.1 Impact. Impact forces caused by either external or internal loads shall be considered in the piping design.

ND-3622.2 Reversing Dynamic Loads. Reversing dynamic loads are those loads that cycle about a mean value and include building filtered loads, and earthquake loads. A reversing dynamic load shall be treated as a

nonreversing dynamic load in applying the rules of ND-3600 when the number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

ND-3622.3 Vibration. Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

ND-3622.4 Exposed Piping. Exposed piping shall be designed to withstand wind loadings, using meteorological data to determine wind forces. When State, Province, or Municipal ordinances covering the design of building structures are in effect and specify wind loadings, these values shall be considered the minimum design values. However, it is not necessary to consider earthquake and wind loadings to be acting concurrently.

ND-3622.5 Nonreversing Dynamic Loads. Nonreversing dynamic loads are those loads that do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems (see Figure ND-3622-1). Reflected waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

ND-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

ND-3623.1 Live Weight. The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

ND-3623.2 Dead Weight. The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

ND-3624 Thermal Expansion and Contraction Loads

ND-3624.1 General Requirements.

(a) The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints.

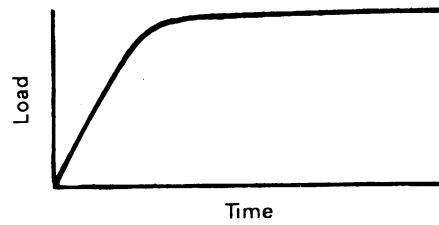
(b) Thermal expansion and contraction shall be provided for, preferably by pipe bends, elbows, offsets, or changes in direction of the piping.

(c) Hangers and supports shall permit expansion and contraction of the piping between anchors.

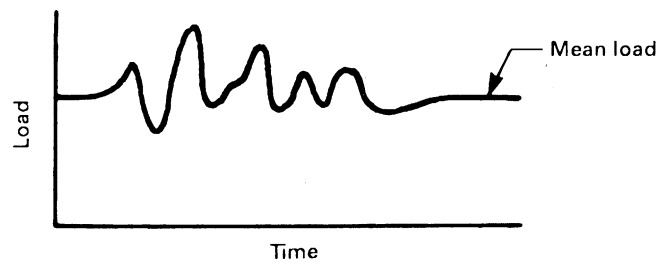
**Table ND-3613.4-1
Weld Joint Efficiency Factor**

Type of Longitudinal Joint	Weld Joint Efficiency Factor <i>E</i>
Arc Weld	
Single butt weld	0.80
Double butt weld	0.90
Single or double butt weld with 100% radiography per ND-2560 for joints welded with filler metal or otherwise examined by ultrasonic methods per ND-2550 for joints welded without filler metal, as applicable	1.00
Electric resistance weld	0.85

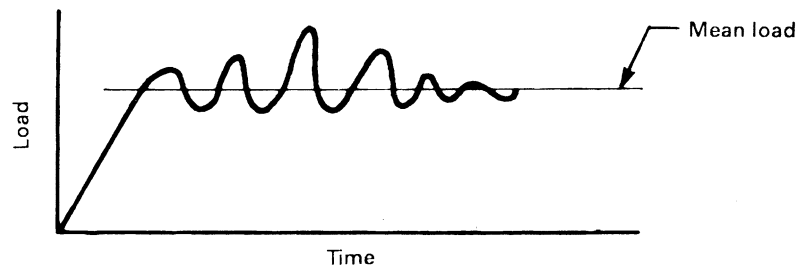
Figure ND-3622-1
Examples of Reversing and Nonreversing Dynamic Loads



(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)



(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)



(c) Nonreversing Dynamic Load
(Initial Water Slug Followed By Reflected Waves)

ND-3624.2 Expansion Joints. Expansion joints of the corrugated, slip sleeve, ball, or swivel types may be used if they conform to the requirements of ND-3649.1 through ND-3649.4, their structural and working parts are designed for the maximum pressure and temperature of the piping system, and their design prevents the complete disengagement of working parts while in service.

ND-3640 PRESSURE DESIGN OF PIPING PRODUCTS

ND-3641 Straight Pipe

(13) ND-3641.1 Straight Pipe Under Internal Pressure.

The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Tables 1A and 1B, Section II, Part D, Subpart 1, including allowances for mechanical strength, shall not be less than that determined by eq. (3) as follows:

$$t_m = \frac{PD_o}{2(SE + Py)} + A \quad (3)$$

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)} \quad (4)$$

where

A = additional thickness, in. (mm):

(a) to compensate for material removed or wall thinning due to threading or grooving, required to make a mechanical joint. The values of A listed in Table ND-3641.1(a)-1 are minimum values for material removed in threading.

(b) to provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect such piping against these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

(c) to provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts that must be added for either or both of these conditions.

D_o = outside diameter of pipe, in. (mm). For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of t_m . When calculating the allowable pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

d = inside diameter of pipe, in. (mm). In using eq. (4) the value of d is for the maximum possible inside diameter allowable under the purchase specification.

E = joint efficiency for the type of longitudinal joint used, as given in Table ND-3613.4-1, or casting quality factor determined in accordance with ND-3613.5

P = internal Design Pressure, psi (MPa)

S = maximum allowable stress for the material at the Design Temperature, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A and 1B)

t_m = minimum required wall thickness, in. (mm). If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness t_m is determined by eq. (4), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from standard thickness schedules such as contained in ASME B36.10M or from manufacturers' schedules for other than standard thickness.

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2SEt}{D_o - 2yt} \quad (5)$$

where

P_a = the calculated maximum allowable internal pressure, psi (MPa), for straight pipe that shall at least equal the Design Pressure.

(a) P_a may be used for piping products with pressure ratings equal to that of straight pipe (see ASME B16.9).

(b) For standard flanged joints, the rated pressure shall be used instead of P_a .

**Table ND-3641.1(a)-1
Values of A**

Type of Pipe	A , in. (mm)
Threaded steel and nonferrous pipe:	
$\frac{3}{4}$ in. nominal (DN 20) and smaller	0.065 (1.5)
1 in. (DN 25) nominal and larger	Depth of thread
Grooved steel and nonferrous pipe	Depth of
	groove plus
	$\frac{1}{64}$ in. (0.4)

(c) For reinforced branch connections (ND-3643) where part of the required reinforcement is in the run pipe, the Design Pressure shall be used instead of P_a .

(d) For other piping products where the pressure rating may be less than that of the pipe (for example, flanged joints designed to Mandatory Appendix XI), the Design Pressure shall be used instead of P_a .

(e) P_a may be rounded out to the next higher unit of 10 psi (0.1 MPa).

t = the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (ND-3642.1), material to be removed by counterboring, in. (mm)

y = a coefficient having a value of 0.4, except that for pipe with a D_o / t_m ratio less than 6, the value of y shall be taken as

$$y = \frac{d}{d + D_o} \quad (6)$$

ND-3641.2 Straight Pipe Under External Pressure.

For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in ND-3133 shall be followed.

ND-3642 Curved Segments of Pipe

ND-3642.1 Pipe Bends. Pipe bends shall be subject to the limitations in (a), (b), and (c) below.

(a) The minimum wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The ovality shall meet the requirements of ND-4223.2.

(c) The information in Table ND-3642.1(c)-1 is given to guide the designer when ordering pipe.²³

ND-3642.2 Elbows. Flanged elbows manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards. In the case of standards under which butt welding elbows are

made to a nominal wall thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness and of the same material.

ND-3643 Intersections

ND-3643.1 General Requirements.

(a) ND-3643 gives acceptable rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, the angle between the axes of the branch and of the run is between 45 deg and 90 deg, inclusive, and no allowance is required for corrosion or erosion.

(b) Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg impose special design and fabrication problems. The rules given for angles between 45 deg and 90 deg, inclusive, may be used as a guide, but sufficient additional strength must be provided to assure safe service. Such branch connections shall be designed to meet the requirements of ND-3649.

(c) Branch connections in piping may be made by using one of the products or methods given in (1) through (5) below:

(1) flanged, butt welding, socket welding, or screwed fittings made in accordance with the applicable standards listed in Table NCA-7100-1;

(2) welding outlet fittings, such as cast or forged nozzles; couplings including ASME B16.11 couplings, to a maximum of NPS 3 (DN 80); and adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch pipe. Such outlet fittings shall be attached to the main pipe

(-a) by the full penetration weld; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure ND-3643.2(b)-2, sketch (e) or (f), provided the requirements of (-1) through (-4), as follows, are met:

(-1) the nominal size of the branch shall not exceed 2 in. (50 mm) or one-quarter of the nominal size of the run, whichever is less;

(-2) the minimum size of the weld, x_{\min} , shall not be less than $1\frac{1}{4}$ times the fitting wall thickness in the reinforcement zone;

(-3) the groove angle, θ , shall be equal to or greater than 45 deg;

(-4) except for attaching ASME B16.11 couplings, the requirements of ND-3643.3 shall be met.

(3) extruded outlets at right angles to the run pipe, in accordance with ND-3643.4, where the attachment of the branch pipe is by butt welding;

(4) by attaching the branch pipe directly to the run pipe by welding or threading as stipulated in (-a) or (-b) below:

(-a) right angle branch connections may be made by attaching the branch pipe to the run pipe by socket

**Table ND-3642.1(c)-1
Minimum Thickness for Bending**

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.16t_m$
3 pipe diameters	$1.25t_m$

NOTE:

(1) t_m is determined by eq. ND-3641.1(3) or eq. ND-3641.1(4).

welding, provided the requirements of (-1) through (-5) below are met:

(-1) the nominal size of branch does not exceed NPS 2 (DN 50) or one-fourth the nominal size of the run, whichever is less;

(-2) the depth of the socket in the run is at least equal to that shown in ASME B16.11 with a minimum shoulder of $\frac{1}{16}$ in. (1.5 mm) between the bottom of the socket and the inside diameter of the run pipe; weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required;

(-3) a minimum of $\frac{1}{16}$ in. (1.5 mm) clearance shall be provided between the bottom of the socket and the end of the inserted pipe;

(-4) the size of the fillet weld shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

(-5) the requirements of ND-3643.3 shall be met.

(-b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of ND-3671.3 and provided the requirements of (-1) and (-2) below are met:

(-1) the nominal size of the branch does not exceed NPS 2 (DN 50) or one-fourth the nominal size of the run, whichever is less;

(-2) minimum thread engagement shall be six full threads for $\frac{1}{2}$ in., and $\frac{3}{4}$ in. (DN 15 and DN 20) branches; seven for 1 in., $1\frac{1}{4}$ in., and $1\frac{1}{2}$ in. (DN 25, DN 32, and DN 40) branches; and eight for NPS 2 (DN 50) branches; weld metal may be deposited on the run pipe to provide sufficient thickness for required thread engagement;

(5) branch connections may be made by attaching the branch pipe directly to the run pipe

(-a) by a full penetration weld as shown in Figure ND-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Figure ND-3643.3(c)(1)-1 or Figure ND-3643.3(c)(1)-2, provided the requirements of ND-3643.3 are met; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure ND-3643.2(b)-2, sketches (a) through (d), provided the requirements of (-1) through (-4), as follows, are met:

(-1) the nominal size of the branch shall not exceed NPS 2 (DN 50) or one-quarter of the nominal size of the run, whichever is less;

(-2) the minimum size of the weld, x_{min} , shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

(-3) the groove angle, θ , shall be equal to or greater than 45 deg;

(-4) the requirements of ND-3643.3 shall be met.

ND-3643.2 Branch Connections Not Requiring Reinforcement. Reinforcement need not be provided if the branch connection is made in accordance with the requirements of (a) through (c) below:

(a) by the use of a fitting manufactured in accordance with one of the standards listed in Table NCA-7100-1 and used within the limits of pressure-temperature ratings specified in such standards, a butt welding fitting made in accordance with ASME B16.9 or MSS SP-97 shall be of nominal thickness not less than the nominal thickness required for the adjoining pipe;

(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Figure ND-3643.2(b)-1 sketch (c)(1) or Figure ND-3643.2(b)-2 sketch (e); and in no case is the thickness of the coupling less than extra heavy or 3,000 lb nominal rating;

(c) by using an extruded outlet, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the pipe, whichever is less, and the minimum wall thickness at the abutting end of the outlet is not less than required for the branch pipe wall.

ND-3643.3 Branch Connections Requiring Reinforcement.

(a) Calculations shall be made to determine the adequacy of reinforcement in branch connections except as exempted in ND-3643.2.

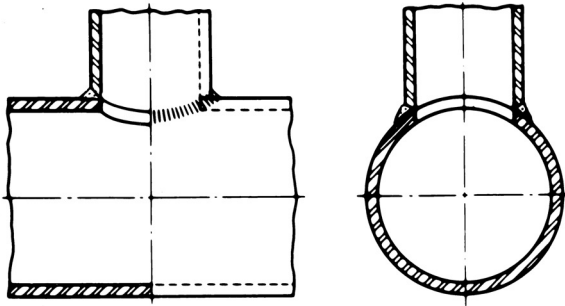
(b) A branch connection may be made by extruding an integrally reinforced outlet on the run pipe. The reinforcement requirements shall be in accordance with ND-3643.4.

(c) A branch connection may be made by welding a pipe or fitting directly to the run pipe with or without added reinforcement, provided the pipe or fitting, deposited weldment, and other reinforcing devices meet the requirements of this subparagraph. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run ranges from 45 deg to 90 deg. ND-3643.5 gives rules governing the design of connections to sustain external pressure.

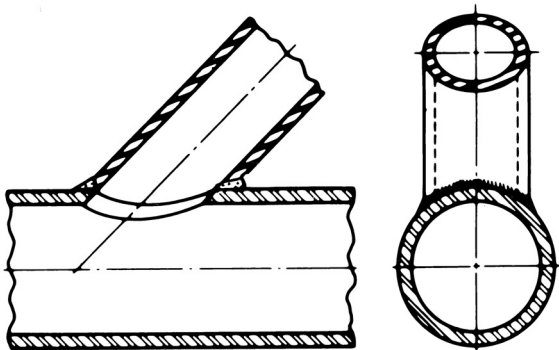
(1) *Nomenclature.* Figures ND-3643.3(c)(1)-1 and ND-3643.3(c)(1)-2 illustrate the notations used in the pressure-temperature design conditions of branch connections, which are as follows:

b = subscript referring to branch
 D_o = outside diameter of pipe, in. (mm)
 d_1 = inside diameter of branch for right angle connections, in. (mm); for connections at angles between 45 deg and 90 deg, $d_1 = (D_{ob} - 2T_b)/\sin \alpha$
 d_2 = half width of reinforcing zone, in. (mm)

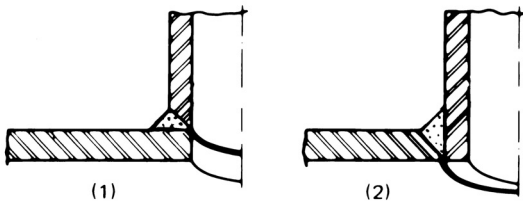
Figure ND-3643.2(b)-1
Typical Welded Branch Connections



(a) Typical Welded Branch Connection Without Additional Reinforcement



(b) Typical Welded Angular Branch Connection Without Additional Reinforcement



(c) Typical Branch Connections Made Using a Full Penetration Weld

= the greater of d_1 or $T_b + T_h + (d_1/2)$ but in no case more than D_{ob}

h = subscript referring to run or header

L = height of reinforcement zone outside of run, in. (mm)

= $2.5T_b + t_e$

T = nominal, actual by measurement, or minimum wall thickness of pipe, in. (mm), permissible under purchase specification

t_e = thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. (mm) [Figure ND-3643.3(c)(1)-2]

t_m = required minimum wall thickness, in. (mm), of pipe for pressure and temperature design conditions as determined by use of eq. ND-3641.1(3) or eq. ND-3641.1(4)

α = angle between axes of branch and run, deg

(2) *Requirements.* A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional reinforcement. The amount of reinforcement required shall be determined in accordance with (3) through (7), ND-3643.4, or ND-3643.5.

(3) *Reinforcement Area.* The required reinforcement area in in.² (mm²) for branch connections shall be the quantity $(t_{mh}) (d_1) (2 - \sin \alpha)$.

(-a) For right angle connections, the required reinforcement becomes $(t_{mh}) (d_1)$.

(-b) The required reinforcement must be within the limits of the reinforcement zone as defined in (5).

(4) *Area Contributing to Reinforcement.* Metal needed to meet reinforcement required by (c) must be within the limits of reinforcement zone determined in (5) and may include the following:

A_1 = area provided by excess pipe wall in the run, in.² (mm²)

= $(2d_2 - d_1) [(T_h - \text{mill tolerance on } T_h) - t_{mh}]$

A_2 = area provided by excess pipe wall in the branch for a distance L above the run, in.² (mm²)

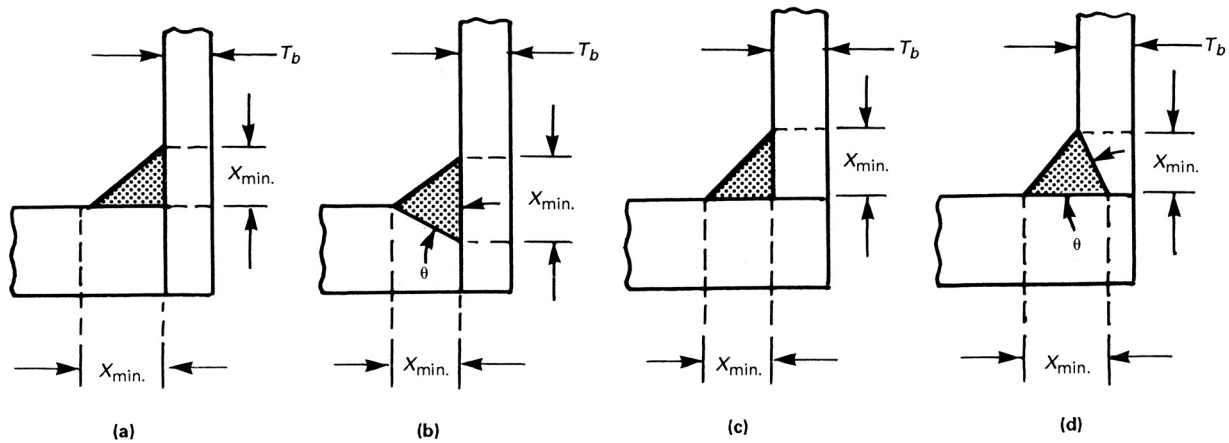
= $2L/\sin \alpha [(T_b - \text{mill tolerance on } T_b) - t_{mb}]$. In areas A_1 and A_2 , mill tolerance becomes zero when the minimum wall is specified instead of nominal wall.

A_3 = area provided by deposited weld metal beyond the outside diameter of the run and branch, in.² (mm²)

A_4 = area provided by reinforcement, in.² (mm²)

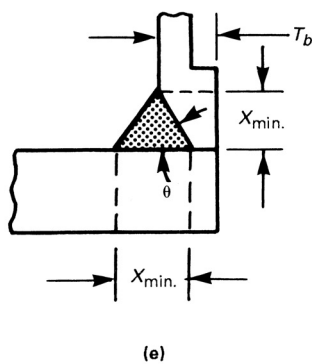
When the reinforcement area is composed of material with lower allowable stress than that of the run pipe, such reinforcement areas shall be increased by the inverse ratio of allowable stresses. No adjustment shall be made in reinforcement area for use of materials that have higher allowable stresses than the materials of the run pipe. Such

Figure ND-3643.2(b)-2
Typical Right Angle Branch Connections Made Using a Fillet Weld or a Partial Penetration Weld

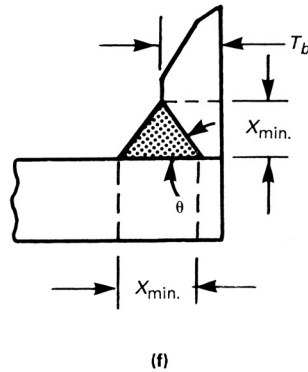


T_b = Nominal branch pipe wall thickness
 $X_{min.} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

ANSI B16.11 Coupling



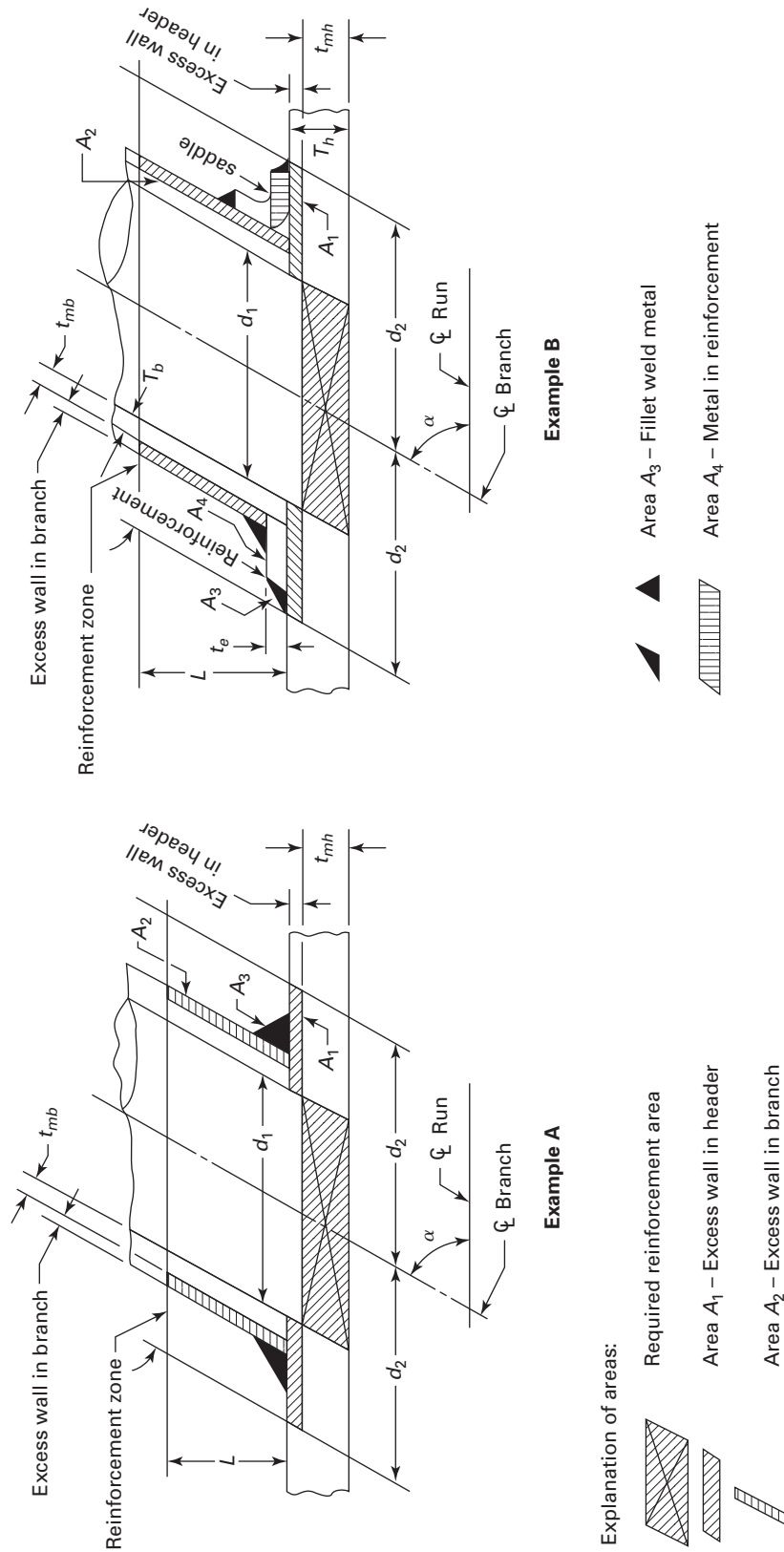
Welded Outlet Fitting



T_b = Fitting wall thickness in the reinforcement zone
 (when the fitting is tapered in the reinforcement zone, use average wall thickness)
 $X_{min.} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

Figure ND-3643.3(c)(1)-1
Reinforcement of Branch Connections

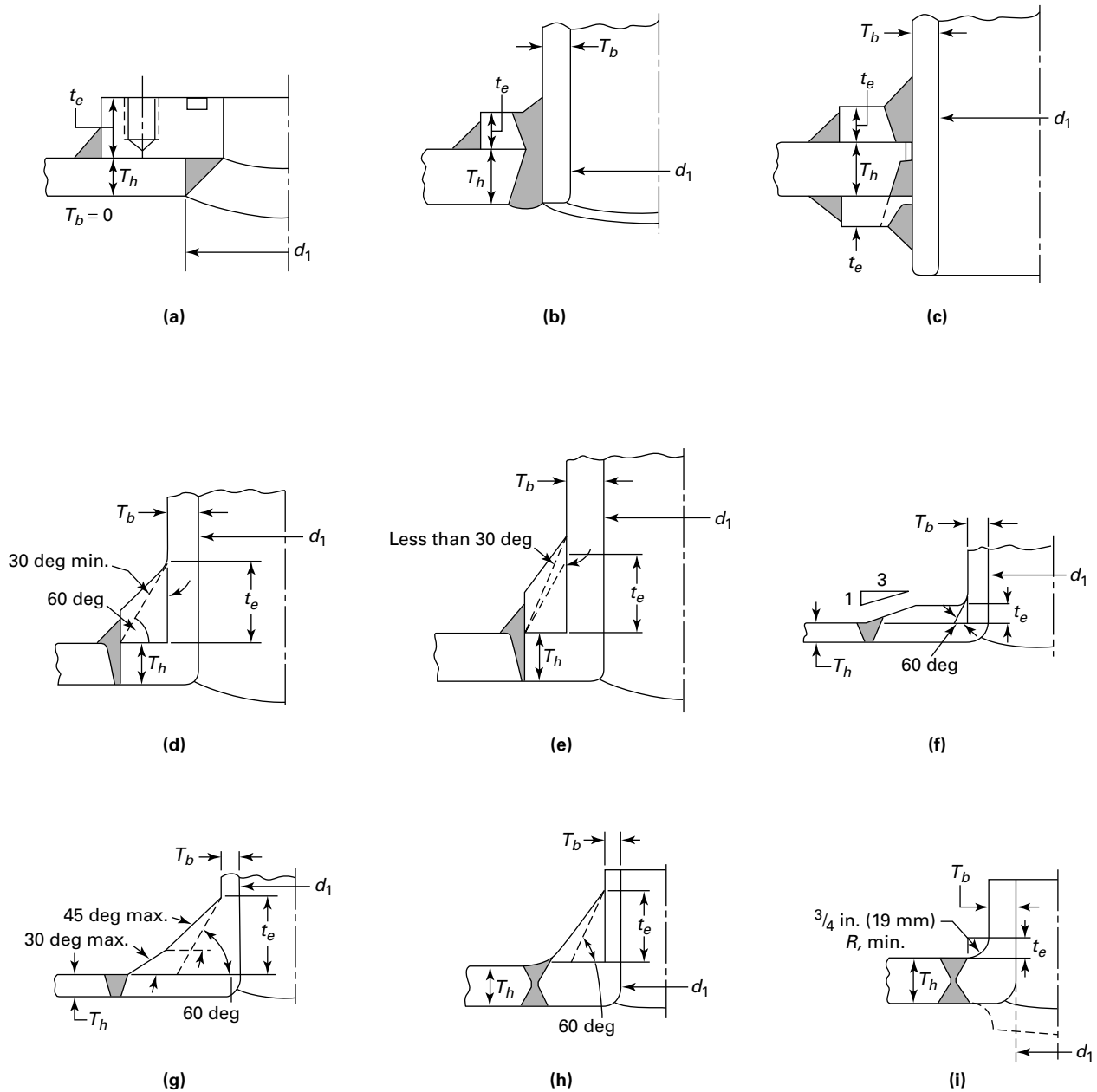
Required reinforcement = $(t_{mh}) (d_1) (2 - \sin \alpha)$
 Reinforcement areas = A_1, A_2, A_3, A_4



GENERAL NOTES:

- When metal is added as reinforcement (Example B), the value of reinforcing area may be taken in the same manner in which excess header metal is considered. Typical acceptable methods of meeting the above requirement are shown in Figure ND-4244.3(d)-1.
- Width to height of reinforcement shall be reasonably proportioned, preferably on a ratio as close as 4 to 1 as the available horizontal space within the limits of the reinforcing zone along the run and the outside diameter of the branch will permit, but in no case may the ratio be less than 1.
- This Figure is to be used only for definitions of terms, not for fabrication details.
- Use of reinforcing saddles and pads is limited as stated in ND-3643.3(c)(7).

Figure ND-3643.3(c)(1)-2
Some Representative Configurations Describing the t_e Reinforcement Dimension



reinforcement areas shall be decreased by the ratio of allowable stresses prior to any combination of areas to meet the reinforcement requirements of (c).

(5) *Reinforcement Zone.* The reinforcement zone is a parallelogram, the length of which shall extend a distance d_2 on each side of the centerline of the branch pipe and the width of which shall start at the inside surface of the run pipe and extend to a distance L from the outside surface of the run pipe, when measured in the plane of the branch connection.

(6) *Reinforcement of Multiple Openings*

(-a) When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with (3) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(-b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least $1\frac{1}{2}$ times their average diameter and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(7) *Rings, Pads, and Saddles*

(-a) Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch.

(-b) A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment.

(-c) Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds and each piece is provided with a vent hole.

(-d) Where saddles or pads are being employed for reinforcement, the potential for increased strain at the attachment welds that may occur as a result of rapid changes in differential metal temperatures between the saddle or pad and the run should be considered in the design evaluation.

ND-3643.4 Special Requirements for Extruded Outlets. The definitions, limitations, nomenclature, and requirements of (a) through (h) below are specifically applicable to extruded outlets.

(a) *Definition.* An extruded outlet header is a header in which the extruded lip at the outlet has a height above the surface of the run that is equal to or greater than the radius of the curvature of the external contoured portion of the outlet $h_o \geq r_o$ [Figure ND-3643.4(a)-1].

(b) *Cases to Which Rules Are Applicable.* These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run.

(c) *Nomenclature.* The notation used herein is illustrated in Figure ND-3643.4(a)-1.

- D = outside diameter of run, in. (mm)
- d = outside diameter of branch pipe, in. (mm)
- D_c = corroded internal diameter of run, in. (mm)
- d_c = corroded internal diameter of branch pipe, in. (mm)
- D_o = corroded internal diameter of extruded outlet measured at the level of the outside surface of the run, in. (mm)
- h_o = height of the extruded lip, in. (mm); this must be equal to or greater than r_o except as permitted in (d)(4)
- L = height of reinforcement zone, in. (mm)
 $= 0.7 \sqrt{dT_o}$
- r_o = radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch, in. (mm); this is subject to the limitations given in (d) below
- r_1 = half width of reinforcement zone, in. (mm) = D_o
- T_b = actual thickness of branch wall, not including the corrosion allowance, in. (mm)
- t_b = required thickness of branch pipe according to wall thickness eq. ND-3641.1(3) or eq. ND-3641.1(4), not including any thickness for corrosion, in. (mm)
- T_o = corroded finished thickness of extruded outlet measured at a height equal to r_o above the outside surface of the run, in. (mm)
- T_r = actual thickness of run wall, not including the corrosion allowance, in. (mm)
- t_r = required thickness of the run according to eq. ND-3641.1(3) or eq. ND-3641.1(4), not including any allowance for corrosion, in. (mm)

(d) *Rad ii*

(1) The minimum radius shall not be less than $0.05d$, except that on branch diameters larger than 30 in. (750 mm) it need not exceed $1\frac{1}{2}$ in. (38 mm).

(2) The maximum radius for outlet pipe sizes 6 in. nominal (DN 150) and larger shall not exceed $0.10d + 0.50$ in. ($0.10d + 13$ mm). For outlet pipe sizes less than NPS 6 (DN 150), this dimension shall be not greater than $1\frac{1}{4}$ in. (32 mm).

(3) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg shall meet the requirements of (1) and (2) above.

(4) Machining shall not be employed in order to meet the above requirements.

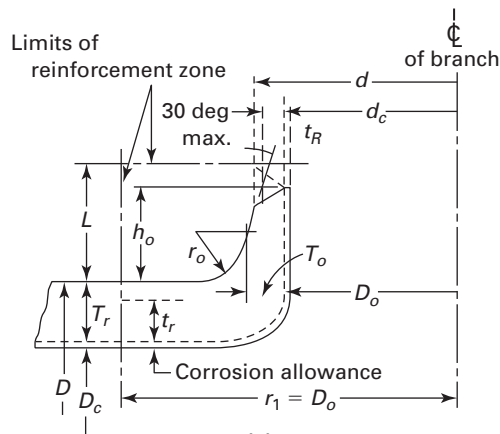
(e) *Required Area.* The required area is defined as

$$A = K(t_r)(D_o)$$

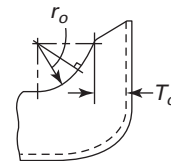
where K shall be taken as follows:

- (1) for d/D greater than 0.60, $K = 1.00$
- (2) for d/D greater than 0.15 and not exceeding 0.60, $K = 0.6 + 2d/3D$
- (3) for d/D equal to or less than 0.15, $K = 0.70$

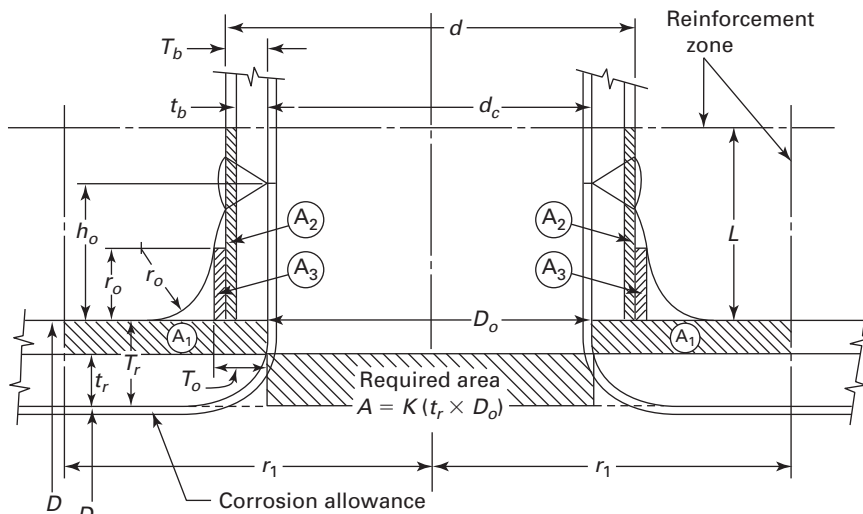
Figure ND-3643.4(a)-1
Reinforced Extruded Outlets



(a)



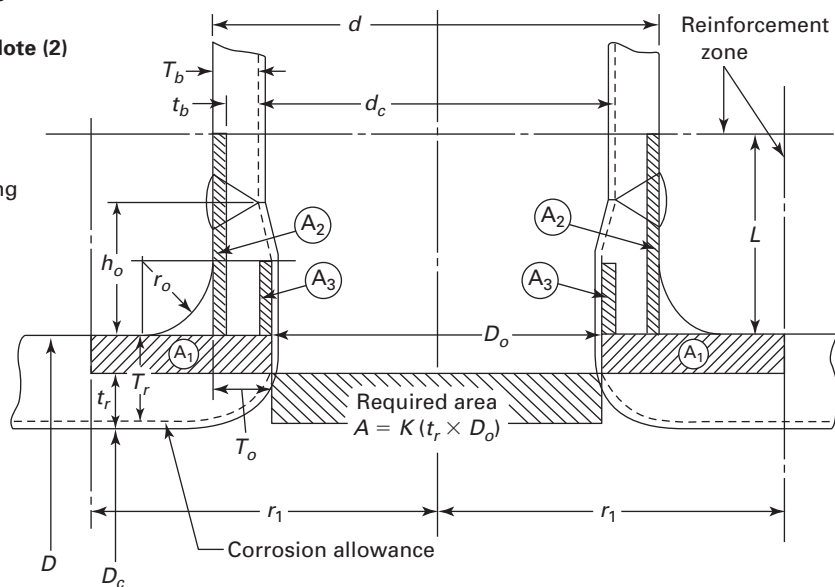
(b) Note (1)



(c) Note (2)

NOTES:

- (1) Sketch to show method of establishing T_o when the taper encroaches on the crotch radius.
- (2) Sketch is drawn for condition where $K = 1.00$.



(d) Note (2)

(f) **Reinforcement Area.** The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ as defined in (1), (2), and (3) below:

(1) Area A_1 is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall

$$A_1 = D_o(T_r - t_r)$$

(2) Area A_2 is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall

$$A_2 = 2L(T_b - t_b)$$

(3) Area A_3 is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip

$$A_3 = 2r_o(T_o - T_b)$$

(g) **Reinforcement of Multiple Openings.** When any two or more adjacent openings are so closely spaced that the reinforcement zones overlap, the two or more openings shall be reinforced in accordance with ND-3643.4, with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(h) **Marking.** In addition to the above, the Certificate Holder shall be responsible for establishing and marking on the section containing extruded outlets, the Design Pressure and Temperature, and the Certificate Holder's name or trademark.

ND-3643.5 Branch Connections Subject to External Pressure.

(a) The reinforcement area in in.² (mm²) required for branch connections subject to external pressure shall be $0.54(t_{mh})(d_1)(2 - \sin \alpha)$. All terms defined in ND-3643.3(c)(1), except (t_{mh}) is the minimum required wall thickness as determined by ND-3641.2.

(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

ND-3643.6 Reinforcement of Other Designs. The adequacy of designs to which the reinforcement requirements of ND-3643 cannot be applied shall be proven by burst or proof tests (ND-3649) on scale models or on full-size structures, or by calculations previously substantiated by successful service of similar design.

ND-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (e) below.

(a) The thickness of a segment of a miter shall be determined in accordance with ND-3641.1. The required thickness thus determined does not allow for the discontinuity stresses that exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased. These discontinuity stresses may be neglected for miters in nonflammable, nontoxic, noncyclic services with incompressible fluids at pressures of 100 psi (700 kPa) and under, and for gaseous vents to atmosphere. Miters to be used in other services or at higher pressures shall meet the requirements of ND-3649.

(b) The number of full pressure or thermal cycles shall not exceed 7,000 during the expected lifetime of the piping system.

(c) The angle θ in Table ND-3673.2(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(d) The centerline distance between adjacent miters shall be in accordance with Table ND-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

ND-3645 Attachments

(a) External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of ND-3135.

(c) The effect of rectangular and circular cross-section welded attachments on straight pipes may be evaluated using the procedures in Nonmandatory Appendix Y.

ND-3646 Closures

(a) Closures in piping systems shall be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NCA-7100-1 and used within the specified pressure-temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NCA-7100-1 may be made in accordance with the rules contained in ND-3300 using the equation

$$t_m = t + A$$

where

A = sum of mechanical allowances (ND-3613), in. (mm)

t = pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in [ND-3000](#), in. (mm)

t_m = minimum required thickness, in. (mm)

(c) Connections to closures may be made by welding, extruding, or threading. Connections to the closure shall be in accordance with the limitations provided in [ND-3643](#) for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening shall be designed as a reducer in accordance with [ND-3648](#).

(d) Other openings in closures shall be reinforced in accordance with the requirements of reinforcement for a branch connection. The total cross-sectional area required for reinforcement in any plane passing through the center of the opening and normal to the surface of the closure shall not be less than the quantity of $d_5 t$, where

d_5 = diameter of the finished opening, in. (mm)

t = pressure design thickness for the closure, in. (mm)

ND-3647 Pressure Design of Flanged Joints and Blanks

ND-3647.1 Flanged Joints.

(a) Flanged joints manufactured in accordance with the standards listed in Table NCA-7100-1, as limited by [ND-3612.1](#), shall be considered as meeting the requirements of [ND-3640](#).

(b) Flanged joints not included in Table NCA-7100-1 shall be designed in accordance with XI-3000.

ND-3647.2 Permanent Blanks. The minimum required thickness of permanent blanks ([Figure ND-3647.2-1](#)) shall be calculated from the following equations:

$$t_m = t + A$$

where

A = sum of mechanical allowances ([ND-3613](#)), in. (mm)

t = pressure design thickness calculated from the equation below, in. (mm)

t_m = minimum required thickness, in. (mm)

$$t = d_6 \left(\frac{3P}{16S} \right)^{1/2}$$

where

d_6 = the inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in. (mm)

P = Design Pressure, psi (MPa)

S = the allowable stress in accordance with Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi (MPa)

ND-3647.3 Temporary Blanks. Blanks to be used for test purposes only shall have a minimum thickness not less than the pressure design thickness t calculated as in [ND-3647.2](#), except that P shall not be less than the test pressure and the allowable stress S may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).

ND-3647.4 Flanges. Flanges shall be integral or be attached to pipe by welding, brazing, threading, or other means within the applicable standards specified in Table NCA-7100-1.

ND-3647.5 Gaskets.

(a) Gaskets shall be made of materials that are not injuriously affected by the fluid or by temperatures within the Design Temperature range.

(b) Only metallic or asbestos metallic gaskets may be used on flat or raised face flanges if the expected normal service pressure exceeds 720 psi (5 MPa) or the temperature exceeds 750°F (400°C). However, compressed sheet asbestos confined gaskets are not limited as to pressures, provided the gasket material is suitable for the temperatures.

(c) The use of metal or metal asbestos gaskets is not limited as to pressure, provided the gasket materials are suitable for the fluid Design Temperature.

ND-3647.6 Bolting.

(a) Bolts, stud bolts, nuts, and washers shall comply with applicable standards and specifications listed in Table NCA-7100-1. Unless otherwise specified, bolting shall be in accordance with the latest edition of ASME B16.5. Bolts and stud bolts shall extend completely through the nuts.

(b) Stud bolts 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 $1\frac{1}{2}$ diameters in length. Stud bolts greater than 8 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 $1\frac{1}{2}$ 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; and

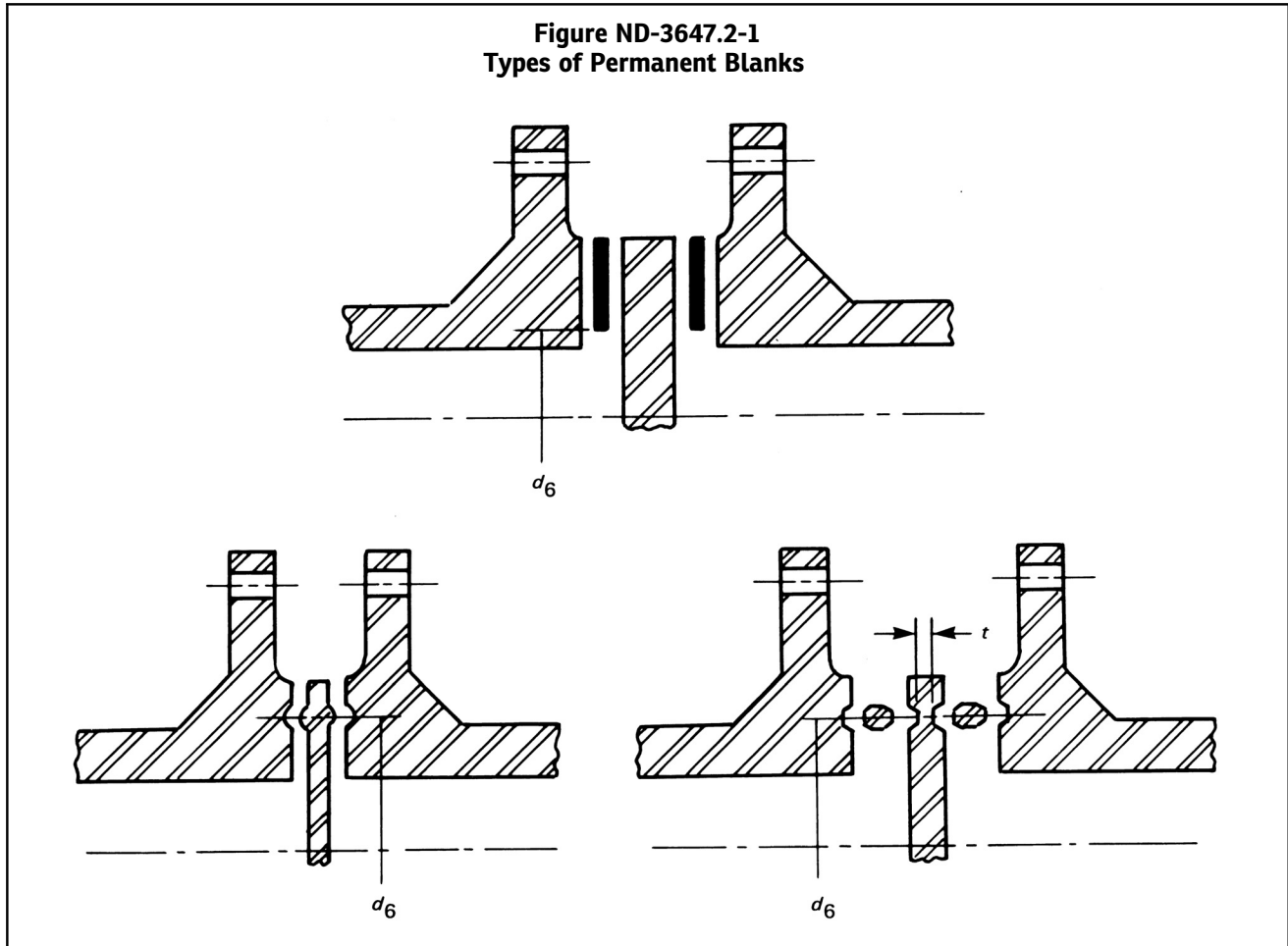
(3) a suitable transition shall be provided between the root diameter and unthreaded portions.

(c) Carbon steel bolts shall be square or heavy hexagon head bolts and shall have heavy semifinished hexagon nuts.

(d) Alloy steel stud bolts shall have heavy hexagon nuts. Headed alloy bolts are not recommended.

(e) It is recommended that all alloy bolts or stud bolts and accompanying nuts be threaded in accordance with ASME B1.1 Class 2A external threads and Class 2B internal threads.

Figure ND-3647.2-1
Types of Permanent Blanks



ND-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

ND-3649 Pressure Design of Other Pressure Retaining Piping Products

Other pressure retaining piping products manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use in piping systems at the specified pressure-temperature ratings. Pressure retaining piping products not covered by the standards listed in Table NCA-7100-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components has been proven satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design

shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:

- (a) proof tests as described in ASME B16.9;
- (b) experimental stress analysis (Appendix II).

ND-3649.1 Expansion Joints — General Requirements. Expansion joints of the bellows, sliding, ball, or swivel type may be used to provide flexibility for piping systems. The design of the piping systems and the design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and shall comply with the requirements of (a) through (e) below.

(a) Piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the expansion joints other than those for the absorption of which they are both suitable and intended. Bellows expansion joints are normally not designed for absorbing torsion. Sliding expansion joints are normally not designed for absorbing bending. In sliding and bellows expansion joints used for absorbing axial motion, the hydrostatic end force caused by fluid pressure and the forces caused by either friction resistance or spring force, or both, should be resisted by rigid end anchors, cross connections of the section ends, or other

means. Where reaction to hydrostatic end forces acts on pipe, guides shall be provided to prevent buckling in any direction. For bellows expansion joints, the pipe guiding and anchorage shall conform to EJMA Standards.²⁴

(b) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection and maintenance and for removal and replacement either directly or by other suitable means.

(c) Expansion joints employing mechanical seals shall be sufficiently leak-tight to satisfy safety requirements. The system designer shall specify the leak-tightness criteria for this purpose.

(d) Material shall conform to the requirements of ND-2000, except that no sheet material in the quenched, aged, or air-hardened condition shall be used for the flexible elements of a bellows joint. If heat treatment is required, it shall be performed either after welding the element into a complete cylinder or after all forming of the bellows is completed, the only welding permissible after such treatment being that required to connect the element to pipe or end flanges.

(e) All welded joints shall comply with the requirements of ND-4800.

ND-3649.2 Bellows Expansion Joints. Expansion joints of the bellows type may be used to provide flexibility for piping systems. The design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and the requirements of (a) through (f) below.

(a) The piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by pressure and the bellows spring force shall be accommodated by or resisted by rigid anchors, cross connections of the expansion joint ends, or other means. Where bellows are used in straight pipe sections to absorb axial motion and where the hydrostatic end force of the bellows acts on the pipe as a column, guides must be provided to prevent buckling of the pipe in any direction. The pipe guiding and anchorage shall conform to the requirements of the Design Specification for the attached piping.

(c) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connected piping that is not properly aligned, unless such misalignments have been specified by the system designer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Unless otherwise stated in the Design Specification, internal sleeves shall be provided when flow velocities exceed the following values:

(1) Air, Steam, and Other Gases

(-a) up to 6 in. (150 mm) diameter — 4 ft/sec/in. (0.05 m/s/mm) of diameter

(-b) 6 in. (150 mm) diameter and over — 25 ft/sec (7.6 m/s)

(2) Water and Other Liquids

(-a) up to 6 in. (150 mm) diameter — 2 ft/sec/in. (0.024 m/s/mm) of diameter

(-b) 6 in. (150 mm) diameter and over — 10 ft/sec (3 m/s)

ND-3649.3 Bellows Expansion Joint Material. Pressure retaining material in the expansion joint shall conform to the requirements of ND-2000.

ND-3649.4 Bellows Expansion Joint Design. Bellows may be of the unreinforced or reinforced convoluted type or of the toroidal type. The design shall conform to the requirements of ND-3000 and to those of (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and reinforcing member, due to pressure, shall not exceed the allowable stresses given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value that results in a permanent decrease in the spaces between adjacent convolutions of 7% after a pressure test of $1\frac{1}{2}$ times the Design Pressure, adjusted for temperature.

(c) The ratio of the internal pressure at which the bellows will become unstable (squirm) to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when the ratio of the maximum convolution pitch under internal pressure to the convolution pitch before application of pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire assembly. No external restraints on the bellows shall be employed during squirm testing other than those that will exist after installation.

(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset

movement. In the case of single joints subjected to rotation movement or universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement shall not be included in the deformation used to define squirm.

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio E_c/E_h , where E_c and E_h are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses S in the bellows due to internal pressure and deflection, multiplied by a stress factor K_s ,²⁵ shall not exceed the value defined by the following equation:

$$K_s S \leq S_f$$

where

- $K_s = (K_{sc})(K_{ss})$, but not less than 1.25
- K_{sc} = factor for differences in design fatigue curves at temperatures greater than 100°F (38°C)
 - = $2S_c/(S_c + S_h)$
- K_{ss} = factor for the statistical variation in test results
 - = 1.470 - 0.044 times the number of replicate tests
- S = total combined meridional membrane and bending stress due to pressure and deflection, psi (MPa). The calculation of the individual stress components and their combination must be determined by the same method as used for determining S_f . In the case of single joints subjected to rotation movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress.
- S_c = basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)
- S_f = total combined stress to failure at design cyclic life (number of cycles to failure) obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best-fit continuous curve or series of curves, psi (MPa). The S_f plot shall be parallel to the best-fit curve and shall lie below all of the data points.
- S_h = basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)

(e) Compliance with (a) through (d) above shall be demonstrated by any one of the procedures of (1), (2), or (3) below.

(1) Calculation of the individual stresses, their combination, and their relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations shall be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. (500 mm) diameter, where the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life versus the combined stress plot used in evaluating (d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining K_s .

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions provided the number of convolutions is not less than three and the diameter, thickness, depth, and pitch of the specimen are identical to the part to be furnished; squirm test specimens shall possess the total number of convolutions.

(-a) Any or all of the above tests of (1) or (2) may be conducted at room temperature, provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of S_c/S_h for rupture specimens and E_c/E_h for squirm specimens.

(-b) The fatigue life of the test specimen shall exceed $K_s^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution

deflection produced by the lateral component of the internal pressure force during the squirm test for single rotation joints and universal joints shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Appendix II. Cumulative fatigue requirements can be satisfied in accordance with (g) without additional testing by assuming that the slope of the fatigue curve is 4.3 and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NC-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, the stress intensity values of Tables 2A and 2B, Section II, Part D, Subpart 1, and fatigue curves of Figs. I-9.0 may be used to evaluate the design.

(-a) The stability requirements of (c) may be demonstrated by either

(-1) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold service pressure exceeds 10; or

(-2) the pressure test of ND-6230, provided that the test is conducted at $2^{1/4}$ times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test, and the requirements of (b) are not exceeded by such a test.

(f) The Certificate Holder's Data Report shall state which of the above procedures was utilized to verify the design.

(g) If there are two or more types of stress cycles that produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 5 below.

Step 1. Designate the specified number of times each stress cycle of types 1, 2, ..., n will be repeated during the life of the component as n_1, n_2, \dots, n_n , respectively.

NOTE: In determining n_1, n_2, \dots, n_n , consideration shall be given to the superposition of cycles of various origins which produce a total stress difference S_1, S_2, \dots, S_n greater than the stress difference of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of stress difference variation from 0 to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from 0 to -50,000 psi, the two types of cycles to be considered are defined by the following parameters:

$$\begin{aligned} \text{Type 1 Cycle : } n_1 &= 1,000, \\ S_1 &= (60,000 + 50,000) \\ &= 110,000 \text{ psi, and} \end{aligned}$$

$$\begin{aligned} \text{Type 2 Cycle : } n_2 &= 9,000, \\ S_2 &= (50,000 + 0) = 50,000 \text{ psi} \end{aligned}$$

Step 2. For each value S_1, S_2, \dots, S_n , use the applicable design fatigue curve and corresponding method of analysis to determine the maximum number of stress cycles that would be allowable if this type of cycle were the only one acting. Call these values N_1, N_2, \dots, N_n . The fatigue curve used may be either the S_f lot defined in (d) or the curve consistent with (e)(2) or (e)(3). If the fatigue curve has been developed based on a total stress difference, then the full value of S_1, S_2, \dots, S_n , of Step 1 must be used to determine N ; however, if the curve is based on an alternating stress, then the values of S_1, S_2, \dots, S_n shall be reduced by a factor of 2, in which case S_1, S_2, \dots, S_n become the alternating stresses.

Step 3. For each type of stress cycle, calculate the usage factors U_1, U_2, \dots, U_n , from $U_1 = n_1/N_1, U_2 = n_2/N_2, \dots, U_n = n_n/N_n$.

Step 4. Calculate the cumulative usage factor U from $U = U_1 + U_2 + \dots + U_n$.

Step 5. The cumulative usage factor U shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with ND-3649.

(i) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars. The design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(j) The spring rates of the expansion joint assembly shall be provided by the Certificate Holder. The spring rates of a bellows can be defined by several methods due to the hysteresis loop that can occur during deflection; a restoring force may be required to return the bellows to the original neutral position after deflection. When applicable, the Design Specification shall state the maximum allowable force that can be imposed on the connecting parts or shall require the Certificate Holder to determine the maximum force necessary to deflect the bellows a given distance, such as the maximum movement to be absorbed.

ND-3649.5 Metallic Braided Flexible Hoses. Metallic braided flexible hoses may be constructed in accordance with Section III Appendices, Nonmandatory Appendix BB.

ND-3650 ANALYSIS OF PIPING SYSTEMS

ND-3651 General Requirements²⁶

(a) The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads. The system design shall meet the limits of ND-3650. The pressure portion of eqs. ND-3652(8), ND-3653.1(a)(9a), and ND-3653.1(b)(9b) may be replaced with the expression

$$S_{LP} = B_1 \frac{2Pd^2}{D_o^2 - d^2}$$

The pressure portion of eq. ND-3653.2(c)(11) may be replaced by the expression

$$S_{LP} = \frac{Pd^2}{D_o^2 - d^2}$$

where the terms are the same as in ND-3652, except

d = nominal inside diameter of pipe, in. (mm)

$P = P$ or P_{max} , psi (MPa)

(b) When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint.

(c) For analysis of flanged joints, see ND-3658.

ND-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of eq. (8)

$$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S_h \quad (8)$$

where

B_1, B_2 = primary stress indices for the specific product under investigation [Table ND-3673.2(b)-1]

D_o = outside diameter of pipe, in. (mm)

M_A = resultant moment loading on cross section due to weight and other sustained loads, in.-lb (N-mm) (ND-3653.3)

P = internal Design Pressure, psi (MPa)

S_h = basic material allowable stress at Design Temperature, psi (MPa)

t_n = nominal wall thickness, in. (mm)

Z = section modulus of pipe, in.³ (mm³) (ND-3653.3)

ND-3653 Consideration of Levels A and B Service Limits

ND-3653.1 Occasional Loads.²⁷ The effects of pressure, weight, other sustained loads, and occasional loads, including reversing and nonreversing dynamic loads, for which Level B Service Limits are designated, must meet the requirements of either (a) or (b) below.

(a) The following requirements shall be met:

$$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \left(\frac{M_A + M_B}{Z} \right) \leq 1.8S_h \quad (9a)$$

but not greater than $1.5S_y$. Terms are the same as in ND-3652, except

M_B = resultant moment loading on cross section due to occasional loads, such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and

nonreversing dynamic loads, in.-lb (N-mm). For reversing and nonreversing dynamic loads, use only $\frac{1}{2}$ the range. Effects of anchor displacement due to reversing and nonreversing dynamic loads may be excluded from eq. (9a) if they are included in either eq. ND-3653.2(a)(10a) or eq. ND-3653.2(c)(11).

P_{max} = peak pressure, psi (MPa)

S_h = material allowable stress at temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at temperature consistent with the loading under consideration, psi (MPa)

(b) As an alternative to (a), for piping fabricated from material designated as P-No. 1 through P-No. 9 in Table 2A, Section II, Part D, and limited to $(D_o / t_n) \leq 40$, if Level B Service limits are specified, which include reversing dynamic loads (ND-3622.4) that are not required to be combined with nonreversing dynamic loads are specified, the requirements below shall apply.

$$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B'_2 \left(\frac{M_A + M'_B}{Z} \right) \leq 1.8S_h \quad (9b)$$

but not greater than $1.5S_y$. Terms are the same as in ND-3652, except

B'_2 = as defined in ND-3655(b)(3)

M'_B = resultant moment loading on cross section due to reversing dynamic loads, in.-lb (N-mm). For reversing dynamic loads, use only $\frac{1}{2}$ the range. Effects of anchor displacement due to reversing dynamic loads may be excluded from eq. (9b) if they are included in either eq. ND-3653.2(a)(10a) or eq. ND-3653.2(c)(11).

P_{max} = peak pressure, psi (MPa)

S_h = material allowable stress at temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at temperature consistent with the loading under consideration, psi (MPa)

ND-3653.2 Thermal Expansion. For Service Loadings for which Level A and B Service Limits are designated, the requirements of either (a)(10a) or (c)(11), and (b)(10b) must be met.

(a) The effects of thermal expansion must meet the requirements of eq. (10a)

$$S_E = \frac{iM_C}{Z} \leq S_A \quad (10a)$$

Terms are the same as in ND-3652 and ND-3653.1, except

i = stress intensification factor (ND-3673.2)

M_C = range of resultant moments due to thermal expansion, in.-lb (N-mm); also include moment effects of anchor displacements due to reversing and non-reversing dynamic loads if anchor displacement effects were omitted from eq. ND-3653.1(a)(9a) or eq. ND-3653.1(b)(9b).

S_A = allowable stress range for expansion stresses (ND-3611.2), psi (MPa)

(b) The effects of any single nonrepeated anchor movement shall meet the requirements of eq. (10b)

$$\frac{iM_D}{Z} \leq 3.0S_C \quad (10b)$$

Terms are the same as in ND-3653.1(a), except

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement), in.-lb (N-mm)

(c) The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of eq. (11)

$$S_{TE} = \frac{PD_o}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \leq (S_h + S_A) \quad (11)$$

For eq. (11) 0.75i shall not be less than 1.0.

ND-3653.3 Determination of Moments and Section Modulus.

(a) For purposes of eqs. ND-3652(8), ND-3653.1(a)(9a), ND-3653.1(b)(9b), ND-3653.2(a)(10a), ND-3653.2(b)(10b), and ND-3653.2(c)(11), the resultant moment for straight through components, curved pipe, or welding elbows may be calculated as follows:

$$M_j = \left(M_{xj}^2 + M_{yj}^2 + M_{zj}^2 \right)^{1/2}$$

where

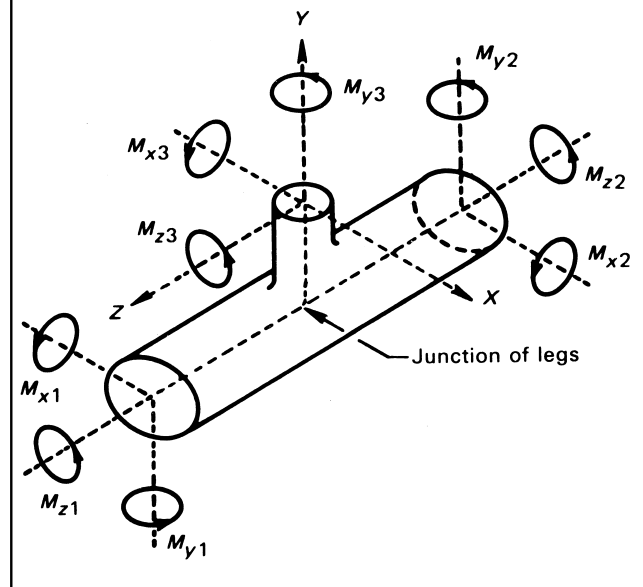
$j = A, B, B', C, \text{ or } D$ which are the subscripts of M_A, M_B, M'_B, M_C, M_D defined in ND-3652, ND-3653.1, and ND-3653.2

(b) For intersections (branch connections or tees), calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure ND-3653.3-1) for full outlet intersections.

(c) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure ND-3653.3-1), except that for $r'_m / R_m < 0.5$, the branch moments at the outside surface of the run pipe may be used for the branch leg.

(d) For intersections, the section modulus used to determine stresses shall be the effective section modulus

Figure ND-3653.3-1
Reducing or Full Outlet Branch Connections, or Tees



$$Z = \pi(r'_m)^2 T'_b \text{ for the branch leg}$$

and

$$Z = \pi(R_m)^2 T_r \text{ for the run legs}$$

where

R_m = run pipe mean cross-sectional radius, in. (mm)
 r'_m = branch pipe mean cross-sectional radius, in. (mm)
 T'_b = nominal branch pipe wall thickness, in. (mm)
 T_r = nominal wall thickness of run pipe, in. (mm)

(e) For components and joints other than intersections, the section modulus used to determine stresses shall be the classic section modulus

$$Z = \frac{2I}{D_o}$$

where

I = moment of inertia, in.⁴ (mm⁴)
 $= 0.0491 (D_o^4 - D_i^4)$
 D_i = inside diameter, in. (mm)

ND-3654 Consideration of Level C Service Limits

ND-3654.1 Permissible Pressure. When Level C Service Limits [NCA-2142.4(b)(3) and ND-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a , calculated in accordance with (13)

eq. ND-3641.1(5), by more than 50%. The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

ND-3654.2 Analysis of Piping Components. For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and ND-3113(b)] are designated, the following requirements shall apply:

(a) For Service Loadings for which Level C Service Limits are designated, except as permitted by (b) below, the conditions of eqs. ND-3653.1(a)(9a) and ND-3653.1(b)(9b) shall be met using Service Level C coincident pressure P and moment $(M_A + M_B)$, which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_h$, but not greater than $1.8S_y$. In addition, if the effects of anchor motion, M_{AM} , from reversing dynamic loads are not considered in ND-3653, then the requirements of ND-3655(b)(4) shall be satisfied using 70% of the allowable stress given in ND-3655(b)(4).

(b) As an alternative to (a), for Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads (ND-3622.4) that are not required to be combined with nonreversing dynamic loads (ND-3622.5), the requirements of ND-3655(b) shall be satisfied using the allowable stress in ND-3655(b)(2), 70% of the allowable stress in ND-3655(b)(3), and 70% of the allowable loads in ND-3655(b)(4).

ND-3654.3 Deformation Limits. Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

(13) ND-3655 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the following requirements shall apply:

(a) For Service Loadings for which Level D Service Limits are designated, except as permitted by (b) below, the requirements of (1), (2), and (3) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with eq. ND-3641.1(5). The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

(2) The conditions of eqs. ND-3653.1(a)(9a) and ND-3653.1(b)(9b) shall be met using Service Level D coincident pressure P and moment $(M_A + M_B)$, which result in the maximum calculated stress. The allowable stress to be used for this condition is $3.0S_h$, but not greater than $2.0S_y$.

(3) If the effects of anchor motion, M_{AM} , from reversing dynamic loads are not considered in ND-3653, then the requirements of (b)(4) shall be satisfied.

(b) As an alternative to (a), for piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D and limited to $D_o/t_n \leq 40$, if Level D Service Limits are designated, which include reversing

dynamic loads (ND-3622.4) that are not required to be combined with nonreversing dynamic loads (ND-3622.5), the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading, P_E , shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5S_h$$

where

M_W = resultant moment due to weight effects, in.-lb (N·mm)

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_E D_o}{2t} + B_2' \frac{D_o}{2I} M_E \leq 3S_h$$

where

$B_2' = B_2$ from Table ND-3673.2(b)-1, except as follows:

where

$B_2' = 1.33$ for girth butt welds between items that do not have nominally identical wall thicknesses

$B_2' = 0.87/h^{2/3}$ for curved pipe or butt welding elbows [h as defined in Table ND-3673.2(b)-1], but not less than 1.0

$B_{2b}' = 0.27 (R_m/T_r)^{2/3}$ and

$B_{2r}' = 0.33 (R_m/T_r)^{2/3}$ for ASME B16.9 or MSS SP-87 butt welding tees [terms as defined in Table ND-3673.2(b)-1], but neither less than 1.0

M_E = the amplitude of the resultant moment in.-lb (N·mm). In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs are obtained, the most conservative combination shall be assumed.

P_E = the pressure occurring coincident with the reversing dynamic load, psi (MPa)

S_h = as defined in ND-3653.1

(4) The range of the resultant moment M_{AM} and the amplitude of the longitudinal force F_{AM} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$c_2 \frac{M_{AM} D_O}{2I} < 6S_h$$

$$\frac{F_{AM}}{A_M} < S_h$$

where

A_M = cross-sectional area of metal in the piping component wall, in.² (mm²)

(5) The use of the $6S_h$ limit in (4) assumes essentially linear behavior of the entire piping system. This assumption is sufficiently accurate for systems where plastic straining occurs at many points or over relatively wide regions, but fails to reflect the actual strain distribution in unbalanced systems where only a small portion of the piping undergoes plastic strain. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(-a) by the use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed.

(-b) by local reduction in size or cross section, or local use of a weaker material.

In the case of unbalanced systems the design shall be modified to eliminate the unbalance or the piping shall be qualified to the equations given in (4) with $6S_h$ taken as $3S_h$.

(6) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to (a) and (b), the rules contained in Appendix F may be used in evaluating these service loadings independently of all other Design and Service Loadings.

ND-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by ND-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either ND-3658.1, ND-3658.2, or ND-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of ND-3651 through ND-3655 using appropriate stress intensification factors from Table ND-3673.2(b)-1. The following nomenclature applies for ND-3658:

A_b = total cross-sectional area of bolts at root of thread or section of least diameter under stress, in.² (mm²)

C = bolt circle diameter, in. (mm)

D_f = outside diameter of raised face, in. (mm)

G = diameter at location of gasket load reaction as defined in XI-3130, in. (mm)

M_{fd} = bending or torsional moment (considered separately) as defined for M_{fs} but including dynamic loadings applied to the flanged joint during the design or service condition, in.-lb (N-mm)

M_{fs} = bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service condition, in.-lb (N-mm). If cold springing is used, the moment may be reduced to the extent permitted by ND-3673.5.

P = Design or Service Condition Pressure as defined in NCA-2140, psi (MPa)

P_{eq} = equivalent pressure to account for the moments applied to the flange joint during the Condition, psi (MPa)

P_{fd} = pressure concurrent with M_{fd} , psi (MPa)

S = allowable bolt stress for the bolt material, psi (MPa)

S_y = yield strength, psi (MPa), of flange material at Design Temperature (Table Y-1, Section II, Part D, Subpart 1)

ND-3658.1 Any Flanged Joint. Flanged joints may be analyzed and the stresses evaluated by using the methods given in Appendix XI as modified by (a) or by (b). Alternatively, they may be analyzed in accordance with Appendix XIII.

(a) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1, and if each P' , as calculated by (b) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of ND-3658 are satisfied.

(b) The Design Pressure used for the calculation of H in Appendix XI shall be replaced by a flange design pressure

$$P' = P + P_{eq}$$

The equivalent pressure P_{eq} shall be determined by the greater of

$$P_{eq} = 16M_{fs} / \pi G^3$$

or

$$P_{eq} = 8M_{fd} / \pi G^3$$

ND-3658.2 Standard Flanged Joints at Moderate Pressures and Temperatures. Flanged joints conforming to ASME B16.5, ASME B16.47, or ANSI/AWWA C207 Class E [275 psi (1.9 MPa)], and used where neither the Design nor Service Pressure exceeds 100 psi (0.7 MPa) and

neither the Design nor Service Temperature exceeds 200°F (95°C), meet the requirements of [ND-3658](#), provided the following equations are satisfied:

$$M_{fs} \leq A_b CS / 4$$

and

$$M_{fd} \leq A_b CS / 2$$

ND-3658.3 ASME B16.5, Flanged Joints With High Strength Bolting. Flanged joints using flanges, bolting, and gaskets as specified in ASME B16.5 and using bolting material having an S value at 100°F (38°C) not less than 20,000 psi (140 MPa) may be analyzed in accordance with the following rules:

(a) Design Limits and Levels A and B Service Limits

(1) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(2) The limitations given by [eqs. \(12\)](#) and [\(13\)](#) shall be met

(U.S. Customary Units)

$$M_{fs} \leq 3,125(S_y / 36,000) CA_b \quad (12)$$

(SI Units)

$$M_{fs} \leq 21.7(S_y / 250) CA_b$$

(U.S. Customary Units)

$$M_{fd} \leq 6,250(S_y / 36,000) CA_b \quad (13)$$

(SI Units)

$$M_{fd} \leq 43.4(S_y / 250) CA_b$$

where the value of $S_y/36,000$ or $(S_y/250)$ shall not be taken as greater than unity.

(b) Level C Service Limits

(1) The pressure shall not exceed 1.5 times the rated pressure.

(2) The limitation given by [eq. \(17\)](#) shall be met

(SI Units)

$$M_{fd} \leq [78.1A_b - (\pi/16)D_f^2P_{fd}]C(S_y/250) \quad (17)$$

(U.S. Customary Units)

$$M_{fd} \leq [11,250A_b - (\pi/16)D_f^2P_{fd}]C(S_y/36,000)$$

where the value of $S_y/36,000$ or $(S_y/250)$ shall not be taken as greater than unity.

(c) Level D Service Limits

(1) The pressure shall not exceed 2.0 times the rated pressure.

(2) The limitation given by [eq. \(b\)\(2\)\(17\)](#) shall be met, where P_{fd} and M_{fd} are pressures, psi (MPa), and moments, in.-lb (N·m), occurring concurrently.

(d) Test Loadings. Analysis for test loadings is not required.

ND-3660 DESIGN OF WELDS

ND-3661 Welded Joints

ND-3661.1 General Requirements. Welded joints shall be in accordance with the requirements of [ND-4200](#) except as limited herein.

ND-3661.2 Butt Welded Joints.

(a) Girth welds shall be Type 1, 2, or 3 ([ND-4245](#)).

(b) Longitudinal welds shall be Type 1 ([ND-4245](#)).

ND-3661.3 Socket Welded Joints.²⁸ Socket welds shall comply with the requirements of [ND-4427](#).

ND-3661.4 Fillet Welds and Partial Penetration Welds for Branch Connections.

²⁹

(a) Fillet welds and partial penetration welds may be used within the limitations of [ND-3643.1\(c\)](#).

(b) For fillet welds, the size of the weld shall be specified on the design drawings.

(c) For partial penetration welds, the size of the weld, the depth of the weld groove, and the groove angle shall be specified on the design drawings.

ND-3670 SPECIAL PIPING REQUIREMENTS

ND-3671 Selections and Limitations of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled.

ND-3671.1 Flanged Joints. Flanged joints shall conform to [ND-3647](#) and [ND-3658](#).

ND-3671.2 Expanded or Rolled Joints. Expanded or rolled joints may be used when experience or test ([ND-3649](#)) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

ND-3671.3 Threaded Joints. Threaded joints may be used within the limitations specified in (a), (b), and (c) below.

(a) All threads on piping products shall be taper pipe threads in accordance with the applicable standard listed in Table NCA-7100-1. Threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seal weld or a seating surface other than the threads and when experience or test (ND-3649) has demonstrated that such threads are suitable.

(b) Threaded joints shall not be used when severe erosion, crevice corrosion, shock, or vibration is expected to occur. Size limits for steam and hot water service above 220°F (100°C) shall be as follows:

Maximum Nominal Size, in. (DN)	Maximum Pressure, psi (MPa)
3 (80)	400 (2.8)
2 (50)	600 (4.1)
1 (25)	1,200 (8.3)
$\frac{3}{4}$ (20) and less	1,500 (10.3)

(c) Pipe with a wall thickness less than that of standard weight of ASME B36.10M steel pipe shall not be threaded, regardless of service. When steel pipe is threaded and used in steam service over 250 psi (1.7 MPa) or water service above 100 psi (700 kPa) and 220°F (100°C), the pipe shall be seamless and at least Schedule 80.

ND-3671.4 Flared, Flareless, and Compression Joints. Flared, flareless, and compression type tubing fittings may be used for tube sizes not exceeding 2 in. (50 mm) O.D. within the limitations of applicable standards and specifications in Table NCA-7100-1 and as specified in (a) through (e) below.

(a) Fittings and their joints shall be compatible with the tubing with which they are to be used and shall conform to the range of wall thicknesses and method of assembly recommended by the manufacturer.

(b) Fittings shall be used at pressure-temperature ratings not exceeding the recommendations of the manufacturer. Service Conditions, such as vibration and thermal cycling, shall be considered in the application.

(c) All threads on piping products shall be taper pipe threads in accordance with applicable standards listed in Table NCA-7100-1. Exceptions are that threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seating surface other than the threads and when experience or tests (ND-3649) have demonstrated that such threads are suitable.

(d) In the absence of standards or specifications, the designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the following requirements.

(1) The pressure design shall meet the requirements of ND-3649.

(2) Prototypes of the fittings to be used shall successfully meet performance tests (ND-3649) to determine the safety of the joint under simulated Service Loadings. When

vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are expected, the applicable conditions shall be incorporated in the test.

(e) Flareless fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body.

(1) When using bite-type fittings, a spot check shall be made for adequate depth of bite and condition of tubing by disassembling and reassembling selected joints.

(2) Grip-type fittings that are tightened in accordance with manufacturer's instructions need not be disassembled for checking.

ND-3671.5 Caulked Joints. Caulked or leaded joints shall not be used.

ND-3671.6 Brazed and Soldered Joints.

(a) *Brazed Joints.* Brazed joints shall be socket-type, and the minimum socket depth shall be sufficient for the intended service, but in no case less than that specified in Figure ND-4511-1.

(b) *Soldered Joints.* Soldered joints shall be socket-type and shall be made in accordance with applicable standards listed in Table NCA-7100-1.

(c) Limitations of Brazed and Soldered Joints

(1) Brazed socket-type joints shall not be used in systems containing flammable or toxic fluids, or in areas where fire hazards are involved.

(2) Soldered socket-type joints shall be limited to systems containing nonflammable and nontoxic fluids.

(3) Soldered socket-type joints shall not be used in piping subject to mechanical or thermal shock, or vibration.

(4) Brazed or soldered joints depending solely upon a fillet, rather than primarily upon brazing or soldering material between the pipe and socket, are not acceptable.

(5) Soldered joints shall be pressure and temperature rated in accordance with the applicable standards in Table NCA-7100-1, except that they shall not be used at pressures in excess of 175 psi (1.2 MPa) or at temperatures in excess of 250°F (120°C).

ND-3671.7 Sleeve-Coupled and Other Patented Joints. Coupling-type, mechanical gland-type, and other patented joints may be used where experience or tests have demonstrated to the satisfaction of the designer that the joint is safe for the Design Loadings and when adequate provision is made to prevent separation of the joint.

ND-3672 Expansion and Flexibility

ND-3672.1 General Requirements.

(a) In addition to the design requirements for pressure, weight, and other loadings, piping systems subject to thermal expansion or contraction or to similar movements

imposed by other sources shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stresses specified in this paragraph.

(b) Piping shall meet the expansion and flexibility requirements of this Subarticle except that, where Class 3 piping is connected to Class 1 piping, the requirements for expansion and flexibility for Class 1 piping shall apply to the Class 3 piping out to the first anchor on the Class 3 piping. However, the effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with ND-3650. Other exceptions as stated in the following subparagraphs shall apply.

ND-3672.2 Properties. Thermal expansion data and moduli of elasticity shall be determined from Tables TE and TM, Section II, Part D, Subpart 2, which cover more commonly used piping materials. For material not included in these Tables, reference shall be to authoritative source data such as publications of the National Institute of Standards and Technology.

ND-3672.3 Thermal Expansion Range. The thermal expansion range shall be determined from Table TE, Section II, Part D, Subpart 2 as the difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service and shutdown conditions.

ND-3672.4 Moduli of Elasticity. The cold and hot moduli of elasticity E_c and E_h shall be as shown in Table TM, Section II, Part D, Subpart 2 for the material based on the temperatures established in ND-3672.3.

ND-3672.5 Poisson's Ratio. Poisson's ratio, when required for flexibility calculations, shall be taken as 0.3 at all temperatures for all materials.

ND-3672.6 Stresses. Calculations for the stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions at the location of local strain. Calculations for the expansion stress S_E shall be based on the modulus of elasticity at room temperature E_c .

(a) *Stress Range.* Stresses caused by thermal expansion, when of sufficient initial magnitude, relax in the hot condition as a result of local yielding or creep. A stress reduction takes place and usually appears as a stress of reversed sign when the component returns to the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The extent of self-springing depends on the material, the magnitude of the initial expansion and fabrication stress, the hot service temperature, and the elapsed time. While the expansion stress in the hot condition tends to diminish with time, the sum of the expansion strains for the hot and cold conditions during any one cycle remains substantially constant. This sum is referred to as the strain range; however, to permit convenient association with allowable stress, stress range is selected as the criterion for the thermal design of piping.

(b) *Local Overstrain.* All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(1) by use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;

(2) by local reduction in size or cross section, or local use of a weaker material;

(3) in a system of uniform size, by use of a line configuration for which the neutral axis or thrust line is situated close to the major portion of the line itself, with only a very small offset portion of the line absorbing most of the expansion strain.

(c) Conditions of this type shall be avoided, particularly where materials of relatively low ductility are used; if unavoidable, they shall be mitigated by the judicious application of cold spring.

(d) It is recommended that the design of piping systems of austenitic steel materials be approached with greater overall care as to general elimination of local stress raisers, examination, material selection, fabrication quality, and erection.

ND-3672.7 Flexibility. Piping systems shall be designed to have sufficient flexibility to prevent pipe movements from causing failure from overstress of the pipe material or anchors, leakage at joints, or detrimental distortion of connected equipment resulting from excessive thrusts and moments. Flexibility shall be provided by changes of direction in the piping through the use of bends, loops, or offsets; or provisions shall be made to absorb thermal movements by utilizing expansion, swivel, or ball joints or corrugated pipe.

ND-3672.8 Expansion, Swivel, or Ball Joints. Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of ND-3649.

ND-3673 Analysis

ND-3673.1 Method of Analysis. All systems shall be analyzed for adequate flexibility by a structural analysis unless one of the following conditions is met:

(a) The system can be judged technically adequate by an engineering comparison with previously analyzed systems.

(b) The operating temperature of the piping system is at or below 150°F (65°C) and the piping is laid out with inherent flexibility, as provided in ND-3672.7.

(c) The operating temperature of the piping system is at or below 250°F (120°C) and the piping is analyzed for flexibility using simplified methods of calculation such as handbooks or charts.

(13) ND-3673.2 Basic Assumptions and Requirements.

(a) When calculating the flexibility of a piping system between anchor points, the system between anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors found to exist in piping products or joints other than straight pipe. Credit may be taken where extra flexibility exists in such products or joints. Flexibility factors and stress intensification factors for commonly used piping products and joints are shown in Table ND-3673.2(b)-1. The stress intensification factors and flexibility factors in Table ND-3673.2(b)-1 shall be used unless specific experimental or analytical data exist that would warrant lower stress intensification factors or higher flexibility factors.

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor is

$$k = \theta_{ab} / \theta_{nom}$$

where

θ_{ab} = rotation of end a , with respect to end b , due to a moment load M and in the direction of the moment M

θ_{nom} = nominal rotation assuming the component acts as a beam with the properties of the nominal pipe. For an elbow, θ_{nom} is the nominal rotation assuming the elbow acts as a curved beam

The flexibility factor k is defined in detail for specific components in Table ND-3673.2(b)-1.

(d) Stress intensification factors are identified herein by i . The definition of a stress intensification factor is based on fatigue bend testing of mild carbon steel fittings and is

(U.S. Customary Units)

$$iS = 245,000 N^{-0.2}$$

(SI Units)

$$iS = 1700 N^{-0.2}$$

where

i = stress intensification factor

= ratio of the bending moment producing fatigue in a given number of cycles in a straight pipe with a girth butt weld to that producing failure in the same number of cycles in the fitting or joint under consideration.

N = number of cycles to failure

S = amplitude of the applied bending stress at the point of failure, psi (MPa)

(e) For piping products or joints not listed in Table ND-3673.2(b)-1, flexibility or stress intensification factors shall be established by experimental or analytical means.

(f) Experimental determination of flexibility factors shall be in accordance with Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Appendix II, II-2000.

(g) Analytical determination of flexibility factors shall be consistent with the definition above.

(h) Analytical determination of stress intensification factors may be based on the empirical relationship

$$i = C_2 K_2 / 2, \text{ but not less than } 1.0$$

where C_2 and K_2 are stress indices for Class 1 piping products or joints from NB-3681(a)-1, or are determined as explained below.

Analytical determination of stress intensification factors shall be correlated with experimental fatigue results. Experimental correlation may be with new test data or with test data from similar products or joints reported in literature. Finite element analyses or other stress analysis methods may be used to determine C_2 ; however, test or established stress concentration factor data should then be used to determine K_2 .

(i) For certain piping products or joints the stress intensification factor may vary depending on the direction of the applied moment, such as in an elbow or branch connection. For these cases, the stress intensification factor used in eqs. ND-3653.2(a)(10a), ND-3653.2(b)(10b) and ND-3653.2(c)(11) shall be the maximum stress intensification factor for all loading directions as determined in accordance with (f) or (h) above.

(j) Stress intensification factors determined in accordance with (f) above shall be documented in accordance with Appendix II, II-2050. The test report may be included and certified with the Design Report (NCA-3551.1 and NCA-3555) for the individual piping system or a separate report furnished (II-2050).

(k) Stress intensification factors determined in accordance with (h) above shall be documented in a report with sufficient detail to permit independent review. The review shall be performed by an engineer competent in the applicable field of design in accordance with Appendix XXIII. The report shall be included and certified as part of the design report for the piping system (NCA-3551.1 and NCA-3555).

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

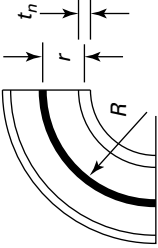
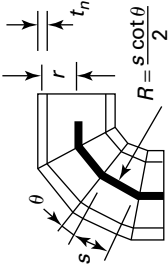
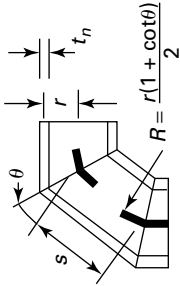
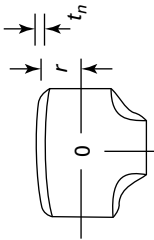
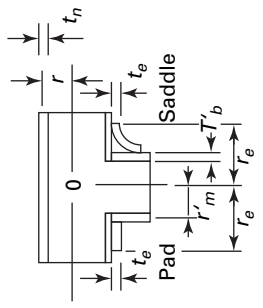
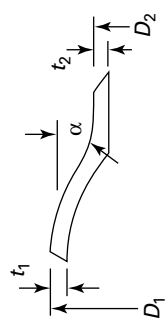
Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4 \ h \ -0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r \ (1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot \theta}{2 r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r \ (1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n (1 + \cot \theta)}{2 r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{t_n} \right)^{2/3}$	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
		Run end: $B_{2r} = 0.5 \left(\frac{r}{t_n} \right)^{2/3}$			For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}} \left(\frac{T'_b}{T'_r} \right)$	

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75 \left(\frac{r}{t_n} \right)^{2/3} \left(\frac{r'_m}{r} \right)^{1/2} \left(\frac{T_b}{t_n} \right) \left(\frac{r'_m}{r_{ps}} \right) \geq 1.0$ [Note (7)]	$\frac{\left(t_n + \frac{t_e}{2} \right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$	
		Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t_e/2t_n)]^{5/3}} \geq 1.0$ [Note (8)]			For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}} \left(\frac{r'_b}{r} \right) \geq 2.1$	
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \leq 0.9$ $B_{2b} = 0.75 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{r_p} \right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	1	1	Branch leg: for $(r'_m/R_m) \leq 0.9$ $i_b = 1.5 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{r_p} \right) \geq 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	<p align="center">Figure ND-3673.2(b)-2</p>
		Run legs: $B_{2r} = 0.9 \left(\frac{r'_m}{t_b} \right)^{1/4}$			Run legs: $i_r = 0.8 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	

**Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)**

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_r b}{T_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 1.5$	1	Branch leg: $i_b = 4.5 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_r b}{T_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 3.0$	Figure ND-3643.2(b)-2
		Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{t_b} \right)^{1/4} \geq 1.5$		Run legs: $i_r = 0.8 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75 \left(\frac{t_n}{c_x} \right) \geq 0.5$	$1.5 \left(\frac{t_n}{c_x} \right)$	1	For $C_x \geq 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1$ (t_n/C_x) ≥ 1.3	Figure ND-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure ND-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 0.113 / t_n \leq 1.9$ (SI Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 2.87 / t_n \leq 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	1.3 + 0.0036 $D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg $< \alpha \leq 60$ deg	1.0	1	$0.5 + 0.01 \alpha \left(\frac{D_2}{t_b} \right)^{1/2} \leq 2.0$	

**Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)**

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

(a) The following nomenclature applies:

D_o = nominal outside diameter, in. (mm)

r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)

r'_m = mean radius of branch pipe, in. (mm)

R = nominal bend radius of elbow or pipe bend, in. (mm)

R_m = mean radius of run pipe, in. (mm)

θ = one-half angle between adjacent miter axes, deg

s = miter spacing at center line, in. (mm)

t_b = thickness in reinforcement zone of branch, in. (mm)

t_e = pad or saddle thickness, in. (mm)

t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]

T'_b = nominal wall thickness of branch pipe, in. (mm)

T_r = nominal wall thickness of run pipe, in. (mm)

For Figure ND-3673.2(b)-2, sketches (a) and (b):

$$t_b = T_b \text{ if } L_1 \geq 0.5(2r'_m T_b)^{1/2} \\ = T'_b \text{ if } L_1 < 0.5(2r'_m T_b)^{1/2}$$

For Figure ND-3673.2(b)-2, sketch (c):

$$t_b = T'_b + \left(\frac{2}{3}\right)y \text{ if } \theta \leq 30 \text{ deg} \\ = T'_b + 0.385L_1 \text{ if } \theta > 30 \text{ deg}$$

For Figure ND-3673.2(b)-2, sketch (d):

$$t_b = T'_b = T_b$$

For branch connection nomenclature, refer to Figs. ND-3643.2(b)-2 and ND-3673.2(b)-2.

(b) The flexibility factors k , stress intensification factors i , and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table ND-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$$X = 1.3 - 0.006(D_o/t_n), \text{ not to exceed } 1.0$$

$$Y = 1.033 - 0.00033T \text{ for Ferritic Material, not to exceed } 1.0; T = \text{Design temperature } (^{\circ}\text{F})$$

$$Y = 1.0224 - 0.000594T \text{ for Ferritic Material, not to exceed } 1.0; T = \text{Design temperature } (^{\circ}\text{C})$$

$$Y = 1.0 \text{ for other materials}$$

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.

(a) One end flanged, $c = h^{1/6}$

(b) Both ends flanged, $c = h^{1/3}$

But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(3) Also includes single miter joints.

**Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)**

NOTES (CONT'D):

(4) For checking branch leg stress:

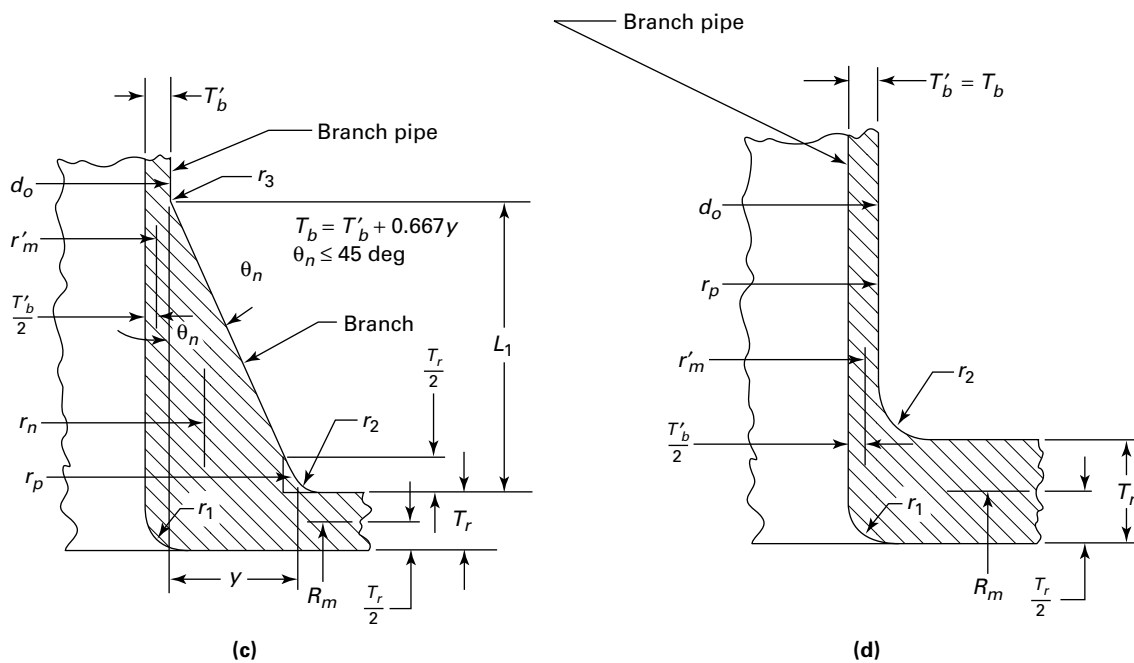
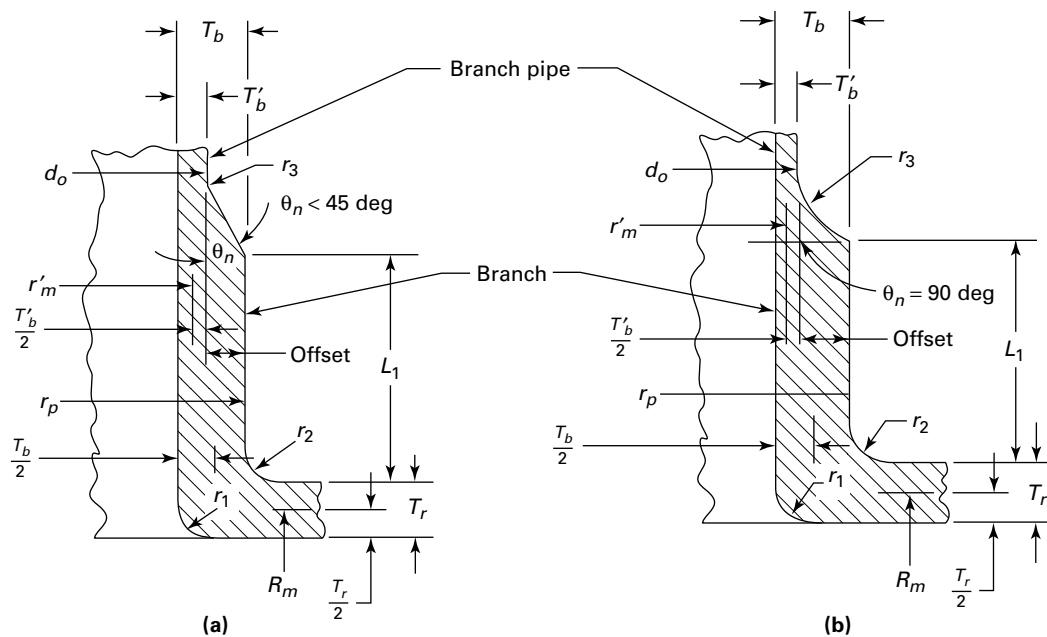
$$Z = \pi (r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

- (5) When $t_e > 1.5 t_n$, $h = 4.05 t_n / r$.
- (6) The equation applies only if the following conditions are met:
 (a) The reinforcement area requirements of [ND-3643](#) are met.
 (b) The axis of the branch pipe is normal to the surface of the run pipe wall.
 (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 (d) The run pipe is a straight pipe.
- (7) r'_m / r shall be taken as 0.5 for $r'_m / r > 0.5$.
 r'_m / r_{ps} shall not be taken as less than 0.5.
- The definition of r_{ps} is:
 $r_{ps} = (r'_m + r_e) / 2$ for $t_e \geq 0.8 t_n$
 $r_{ps} = r'_m + (T'_b / 2)$ for $t_e < 0.8 t_n$
- (8) The definition of t'_e is:
 $t'_e = t_e [(r_e / r'_m) - 1]$ but not greater than $1.0 t_n$
- (9) If an r_2 radius is provided [[Figure ND-3673.2\(b\)-2](#)] that is not less than the larger of $T_b / 2$, $(T'_b + y) / 2$ [sketch (c)], or $T_r / 2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$.
- (10) The equations apply only if $r'_m / R_m \leq 0.5$.
- (11) In [Figure ND-4427-1](#) sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25 t_n$. For unequal leg lengths, use the smaller leg length for C_x .
- (12) The equation applies only if the following conditions are met:
 (a) Cone angle α does not exceed 60 deg.
 (b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100.
 (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 (d) For eccentric reducers, α is the maximum cone angle.

Figure ND-3673.2(b)-2
Branch Connection Nomenclature



GENERAL NOTES:

- (a) T_b , θ , r_1 , r_2 , r_3 , r_p , and y are defined in this figure.
- (b) Nomenclature
- d_o = outside diameter of branch pipe, in. (mm)
 r'_m = mean radius of branch pipe, in. (mm)
 T'_b = nominal thickness of branch pipes, in. (mm)
 R_m = mean radius of run pipe, in. (mm)
 T_r = nominal thickness of run pipe, in. (mm)

(l) The total expansion range as determined from ND-3672.3 shall be used in all calculations, whether or not the piping is cold sprung. Expansion of the line, linear and angular movements of the equipment, supports, restraints, and anchors shall be considered in the determination of the total expansion range.

(m) Where simplifying assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(n) Dimensional properties of pipe and fittings used in flexibility calculations shall be based on nominal dimensions.

(o) When determining stress intensification factors by experimental methods, ND-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.

ND-3673.3 Cold Springing. The beneficial effect of judicious cold springing in assisting a system to attain its most favorable position is recognized. Inasmuch as the life of a system under cyclic conditions depends on the stress range rather than the stress level at any one time, no credit for cold spring is allowed with regard to stresses. In calculating end thrusts and moments acting on equipment, the actual reactions at any one time, rather than their range, shall be used. Credit for cold springing is allowed in the calculations of thrusts and moments, provided the method of obtaining the designed cold spring is specified and used.

ND-3673.4 Movements. Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

ND-3673.5 Computing Hot and Cold Reactions.

(a) In a piping system with no cold spring or an equal percentage of cold springing in all directions, the reactions of R_h and R_c , in the hot and cold conditions, respectively, shall be obtained from the reaction R derived from the flexibility calculations based on the modulus of elasticity at room temperature E_c using (14) and (15)

$$R_h = \left(1 - \frac{2}{3}C\right) \left(\frac{E_h}{E_c}\right) R \quad (14)$$

$$R_c = CR = \left[1 - \frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)}\right] R \quad (15)$$

whichever is greater, and with the further condition that

$$\frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)} < 1$$

where

C = cold spring factor varying from zero for no cold spring to 1.00 for 100% cold spring

E_c = modulus of elasticity in the cold condition, psi (MPa)

E_h = modulus of elasticity in the hot condition, psi (MPa)

R = maximum reaction for full expansion range based on E_c that assumes the most severe condition (100% cold spring, whether such is used or not), lb (N)

R_c, R_h = maximum reactions estimated to occur in the cold and hot conditions, respectively, lb (N)

S_E = computed expansion stress, psi (MPa) [ND-3653.2(a)]

(b) If a piping system is designed with different percentages of cold spring in various directions, (a)(14) and (a)(15) are not applicable. In this case, the piping system shall be analyzed by a comprehensive method. The calculated hot reactions shall be based on theoretical cold springs in all directions not greater than two-thirds of the cold springs as specified or measured.

ND-3673.6 Reaction Limits. The reactions computed shall not exceed limits that the attached equipment can safely sustain.

ND-3674 Design of Pipe Supports

Pipe supports shall be designed in accordance with the requirements of Subsection NF.

ND-3677 Pressure Relief Piping

ND-3677.1 General Requirements. Pressure relief piping within the scope of this Subarticle shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

ND-3677.2 Piping to Pressure Relieving Safety Devices.

(a) Piping that connects a pressure relief device to a piping system shall comply with all the requirements of the Class of piping of the system that it is designed to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices, except as provided for in ND-7142.

ND-3677.3 Discharge Piping From Pressure Relieving Safety Devices.

(a) Discharge piping from pressure relief devices shall comply with the requirements of the Class of piping applicable to the conditions under which it operates.

(b) There shall be no intervening stop valves between the protective device or devices and the point of discharge, except as provided for in ND-7142.

(c) When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel.

(d) It is recommended that individual discharge lines be used. For requirements on discharge piping, see ND-7141(f).

(e) Discharge lines from pressure relieving safety devices within the scope of this Subarticle shall be designed to facilitate drainage.

(f) When the umbrella or drip pan type of connection is used, the discharge piping shall be so designed as to prevent binding due to expansion movements. Drainage shall be provided to remove water collected above the safety valve seat.

ND-3678 Temporary Piping Systems

Prior to service of piping systems and associated equipment, certain temporary piping may be installed to accommodate cleaning by blowing out with steam or air, or by acid or caustic fluid circulation, or other flushing methods. Such temporary piping shall be designed to safeguard against rupture or other failure that could become a hazard to health or safety.

ND-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

ND-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NCA-7100-1.

ND-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance equivalent to standard products, except as permitted in ND-3641.

ND-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

ND-3720 DESIGN RULES

(a) The design of the pressure retaining portion of electrical and mechanical penetration assemblies shall be the same as for vessels (ND-3300).

(b) For closing seams in electrical and mechanical penetration assemblies meeting the requirements of ND-4730(c), the closure head shall meet the requirements of ND-3325 using a factor $C = 0.20$. The fillet weld shall be designed using an allowable stress of $0.5S$.

ND-3800 DESIGN OF ATMOSPHERIC STORAGE TANKS

ND-3810 GENERAL REQUIREMENTS

ND-3811 Acceptability

The requirements for acceptability of atmospheric storage tanks are given in the following subparagraphs.

ND-3811.1 Scope. The design rules for atmospheric storage tanks cover vertical cylindrical flat bottom above ground³⁰ welded tanks at atmospheric pressure. The tanks may contain liquids such as refueling water,

condensate, borated reactor coolant, or liquid radioactive waste. Such tanks may be within building structures, depending upon the liquid to be contained, or they may be above grade exposed to atmospheric conditions.

ND-3811.2 Design Requirements. The design rules for atmospheric storage tanks shall conform to the design requirements of ND-3100 and ND-3300, except as they may be modified by the requirements of this Subarticle. The joint efficiency E shall be based on the requirements of ND-3352. The specific design requirements shall be stipulated in the Design Specifications.

ND-3812 Design Report

The manufacturer of a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility of achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

ND-3820 DESIGN CONSIDERATIONS

ND-3821 Design and Service Conditions

(a) Conditions shall be identified as Design or Service, and if Service they shall have Level A, B, C, or D Service Limits designated.

(b) The provisions of ND-3110 shall apply.

(c) The stress limits given in ND-3821.5 shall be met.

ND-3821.1 Design Pressure. The Design Pressure³¹ shall be atmospheric.

ND-3821.2 Design Temperature. The Design Temperature shall be not greater than 200°F (90°C).

ND-3821.3 Loadings. The requirements of ND-3111 shall be met.

ND-3821.4 Welded Joint Restrictions. The restrictions given in (a) through (c) below on type and size of joints or welds shall apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The minimum size of fillet welds shall be in accordance with ND-4246.6.

(c) All nozzle welds shall be in accordance with ND-4246.5.

ND-3821.5 Limits of Calculated Stresses for Design and Service Loadings. Stress⁷ limits for Design and Service Loadings are specified in Table ND-3821.5-1. The symbols used in Table ND-3821.5-1 are defined as follows:

S = allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m , except that it includes the effect of discontinuities.

σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1, with σ considered as equivalent to P in Table XIII-1130-1.

ND-3830 BOTTOM DESIGN

ND-3831 Plate Sizes

(a) All bottom plates shall have a minimum nominal thickness of $\frac{1}{4}$ in. (6 mm) exclusive of any corrosion allowance required by the Design Specifications.

(b) Bottom plates shall be ordered of sufficient size so that, when trimmed, at least a 1 in. (25 mm) width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

(c) The type of foundation used for supporting the tank shall be taken into account in the design of the bottom plates and welds. For recommended practice for construction of foundations, see API-650, Appendix B.

**Table ND-3821.5-1
Design and Service Limits**

Service Limit	Stress Limits [Note (1)] and [Note (2)]
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$
NOTES: (1) See ND-3821.5 for definitions of symbols. (2) These limits do not take into account either local or general buckling which might occur in thin wall vessels.	

ND-3832 Methods of Construction

Bottoms shall be built to either one of the alternative methods of construction given in ND-4246.1.

ND-3833 Shell-to-Bottom Attachment

The requirements for shell-to-bottom attachments are given in ND-4246.2.

ND-3840 SHELL DESIGN

ND-3841 Loads

(a) Thicknesses shall be computed on the basis of the specific gravity of the stored material, but in no case shall the specific gravity be less than 1.00. The tension in each ring shall be computed 12 in. (300 mm) above the centerline of the lower horizontal joint of the course in question. In computing these stresses, the tank diameter shall be taken as the nominal diameter of the bottom course.

(b) Isolated radial loads on tank shells, such as caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members, preferably in a horizontal position.

ND-3842 Diameters and Thicknesses of Shell Plates

(a) For method of determining minimum thicknesses³² of shell plates, see ND-3324.3. See ND-2121 for pressure retaining material.

(b) In no case shall the nominal thickness³³ of shell plates be less than the following:

Ferrous Material		Aluminum Material	
Nominal Tank Diameter, ft (m)	Nominal Thickness, in. (mm)	Nominal Tank Diameter, ft (m)	Nominal Thickness, in. (mm)
[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]
Smaller than 60 (18)	$\frac{3}{16}$ (5)	Smaller than 20 (18)	$\frac{3}{16}$ (5)
60 to 120 (18 to 36), incl.	$\frac{1}{4}$ (6)	20 to 120 (18 to 36), incl.	$\frac{1}{4}$ (6)
NOTE: (1) Nominal tank diameter shall be the centerline diameter of the shell plates, unless otherwise stipulated in the Design Specifications.			

(c) The maximum nominal thickness of tank shell plates shall be $1\frac{1}{2}$ in. (38 mm).

ND-3843 Arrangement of Members

(a) The tank shell shall be designed to have all courses vertical. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical center line of thickness. Vertical joints in adjacent shell courses shall not be in alignment but shall be offset from each other a minimum distance of 6 in.

(b) Except as specified for self-supporting roofs and for tanks having the flanged roof-to-shell detail described in (c) below, tank shells shall be supplied with top angles of not less than the following sizes: tanks 35 ft (10.6 m) and smaller in diameter, $2\frac{1}{2}$ in. \times $2\frac{1}{2}$ in. \times $\frac{1}{4}$ in. (64 mm \times 64 mm \times 6 mm); tanks of more than 35 ft to 60 ft (10.6 m to 18.3 m), inclusive, in diameter, $2\frac{1}{2}$ in. \times $2\frac{1}{2}$ in. \times $\frac{5}{16}$ in. (64 mm \times 64 mm \times 8 mm); tanks larger than 60 ft (18.3 m) in diameter, 3 in. \times 3 in. \times $\frac{3}{8}$ in. (75 mm \times 75 mm \times 10 mm). The outstanding leg of the top angle may extend inside or outside the tank shell.

(c) See below:

(1) For tanks not exceeding 35 ft (10.6 m) in diameter and having supported cone roofs, the top edge of the shell may be flanged in lieu of installing a top angle. The radius of bend and the width of the flanged edge shall conform to the details of [Figure ND-4246.3-1](#) sketch (c).

(2) This construction may be used for any tank having a self-supporting roof if the total cross-sectional area of the junction fulfills the stated area requirements for the top angle construction. No additional member, such as an angle or bar, shall be added to the flanged roof-to-shell detail.

(d) For tanks not exceeding 35 ft (10.6 m) in diameter and having a supported flat roof, the roof plates may be flanged and butt welded to the shell. The flanged tank roof plates shall be butt welded. The inside radius of the knuckle shall not be less than $1.75t$ nor more than $8t$.

ND-3850 ROOF DESIGN

ND-3851 Types of Roofs

The types of roofs are defined in the following subparagraphs.

ND-3851.1 Supported Cone Roof. A supported cone roof is a roof formed to approximately the surface of a right cone, with its principal support provided by either rafters on girders and columns or rafters on trusses with or without columns.

ND-3851.2 Supported Flat Roof. A supported flat roof is a roof that is essentially flat, with its principal support provided by either rafters supported by the shell without columns or by rafters in conjunction with girders and trusses with or without columns.

ND-3851.3 Self-Supporting Cone Roof. A self-supporting cone roof is a roof formed to approximately the surface of a right cone, supported only at its periphery.

ND-3851.4 Self-Supporting Dome Roof. A self-supporting dome roof is a roof formed to approximately a spherical surface, supported only at its periphery.

ND-3851.5 Self-Supporting Umbrella Roof. A self-supporting umbrella roof is a modified dome roof so formed that any horizontal section is a regular polygon with as many sides as there are roof plates, supported only at its periphery.

ND-3852 General Roof Design Requirements

ND-3852.1 Loading Requirements. All roofs and supporting structures shall be designed to support dead load, plus a uniform live load of not less than 25 lb/ft² (120 kg/m²) of projected area unless otherwise specified, except that tanks installed in an enclosed area, not exposed to the elements, shall be designed to support the dead load plus a uniform live load of not less than 10 lb/ft² (0.5 kPa).

ND-3852.2 Minimum Plate Thickness. Roof plates shall have a minimum nominal thickness of $\frac{3}{16}$ in. (5 mm). A greater thickness may be required for self-supporting roofs. Any specified corrosion allowance for the plates of self-supporting roofs shall be added to calculated thickness. Any specified corrosion allowance for plates of supported roofs shall be added to the minimum nominal thickness.

ND-3852.3 Minimum Thickness of Supporting Members. All internal and external structural members shall have a minimum nominal thickness, in any component, of 0.17 in. (4 mm).

ND-3852.4 Attachment of Roof Plates. Roof plates shall be attached to the top angle of the tank in accordance with [ND-4246.3](#). Roof plates of supported roofs shall not be attached to internal supporting members.

ND-3852.5 Welding of Roof Plates.

(a) If the continuous fillet weld between the roof plates and the top angle does not exceed $\frac{3}{16}$ in. (5 mm) and the slope of the roof at the top angle attachment does not exceed 2 in./ft (167 mm/m), the joint may be considered to serve as an emergency venting device which, in case of excessive internal pressure, will fail before failure occurs in the tank shell joints or the shell-to-bottom joint. Failure of the roof-to-shell joint may be accompanied by buckling of the top angle.

(b) Where the weld size exceeds $\frac{3}{16}$ in. (5 mm) or where the slope of the roof at the top angle attachment is greater than 2 in./ft (167 mm/m), emergency venting devices conforming to the specifications noted in API Standard 2000³⁴ shall be provided. The Certificate Holder shall provide a suitable tank connection for the device.

(c) Roof plates shall be welded in accordance with [ND-4246.4](#).

ND-3852.6 Allowable Stresses for Ferrous Steel Structures.³⁵ All parts of the structure shall be so proportioned that the sum of the static stresses shall not exceed the values given in (a) through (d) below.

(a) Tension

(1) in rolled steel, on net section, 20.0 ksi (138 MPa);

(2) in full penetration groove welds on the thinner plate area, 18.0 ksi (124 MPa).

(b) Compression

(1) in rolled steel, where lateral deflection is prevented, 20.0 ksi (138 MPa);

(2) in full penetration groove welds on the thinner plate area, 20.0 ksi (138 MPa);

(3) in columns, on cross-sectional area, ksi (MPa)

For L/r not over 120

$$\left[1 - \frac{(L/r)^2}{34,700} \right] \left[\frac{33 Y}{FS} \right]$$

For L/r over 120 to 131.7, inclusive

$$\frac{\left[1 - \frac{(L/r)^2}{34,700} \right] \left[\frac{33 Y}{FS} \right]}{1.6 - (L/200 r)}$$

For L/r over 131.7

$$\frac{(149,000 Y)}{(L/r)^2 [1.6 - (L/200 r)]}$$

where

FS = factor of safety

$$= 5/3 + \left[\frac{(L/r)}{350} \right] - \left[\frac{(L/r)^3}{18,300,000} \right]$$

L = unbraced length of column, in. (mm)

R = outside radius of tubular section, in. (mm)

r = least radius of gyration of column, in. (mm)

t = thickness of tubular section, in. (mm); $\frac{1}{4}$ in. (6 mm) minimum for main compression members, $\frac{3}{16}$ in. (5 mm) minimum for bracing and other secondary members

Y = 1.0 for structural sections or tubular sections having t/R values equal to or exceeding 0.015

= $(\frac{200}{3})(t/R)[2 - (\frac{200}{3})(t/R)]$ for tubular sections having t/R values less than 0.015

For main compression members, the ratio L/r shall not exceed 180. For bracing and other secondary members, the ratio L/r shall not exceed 200.

(c) Bending

(1) in tension and compression on extreme fibers of rolled shapes and built-up members with an axis of symmetry in the plane of loading, where the laterally unsupported length of compression flange is no greater than 13 times its width, the compression flange width-thickness ratio does not exceed 17, and the web depth-thickness ratio does not exceed 70, 22.0 ksi (150 MPa);

(2) in tension and compression on extreme fibers of unsymmetrical members, where the member is supported laterally at intervals no greater than 13 times its compression flange width, 20.0 ksi (140 MPa);

(3) in tension on extreme fibers of other rolled shapes, built-up members, and plate girders, 20.0 ksi (140 MPa);

(4) in compression on extreme fibers of other rolled shapes, plate girders, and built-up members having an axis of symmetry in the plane of loading, the larger value computed by the following, ksi (MPa)

$$20.0 - \frac{0.571}{1000} (l/r)^2$$

or

$$\frac{12,000}{ld/A_f} \leq 20.0$$

where

A_f = area of compression flange, in.² (mm²)

d = depth of section, in. (mm)

l = unbraced length of compression flange, in. (mm)

r = radius of gyration of section about an axis in the plane of loading, in. (mm)

Compression on extreme fibers of other unsymmetrical sections, ksi (MPa)

$$\frac{12,000}{ld/A_f} \leq 20$$

(d) Shearing

(1) in fillet, plug, slot, and partial penetration groove welds across throat area, 13.6 ksi (94 MPa);

(2) on the gross area of the webs of beams and girders, when t is the thickness of the web, in. (mm), and h , the clear distance between web flanges, in. (mm), is not more than $60t$, or when the web is adequately stiffened, 13.0 ksi (90 MPa);

(3) on the gross area of the webs of beams and girders, if the web is not stiffened so that h is more than $60t$, the greatest average shear V/A shall not exceed, ksi

$$\frac{19.5}{1 + h^2/7200t^2}$$

where

A = the gross area of the web, in.² (mm²)

V = the total shear, kips (N)

ND-3852.7 Allowable Stresses for Aluminum Structures. All parts of the structure shall be so proportioned that the sum of the static stresses shall not exceed the allowable stresses given in [Tables ND-3852.7-1 through ND-3852.7-6](#).

ND-3853 Supported Cone Roofs — General Requirements

ND-3853.1 Slope of Roof. The slope of roof shall be $\frac{3}{4}$ in./ft (62 mm/m) (6.25%) or greater. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified roof slope.

Table ND-3852.7-1
Allowable Tensile Stresses for Roof Supports
Tension on Net Section

Alloy and Temper	Maximum Temperature, °F (°C)	Allowable Stress, ksi (MPa)	
		Cross Sections Farther Than 1 in. (25 mm) From Any Weld	Cross Sections Within 1 in. (25 mm) of a Weld
6061-T6	To 100 (38)	19 (131)	11 (76) [Note (1)]
	150 (65)	19 (131)	11 (76) [Note (1)]
	200 (95)	18 (124)	10.5 (72) [Note (1)]
6063-T6	To 100 (38)	15 (103)	6.5 (45)
	150 (65)	14.5 (100)	6.5 (45)
	200 (95)	14 (97)	6 (41)

NOTE:

(1) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8.

ND-3853.2 Main Supporting Members. Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered to receive no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by ND-3852.6.

ND-3853.3 Design of Rafters. Structural members, serving as rafters, may be rolled or fabricated sections but in all cases shall conform with the rules of ND-3852 through ND-3853. Rafters in direct contact with the roof plates applying the loading to the rafters may be considered to receive adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

- (a) trusses and open web joints used as rafters;
- (b) rafters having a nominal depth greater than 15 in. (375 mm);
- (c) rafters having a slope greater than 2 in./ft (167 mm/m) (16.7%).

ND-3853.4 Spacing of Rafters. Rafters shall be spaced so that, in the outer ring, their centers shall not be more than 6.28 ft (1.9 m) apart, measured along the circumference of the tank. Spacing on inner rings shall not be greater than $5\frac{1}{2}$ ft (1.67 m).

ND-3853.5 Roof Columns. Roof columns shall be made from structural shapes or pipe.

ND-3853.6 Attachment of Rafter Clips and Column Base Clip Guides. Rafter clips for the outer row of rafters shall be welded to the tank shell. Column base clip guides

shall be welded to the tank bottom to prevent lateral movement of column bases. All other structural attachments shall be either bolted or welded.

ND-3853.7 Welding of Roof Plates. Roof plates shall be welded in accordance with ND-4246.4. The size of the roof-to-top angle weld shall be $\frac{3}{16}$ in. (5 mm) or smaller.

ND-3854 Supported Flat Roofs

ND-3854.1 General Requirements. The use of supported flat roofs shall be limited to tanks having diameters not greater than 35 ft (10.5 mm). The design of supported flat roofs shall be in accordance with ND-3853 except as noted below.

ND-3854.2 Main Supporting Members.

- (a) Requirements of ND-3853.1 do not apply.
- (b) Supporting structural members may be either internal or external to the roof plate.
- (c) External rafters shall not be welded to the top angle or attached to the shell plate.
- (d) External rafters shall be welded to the roof plate. The weld shall be sized to carry the combined dead and live loads on the roof plate.

ND-3855 Self-Supporting Cone Roofs

ND-3855.1 Nomenclature. The symbols are defined as follows:

- A_t = combined cross-sectional area of roof plate, shell plate, and top shell angle, in.² (mm²)
- D = nominal diameter of tank shell, ft (m)
- f = tensile working stress for the material of the roof plates, shell plates, or top shell angle, whichever is the least value, at the service temperature, psi (MPa)
- P = dead load of roof, plus the live load, lb/ft² (kPa)

Table ND-3852.7-2
Allowable Axial Compression Stresses for Roof Supports
Axial Compression

Alloy and Temper	Maximum Temp., °F (°C)	Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi (MPa)	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi (MPa)
		(MPa)		Cross Sections Farther Than 1.0 in. (25 mm) From Any Weld		
6061-T6	To 100 (38)	19 (131)	$\frac{L}{r} = 10$	$20.4 - 0.135 \frac{L}{r}$ $\left(140 - 0.930 \frac{L}{r}\right)$	$\frac{L}{r} = 67$	$\frac{51,000}{(L/r)^2}$ $\left[\frac{351,000}{(L/r)^2}\right]$
	150 (65)	19 (131)	$\frac{L}{r} = 8.9$	$20.2 - 0.135 \frac{L}{r}$ $\left(140 - 0.930 \frac{L}{r}\right)$	$\frac{L}{r} = 67$	$\frac{50,000}{(L/r)^2}$ $\left[\frac{345,000}{(L/r)^2}\right]$
	200 (95)	18 (124)	$\frac{L}{r} = 14$	$19.8 - 0.133 \frac{L}{r}$ $\left(136 - 0.916 \frac{L}{r}\right)$	$\frac{L}{r} = 67$	$\frac{49,000}{(L/r)^2}$ $\left[\frac{335,000}{(L/r)^2}\right]$
6063-T6	To 100 (38)	13.5 (93)	$\frac{L}{r} = 11$	$14.4 - 0.080 \frac{L}{r}$ $\left(99.2 - 0.551 \frac{L}{r}\right)$	$\frac{L}{r} = 80$	$\frac{51,000}{(L/r)^2}$ $\left[\frac{351,000}{(L/r)^2}\right]$
	150 (65)	13 (90)	$\frac{L}{r} = 11$	$13.8 - 0.076 \frac{L}{r}$ $\left(95.1 - 0.524 \frac{L}{r}\right)$	$\frac{L}{r} = 81$	$\frac{50,000}{(L/r)^2}$ $\left[\frac{345,000}{(L/r)^2}\right]$
	200 (95)	12.5 (86)	$\frac{L}{r} = 11$	$13.3 - 0.073 \frac{L}{r}$ $\left(91.6 - 0.503 \frac{L}{r}\right)$	$\frac{L}{r} = 82$	$\frac{49,000}{(L/r)^2}$ $\left[\frac{335,000}{(L/r)^2}\right]$
6061-T6	To 100 (38)	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L}{r} = 68$ [Note (2)]	$\frac{51,000}{(L/r)^2}$ $\left[\frac{351,000}{(L/r)^2}\right]$
	150 (65)	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L}{r} = 67$ [Note (2)]	$\frac{50,000}{(L/r)^2}$ $\left[\frac{345,000}{(L/r)^2}\right]$
	200 (95)	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L}{r} = 67$ [Note (2)]	$\frac{49,000}{(L/r)^2}$ $\left[\frac{335,000}{(L/r)^2}\right]$

Table ND-3852.7-2
Allowable Axial Compression Stresses for Roof Supports
Axial Compression (Cont'd)

Alloy and Temper	Maximum Temp., °F (°C)	Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi (MPa)	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi (MPa)
		(MPa)		(MPa)		(MPa)
		Cross Sections Farther Than 1.0 in. (25 mm) From Any Weld				
6063-T6	To 100 (38)	6.5 (45)	...	6.5 (45)	$\frac{L}{r} = 88$	$\frac{51,000}{(L/r)^2}$ $\left[\frac{351\,000}{(L/r)^2} \right]$
	150 (65)	6.5 (45)	...	6.5 (45)	$\frac{L}{r} = 88$	$\frac{50,000}{(L/r)^2}$ $\left[\frac{345\,000}{(L/r)^2} \right]$
	200 (95)	6 (41)	...	6 (41)	$\frac{L}{r} = 90$	$\frac{49,000}{(L/r)^2}$ $\left[\frac{335\,000}{(L/r)^2} \right]$

GENERAL NOTES:

- (a) L = length of column between points of lateral support or twice the length of a cantilever column, except where analysis shows that a shorter length can be used, in. (mm)
 (b) r = least radius of gyration of column, in. (mm)

NOTES:

- (1) The allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a number in parentheses apply to material welded with either 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), or either 4043 or 5554 filler alloy.
 (2) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in [Note (1)] above.

R = radius of curvature of roof, ft (m)

t_r = nominal thickness of roof plates, in. (mm)

θ = angle of cone elements with the horizontal, deg

ND-3855.2 Design Requirements for Ferrous Material.

Self-supporting cone roofs shall conform to the requirements³⁶ of (a) through (c) below:

(a) Slope

Maximum θ = 37 deg (tangent=9:12)

Minimum $\sin \theta$ = 0.165 [slope 2 in./ft (167 mm/m) (16.7%)]

(b) Plate Thickness

(1) Minimum/Maximum

(U.S. Customary Units)

$$\text{Minimum } t_r = \frac{D}{400 \sin \theta}, \text{ but not less than } \frac{3}{16} \text{ in.}$$

$$\text{Maximum } t_r = \frac{1}{2} \text{ in.}$$

(SI Units)

$$\text{Minimum } t_r = \frac{D}{4.8 \sin \theta}, \text{ but not less than 5 mm.}$$

$$\text{Maximum } t_r = 13 \text{ mm.}$$

Table ND-3852.7-3

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Table ND-3852.7-3
Allowable Bending Stresses for Roof Supports
Compression in Extreme Fibers of Shapes, Girders, and Built-Up Members, Subjected to Bending (Cont'd)

Alloy and Temper	Maximum Temp., °F (°C)	Cross Sections Farther Than 1.0 in. (25 mm) From Any Weld			Cross Sections Within 1.0 in. (25 mm) of a Weld		
		Allowable Stress for Slenderness Less Than S_1 , ksi (MPa)	Slenderness Limit S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi (MPa)	Slenderness Limit S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi (MPa)	Allowable Stress for Slenderness Between S_1 and S_2 , ksi (MPa)
6063-T6	To 100 (40)	13.5 (93)	$\frac{L_b}{r_y} = 14$	$14.4 - 0.066 \frac{L_b}{r_y}$ $\left(99.2 - 0.455 \frac{L_b}{r_y} \right)$	$\frac{L_b}{r_y} = 96$	$\frac{74,000}{\left(\frac{L_b}{r_y} \right)^2}$ $\left[\frac{510,000}{\left(\frac{L_b}{r_y} \right)^2} \right]$	6.5 (45) ...
	150 (70)	13 (90)	$\frac{L_b}{r_y} = 13$	$13.8 - 0.064 \frac{L_b}{r_y}$ $\left(99.1 - 0.441 \frac{L_b}{r_y} \right)$	$\frac{L_b}{r_y} = 97$	$\frac{72,000}{\left(\frac{L_b}{r_y} \right)^2}$ $\left[\frac{496,000}{\left(\frac{L_b}{r_y} \right)^2} \right]$	6.5 (45) ...
	200 (90)	12.5 (86)	$\frac{L_b}{r_y} = 13$	$13.3 - 0.061 \frac{L_b}{r_y}$ $\left(91.6 - 0.420 \frac{L_b}{r_y} \right)$	$\frac{L_b}{r_y} = 98$	$\frac{71,000}{\left(\frac{L_b}{r_y} \right)^2}$ $\left[\frac{489,000}{\left(\frac{L_b}{r_y} \right)^2} \right]$	6 (41) ...

GENERAL NOTES:

- (a) L_b = length of beam between points at which the compression flange is supported against lateral movement or length of cantilever beam from free end to point at which the compression flange is supported against lateral movement, in. (mm).
- (b) r_y = radius of gyration of beam about axis parallel to web, in. (mm). For beams that are unsymmetrical about the horizontal axis, r_y should be calculated as though both flanges were the same as the compression flange.
- (c) Rafters with compression flanges in direct contact with the roof plates which they support may be considered to have adequate and continuous lateral support; therefore, allowable stresses for zero length may be used.

NOTES:

- (1) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a number in parentheses apply to material welded with either 5556 or 5356 filler alloy for temperatures not exceeding 150°F (66°C), or either 4043 or 5554 alloy.
- (2) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in [Note (1)] above.

Table ND-3852.7-4
Allowable Shear Stresses for Roof Supports
Shear in Webs of Beams and Girders

Alloy and Temper	Maximum Temp., °F (°C)	Allowable Stress for Slenderness Less Than S_1 , ksi (MPa)	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi (MPa)	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi (MPa)	Allowable Stress for Slenderness Less Than S_1 , ksi (MPa)	Slenderness Limit, S_1	Allowable Stress for Slenderness Greater Than S_1 , ksi (MPa)
		Cross Sections Farther Than 1.0 in. (25 mm) From Any Weld				Cross Sections Within 1.0 in. (25 mm) of a Weld			
6061-T6	To 100 (38)	12 (83)	$\frac{h}{t} = 18$	$13.7 - 0.092 \frac{h}{t}$ $\left(94.5 - 0.634 \frac{h}{t} \right)$	$\frac{h}{t} = 66$	$\frac{33,000}{(h/t)^2}$ $\left[\frac{227,000}{(h/t)^2} \right]$	7 (48) [Note (1)]	$\frac{h}{t} = 69$ [Note (2)]	$\frac{33,000}{(h/t)^2}$ $\left[\frac{227,000}{(h/t)^2} \right]$
	150 (65)	12 (83)	$\frac{h}{t} = 16$	$13.5 - 0.093 \frac{h}{t}$ $\left(93.0 - 0.641 \frac{h}{t} \right)$	$\frac{h}{t} = 66$	$\frac{32,000}{(h/t)^2}$ $\left[\frac{220,000}{(h/t)^2} \right]$	7 (48) [Note (1)]	$\frac{h}{t} = 68$ [Note (2)]	$\frac{32,000}{(h/t)^2}$ $\left[\frac{220,000}{(h/t)^2} \right]$
	200 (95)	11.5	$\frac{h}{t} = 20$	$13.3 - 0.092 \frac{h}{t}$ $\left(91.6 - 0.634 \frac{h}{t} \right)$	$\frac{h}{t} = 66$	$\frac{31,000}{(h/t)^2}$ $\left[\frac{214,000}{(h/t)^2} \right]$	7 (48) [Note (1)]	$\frac{h}{t} = 67$ [Note (2)]	$\frac{31,000}{(h/t)^2}$ $\left[\frac{214,000}{(h/t)^2} \right]$
6063-T6	To 100 (38)	8.5 (59)	$\frac{h}{t} = 19$	$9.5 - 0.054 \frac{h}{t}$ $\left(65.5 - 0.372 \frac{h}{t} \right)$	$\frac{h}{t} = 79$	$\frac{33,000}{(h/t)^2}$ $\left[\frac{227,000}{(h/t)^2} \right]$	4 (28)	$\frac{h}{t} = 91$	$\frac{33,000}{(h/t)^2}$ $\left[\frac{227,000}{(h/t)^2} \right]$
	150 (65)	8.5 (59)	$\frac{h}{t} = 13$	$9.2 - 0.052 \frac{h}{t}$ $\left(63.4 - 0.358 \frac{h}{t} \right)$	$\frac{h}{t} = 79$	$\frac{32,000}{(h/t)^2}$ $\left[\frac{220,000}{(h/t)^2} \right]$	3.6 (25)	$\frac{h}{t} = 94$	$\frac{32,000}{(h/t)^2}$ $\left[\frac{220,000}{(h/t)^2} \right]$
	200 (95)	8 (55)	$\frac{h}{t} = 16$	$8.8 - 0.049 \frac{h}{t}$ $\left(60.6 - 0.338 \frac{h}{t} \right)$	$\frac{h}{t} = 80$	$\frac{31,000}{(h/t)^2}$ $\left[\frac{214,000}{(h/t)^2} \right]$	3.5 (24)	$\frac{h}{t} = 94$	$\frac{31,000}{h/t^2}$ $\left[\frac{214,000}{(h/t)^2} \right]$

GENERAL NOTES:

(a) h = clear height of web, in. (mm)(b) t = thickness of web, in. (mm)

NOTES:

- (1) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a number in parentheses apply to material welded with either 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), or either 4043 or 5554 alloy.
- (2) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in [Note (1)] above.

Table ND-3852.7-5
Allowable Shear and Tension Stresses for Bolts for Roof Supports

Description of Bolt	Maximum Temperature, °F (°C), for Allowable Stress, ksi (MPa)		
	To 100 (38)	150 (65)	200 (95)
2024-T4 bolts	Shear		
	16 (110)	15 (103)	14.5 (100)
	Tension		
2024-T4 bolts	26 (179)	26 (179)	25 (172)
6061-T6 bolts	18 (124)	17 (117)	17 (117)

GENERAL NOTE: Bolts shall not be welded.

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in. (5 mm).

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, in square inches (mm²), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed

(U.S. Customary Units)

$$\frac{D^2}{3000 \sin \theta}$$

(SI Units)

$$\frac{D^2}{0.43 \sin \theta}$$

ND-3855.3 Design Requirements for Aluminum Material. Self-supporting cone roofs shall conform to the requirements of (a) through (c) below:

(a) Slope

(1) Minimum $\sin \theta = 0.165$ [slope 2 in./ft (167 mm/m) (16.7%)]

(2) Maximum $\theta = 37$ deg (tangent = 9:12)

(b) Plate Thickness

(U.S. Customary Units)

$$t_r = \frac{D}{1414 \sin \theta} \sqrt{P}$$

(SI Units)

$$t_r = \frac{D}{539 \sin \theta} \sqrt{P}$$

but not less than $\frac{3}{16}$ in. (5 mm) nominal.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, in square inches (mm²), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed

(U.S. Customary Units)

$$\text{Minimum } A_t = \frac{PD^2}{8f \sin \theta}$$

(SI Units)

$$\text{Minimum } A_t = \frac{PD^2}{138f \sin \theta}$$

Table ND-3852.7-6
Allowable Bearing Stresses for Bolts for Roof Supports

Alloy and Temper	Maximum Temperature, °F (°C)	Allowable Stress, ksi (MPa)	
		Cross Sections Farther Than 1 in. (25 mm) From Any Weld	Cross Sections Within 1 in. (25 mm) of a Weld
		Bolts [Note (1)]	
6061-T6	To 100 (38)	34 (234)	18 (124) [Note (2)]
	150 (65)	33 (228)	18 (124) [Note (2)]
	200 (95)	32 (221)	18 (124) [Note (2)]
6063-T6	To 100 (38)	24 (165)	10 (69)
	150 (65)	23 (159)	9.5 (66)
	200 (95)	22 (152)	9 (62)

GENERAL NOTE: Bolts shall not be welded.

NOTES:

(1) These values apply for a ratio of edge distance to bolt diameter of 2 or more. For smaller ratios, multiply these allowable stresses by the ratio (edge distance)/(twice the bolt diameter).

(2) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F (65°C), and to material $\frac{3}{8}$ in. (10 mm) or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8.

ND-3856 Self-Supporting Dome and Umbrella Roofs

ND-3856.1 Nomenclature. See ND-3855.1 for nomenclature.

ND-3856.2 Design Requirements for Ferrous Material. Self-supporting dome and umbrella roofs shall conform to the requirements³⁴ of (a) through (c) below.

(a) Radius of Curvature

$R = D$ unless otherwise specified

Minimum $R = 0.80D$

Maximum $R = 1.2D$

(b) Plate Thickness

(1) Minimum $t = R/200 \left(t = \frac{R}{2.39} \right)$ but not less than $\frac{3}{16}$ in. (5 mm). Maximum $t = \frac{1}{2}$ in. (13 mm)

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in. (5 mm).

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, in square inches (mm^2), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed

(U.S. Customary Units)

$$\frac{DR}{1500}$$

(SI Units)

$$\frac{DR}{0.21}$$

ND-3856.3 Design Requirements for Aluminum Material. Self-supporting dome and umbrella roofs shall conform to the requirements of (a) through (c) below:

(a) Radius of Curvature

Minimum $R = 0.80D$

Maximum $R = 1.2D$

(b) Plate Thickness

(U.S. Customary Units)

$$t_r = \frac{R}{707} \sqrt{P}$$

(SI Units)

$$t_r = \frac{R}{266} \sqrt{P}$$

but not less than $\frac{3}{16}$ in. (5 mm) nominal.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top shell angle, in square inches, plus the cross-sectional areas of shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top shell angle, shall equal or exceed

(U.S. Customary Units)

$$\text{Minimum } A_t = \frac{PRD}{4f}$$

(SI Units)

$$\text{Minimum } A_t = \frac{PRD}{0.56f}$$

ND-3856.4 Top Angle Attachment for Self-Supporting Roofs.

(a) The top angle sections for self-supporting roofs shall meet the requirements of ND-4246.6(d). Joint efficiency factors need not be applied.

(b) For self-supporting roofs, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.

ND-3860 TANK CONNECTIONS AND APPURTENANCES

ND-3861 Roof Manholes

Roof manholes shall conform to Figure ND-3861-1 and Table ND-3861-1, except that alternative designs that provide equivalent strength are permissible if agreed to by the Owner or his designee.

ND-3862 Roof Nozzles

(a) Flanged roof nozzles shall conform to Figure ND-3862(a)-1 and Table ND-3862(a)-1. Threaded nozzles shall conform to Figure ND-3862(a)-2 and Table ND-3862(a)-2. Alternative designs for flanged roof nozzles and threaded nozzles can be used, provided they are of equivalent strength and are agreed to by the Owner or his designee.

(b) Roof nozzles are not intended to take loads from pipe reactions. Earthquake loadings need not be considered.

ND-3863 Bottom Outlet Elbows

Bottom outlet elbows shall conform to Figure ND-3863-1 and Table ND-3863-1.

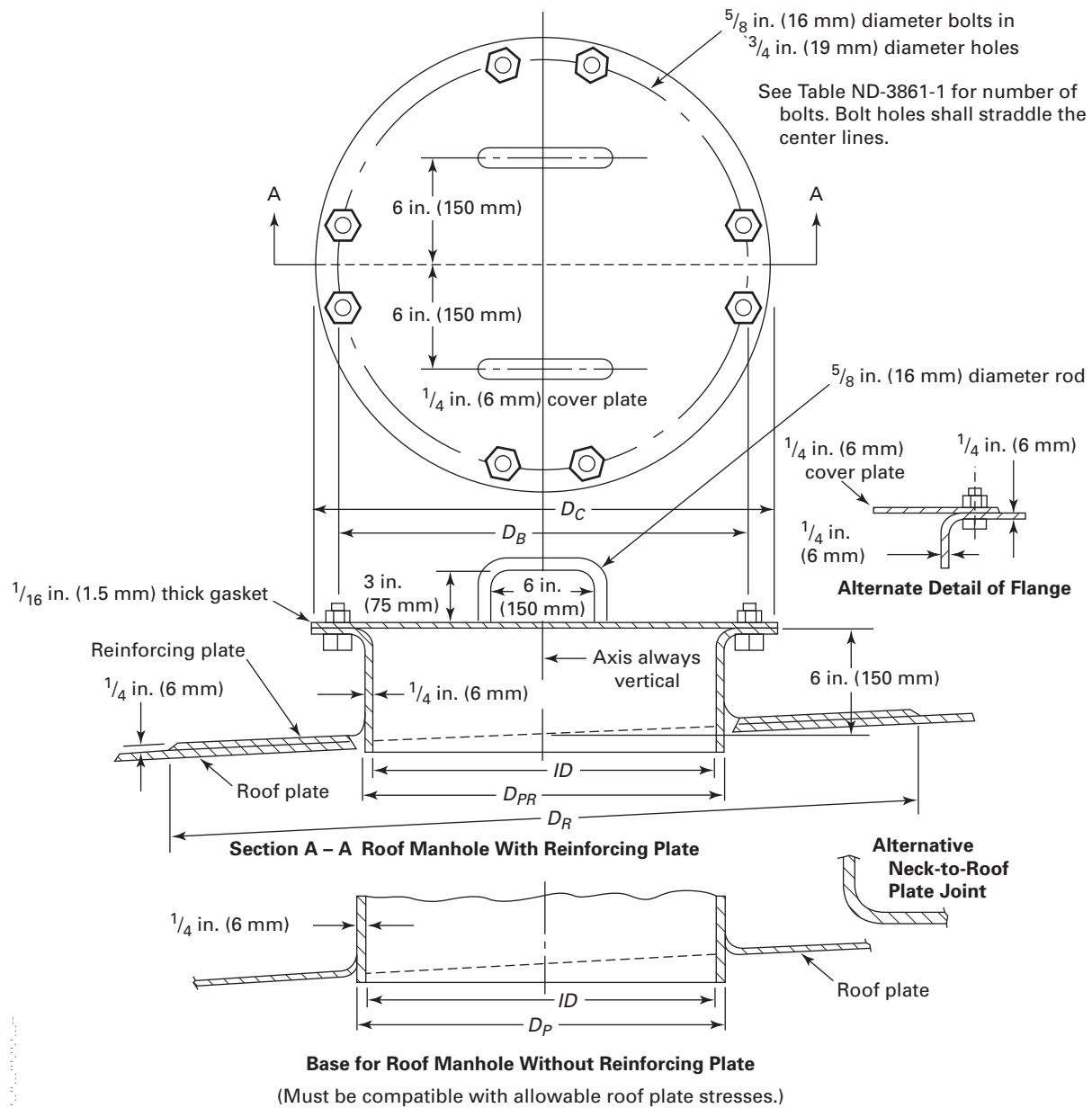
ND-3864 Threaded Connections

Threaded piping connections shall be female and shall be tapered. The threads shall conform to the requirements for taper pipe threads included in ANSI/ASME B1.20.1.

ND-3865 Platforms, Walkways, and Stairways

Platforms, walkways, and stairways shall be in accordance with Tables ND-3865-1 through ND-3865-3.

Figure ND-3861-1
Roof Manholes
 (see [Table ND-3861-1](#))



**Table ND-3861-1
Roof Manholes**

Size of Manhole, in. (mm)	Diameter of Neck I.D., in. (mm)	Diameter of Cover Plate D_C , in. (mm)	Diameter of Bolt Circle D_B , in. (mm)	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P , in. (mm)	O.D. of Reinforcing Plate D , in. (mm)
					I.D., in. (mm)	O.D., in. (mm)		
20 (500)	20 (500)	26 (660)	23 $\frac{1}{2}$ (588)	16	21 $\frac{1}{2}$ (545)	26 (660)	20 $\frac{5}{8}$ (525)	42 (1 070)
24 (600)	24 (600)	30 (750)	27 $\frac{1}{2}$ (700)	20	25 $\frac{1}{2}$ (650)	30 (750)	24 $\frac{5}{8}$ (625)	46 (1 170)

GENERAL NOTE: See Figure ND-3861-1.

ND-3866 Nozzle Piping Transitions

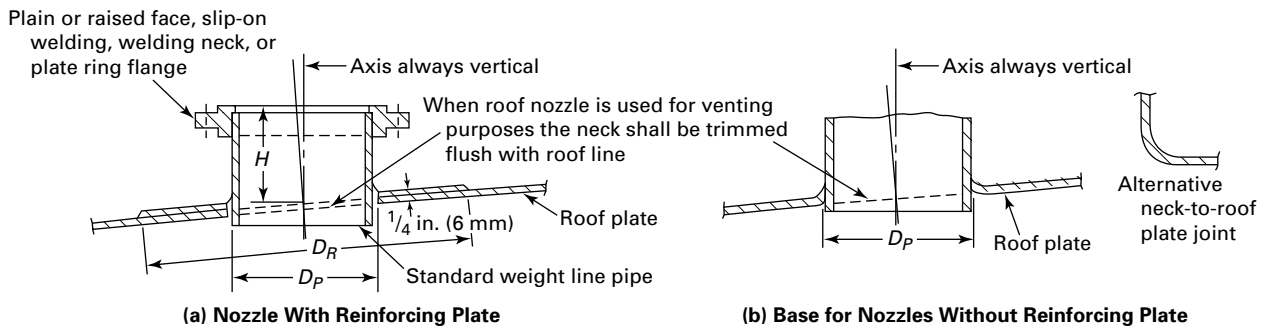
The stress limits of Table ND-3821.5-1 shall apply to all portions of nozzles that lie within the limits of reinforcement given in ND-3334, except as provided in ND-3867. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

ND-3867 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy

the limits of Table ND-3821.5-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3821.5-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table ND-3821.5-1, for a given loading.

**Figure ND-3862(a)-1
Flanged Roof Nozzles
[See Table ND-3862(a)-1]****GENERAL NOTES:**

- Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
- Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

Table ND-3862(a)-1
Flanged Roof Nozzles

Nominal Size of Nozzle, in. (mm)		O.D. of Pipe Neck, in. (mm)		Diameter of Hole in Roof Plate or Reinforcing Plate D_P , in. (mm)		Height of Nozzle, H , in. (mm)	O.D. of Reinforcing Plate, D_R , in. (mm)
1½	(40)	1.900	(48)	2	(50)	6 (150)	5 (125) [Note (1)]
2	(50)	2¾	(60)	2½	(64)	6 (150)	7 (175) [Note (1)]
3	(80)	3½	(89)	3⅝	(92)	6 (150)	9 (230) [Note (1)]
4	(100)	4½	(114)	4⅞	(117)	6 (150)	11 (280) [Note (1)]
6	(150)	6⅝	(168)	6¾	(171)	6 (150)	15 (380) [Note (1)]
8	(200)	8⅝	(219)	8⅞	(225)	6 (150)	18 (450)
10	(250)	10¾	(273)	11	(280)	8 (200)	22 (560)
12	(300)	12¾	(324)	13	(330)	8 (200)	24 (600)

GENERAL NOTE: See Figure ND-3862(a)-1.

NOTE:

(1) Reinforcing plates are not required on 6 in. (150 mm) or smaller nozzles, but may be used if desired.

Figure ND-3862(a)-2
Screwed or Socket Weld Roof Nozzles
[See Table ND-3862(a)-2, ND-3864]

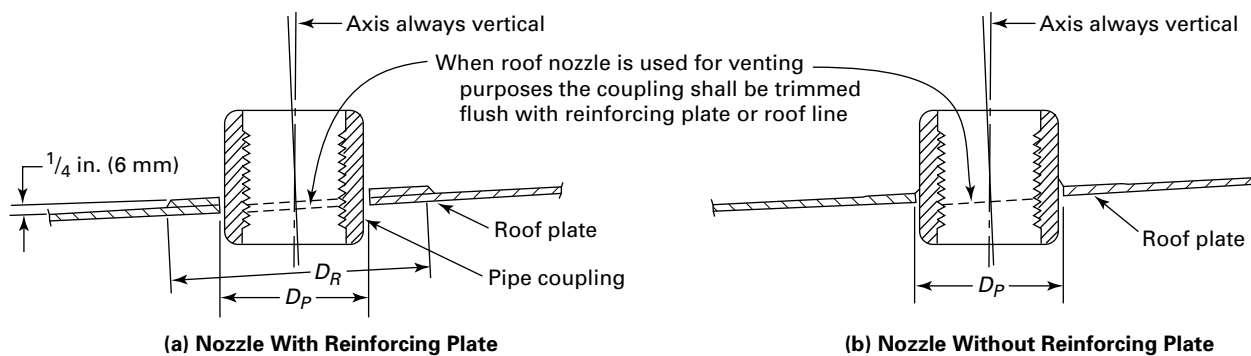


Table ND-3862(a)-2
Screwed or Socket Weld Roof Nozzles

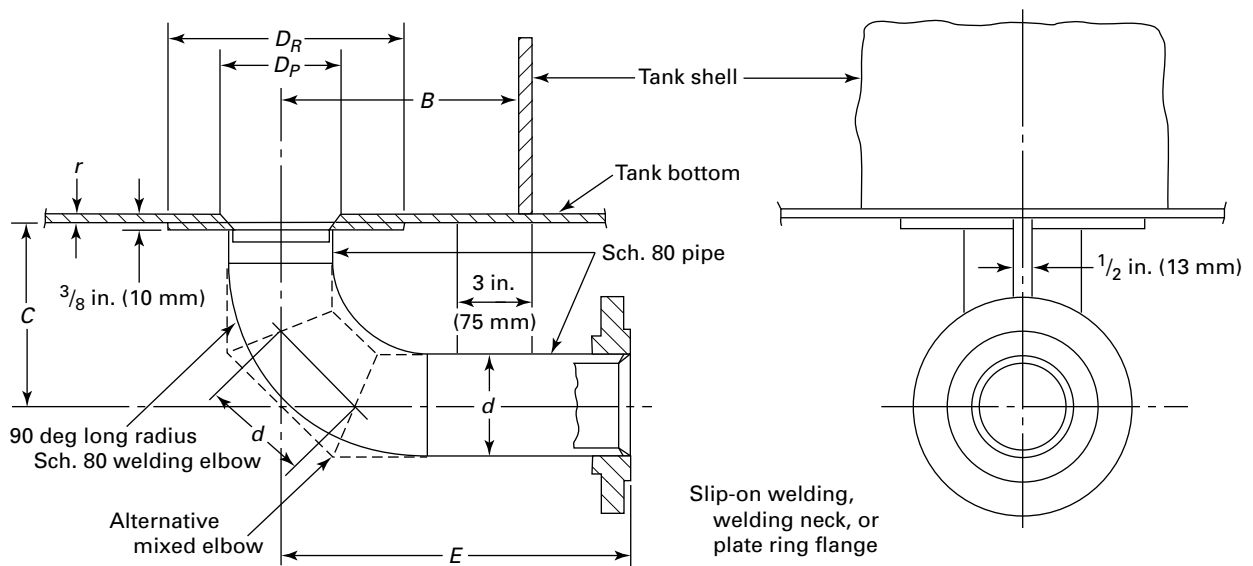
Nominal Size of Nozzle, in. (mm)		Nominal Size of Coupling, in. (mm)		Diameter of Hole in Roof Plate or Reinforcing Plate, D_P , in. (mm)		O.D. of Reinforcing Plate, D_R , in. (mm)	
$\frac{3}{4}$	(20)	$\frac{3}{4}$	(20)	$1\frac{7}{16}$	(37)	4	(100) [Note (1)]
1	(25)	1	(25)	$1\frac{23}{32}$	(44)	$4\frac{1}{2}$	(113) [Note (1)]
$1\frac{1}{2}$	(40)	$1\frac{1}{2}$	(40)	$2\frac{11}{32}$	(60)	5	(125) [Note (1)]
2	(50)	2	(50)	3	(75)	7	(175) [Note (1)]
3	(75)	3	(75)	$4\frac{1}{8}$	(105)	9	(230) [Note (1)]
4	(100)	4	(100)	$5\frac{11}{32}$	(136)	11	(280) [Note (1)]
6	(150)	6	(150)	$7\frac{17}{32}$	(191)	15	(380) [Note (1)]
8	(200)	8	(200)	$9\frac{7}{8}$	(251)	18	(450)
10	(250)	10	(250)	12	(300)	22	(560)
12	(300)	12	(300)	$14\frac{1}{4}$	(362)	24	(600)

GENERAL NOTE: See Figure ND-3862(a)-2.

NOTE:

(1) Reinforcing plates are not required on 6 in. (150 mm) or smaller nozzles, but may be used if desired.

Figure ND-3863-1
Welded Bottom Outlet Elbow
(See Table ND-3863-1)



GENERAL NOTES:

- Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
- Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

Table ND-3863-1
Welded Bottom Outlet Elbow

Nominal Pipe Size, in. (mm) [Note (1)]	Distance from Center of Elbow to Shell <i>B</i> , in. (mm)	Distance from Center of Outlet to Bottom <i>C</i> , in. (mm)	Diameter of Hole in Tank Bottom <i>D_P</i> , in. (mm)	O.D. of Reinforcing Plate <i>D_R</i> , in. (mm)	Distance from Center of Elbow to Face of Flange <i>E</i> , in. (mm)
2 (50)	7½ (191)	6 (150)	3⅛ (79)	6¼ (159)	12 (300)
3 (75)	8½ (216)	7 (175)	4¼ (108)	7¾ (197)	13 (330)
4 (100)	9½ (241)	7⅓/₁₆ (198)	5¼ (133)	9¾ (248)	14 (350)
6 (150)	11 (280)	9¾ (238)	7¾ (187)	12¾ (324)	16 (400)
8 (200)	13 (330)	12¾ (314)	9¾ (238)	16½ (419)	18 (450)

GENERAL NOTE: See [Figure ND-3863-1](#).

NOTE:

(1) Extra-strong pipe, refer to ASME B36.10M.

Table ND-3865-1
Platforms and Walkways

- All parts to be made of metal.
- Width of floor level (min.): 24 in. (600 mm).
- Flooring to be made of grating or nonslip material.
- Height of top railing above floor: 42 in. (1 050 mm) [Note (1)].
- Height of toeboard (min.): 3 in. (75 mm).
- Space between top of floor and bottom of toeboard (max.): ¼ in. (6 mm).
- Height of midrail: approximately one-half the distance from top of walkway to top of railing.
- Distance between railing posts (max.): 96 in. (2 400 mm).
- The completed structure shall be capable of supporting a moving concentrated load of 1,000 lb (4 450 N), and the handrailing structure shall be capable of withstanding a load of 200 lb (890 N) applied in any direction at any point on the top rail.
- Handrails to be on both sides of platform, discontinuing where necessary for access.
- At handrail openings, any space between tank and platform wider than 6 in. (150 mm) should be floored.
- Tank runways, which extend from one part of a tank to any part of an adjacent tank, or to ground or other structure, shall be so supported as to permit free relative movement of the structures joined by the runway. This may be accomplished by firm attachment of runway to one tank, but with a slip joint at point of contact between runway and other tank. This is to permit either tank to settle or be disrupted by an explosion without endangering the other.

NOTE:

(1) Handrail height as required by ANSI specifications. This height is mandatory in some states.

Table ND-3865-2
Stairways

- All parts to be made of metal.
- Width of stairs (min.): 24 in. (600 mm).
- Angle of stairway with a horizontal line (max.): 50 deg [Note (1)].
- Width of stair treads (min.): 8 in. (200 mm). [The run (defined as the horizontal distance between the noses of successive tread pieces) and the rise of stair treads shall be such that the sum of twice the rise, plus the run, shall be not less than 24 in. (600 mm) nor more than 26 in. (660 mm). Rises shall be uniform throughout the height of the stairway.]
- Treads to be made of grating or nonslip material.
- Top railing shall join platform handrail without offset, and the height measured vertically from tread level at nose of tread shall be 30 to 34 in. (750 to 850 mm).
- Distance between railing posts (max.) measured along slope of railing: 96 in. (2 400 mm).
- The completed structure shall be capable of supporting a moving concentrated load of 1,000 lb (4 450 N), and the handrailing structure shall be capable of withstanding a load of 200 lb (890 N) applied in any direction at any point on the top rail.
- Handrails shall be on both sides of straight stairs; also, handrails shall be on both sides of circular stairs when the clearance between tank shell and stair stringer exceeds 8 in. (200 mm).
- Circumferential stairways should be completely supported on the shell of the tank, and ends of the stringers should be clear of the ground.

NOTE:

(1) It is recommended that the same angle be employed for all stairways in a tank group or plant area.

Table ND-3865-3
Stairway Rise, Run, and Angle Relationships

Height of Rise, in. (mm) <i>R</i>	<i>2R + r = 24 in. (600 mm)</i>				<i>2R + r = 26 in. (650 mm)</i>			
	Width of Run, in. (mm) <i>r</i>	Angle			Width of Run, in. (mm) <i>r</i>	Angle		
		deg	min			deg	min	
5 $\frac{1}{4}$ (135)	13 $\frac{1}{2}$ (345)	21	15		...	...	...
5 $\frac{1}{2}$ (140)	13 (330)	22	56		15 (380)	20	9	
5 $\frac{3}{4}$ (145)	12 $\frac{1}{2}$ (320)	24	43		14 $\frac{1}{4}$ (360)	21	38	
6 (150)	12 (305)	26	34		14 (355)	23	12	
6 $\frac{1}{4}$ (160)	11 $\frac{1}{2}$ (290)	28	30		13 $\frac{1}{2}$ (345)	24	53	
6 $\frac{1}{2}$ (165)	11 (280)	30	35		13 (330)	26	34	
6 $\frac{3}{4}$ (170)	10 $\frac{1}{2}$ (265)	32	45		12 $\frac{1}{2}$ (320)	28	23	
7 (180)	10 (255)	35	0		12 (305)	30	15	
7 $\frac{1}{4}$ (185)	9 $\frac{1}{2}$ (240)	38	20		11 $\frac{1}{2}$ (290)	32	13	
7 $\frac{1}{2}$ (190)	9 (230)	39	50		11 (280)	34	18	
7 $\frac{3}{4}$ (195)	8 $\frac{1}{2}$ (215)	42	22		10 $\frac{1}{2}$ (265)	36	26	
8 (200)	8 (200)	45	0		10 (255)	38	40	
8 $\frac{1}{4}$ (210)	7 $\frac{1}{2}$ (190)	47	43		9 $\frac{1}{2}$ (240)	41	0	
8 $\frac{1}{2}$ (215)	...	...	...		9 (230)	43	23	
8 $\frac{3}{4}$ (220)	...	...	...		8 $\frac{1}{2}$ (215)	45	49	
9 (230)	...	...	...		8 (205)	48	22	

ND-3900 DESIGN OF 0 psi TO 15 psi (0 kPa TO 100 kPa) STORAGE TANKS

ND-3910 GENERAL REQUIREMENTS

ND-3911 Acceptability

ND-3911.1 Scope. The design rules for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks shall cover above ground³⁰ welded storage tanks. These tanks may contain liquids or gases such as refueling water, condensate, borated reactor coolant, or radioactive waste. Such tanks are normally located within building structures.

ND-3911.2 Design Requirements.

(a) The design requirements for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks shall conform to the design rules of ND-3100 and ND-3300 except where they are modified by the requirements of this Subarticle. The joint efficiency *E* shall be based on the requirements of ND-3352. The specific design requirements shall be stipulated by the Design Specifications.

(b) The total liquid capacity of a tank shall be defined as the total volumetric liquid capacity below the high liquid design level. The nominal liquid capacity of a tank shall be defined as the total volumetric liquid capacity between the plane of the high liquid design level and the elevation of the tank grade immediately adjacent to the wall of the tank or such other low liquid design level as the Certificate Holder shall stipulate.

ND-3912 Design Report

The Certificate Holder of a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility of achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

ND-3920 DESIGN CONSIDERATIONS

ND-3921 Design and Service Loadings

(a) Loadings shall be identified as Design or Service, and, if Service, they shall have Level A, B, C, or D Service Limits designated (NCA-2142).

(b) The provisions of ND-3110 shall apply.

(c) The stress limits of ND-3921.8 shall be met.

ND-3921.1 Design Pressure.

(a) The walls of the gas or vapor space and other components of the tank above the maximum liquid level³⁷ at the top of the tank shall be designed for a pressure not less than that at which the pressure relief valves are to be set³⁸ and for the maximum partial vacuum which can be developed in such space³⁹ when the inflow of air, gas, or vapor through the vacuum relief valves is at its maximum specified rate. The maximum positive gage pressure for which this space is designed shall be understood to be the nominal pressure rating for the tank and shall not exceed 15 psi (100 kPa).

(b) All portions of the tank at levels below maximum liquid level shall be designed for the most severe combination of gas pressure, partial vacuum, and static liquid head.

ND-3921.2 Design Temperature. The Design Temperature shall not be greater than 200°F (95°C).

ND-3921.3 Tank Shape. Tank walls shall be so shaped as to avoid any pockets on the inside where gases may become trapped when the liquid level is being raised or pockets on the outside where rainwater may collect.

ND-3921.4 Loadings. See ND-3111 for loadings to be considered.

ND-3921.5 Corrosion Allowance. When corrosion is expected on any part of the tank wall or on any external or internal supporting or bracing members upon which the safety of the completed tank depends, additional metal thickness in excess of that required by the design computations shall be provided or some satisfactory method of protecting these surfaces from corrosion shall be employed. Such added thickness need not be the same for all zones of exposure inside and outside of the tank.

ND-3921.6 Linings. When corrosion resistant linings are attached to any element of the tank wall, including nozzles, their thickness shall not be included in the computation for the required wall thickness.

ND-3921.7 Welded Joint Restrictions. The restrictions on type and size of joints or welds given in (a) through (c) below shall apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The weld joint requirements shall be as given in ND-4247.

(c) All nozzle welds shall be in accordance with ND-4244.

ND-3921.8 Limits of Calculated Stresses for Design and Service Loadings. Stress⁷ limits for Design and Service Loadings are specified in Table ND-3921.8-1. The symbols used in Table ND-3921.8-1 are defined as follows:

- S = allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.
- σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
- σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m , except that it includes the effect of discontinuities.
- σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

**Table ND-3921.8-1
Design and Service Limits for Steel Tanks**

Service Limit	Stress Limits [Note (1)] and [Note (2)]
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

NOTES:

(1) See ND-3921.8 for definitions of symbols.

(2) These limits do not take into account either local or general buckling which might occur in thin wall vessels.

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1 with σ in Table ND-3921.8-1 considered as equivalent to P in Table XIII-1130-1.

ND-3922 Maximum Allowable Stress Values for Tanks

ND-3922.1 Nomenclature. The various symbols used for stresses are defined as follows:

- c = allowance for corrosion, in. (mm)
- M = ratio of the compressive stress S_c to the maximum allowable compressive stress S_{cs} (Figure ND-3922.1-2)
- N = ratio of the tensile stress S_t to the maximum allowable stress for simple tension S_{ts}
- R = radius of the wall, in. (mm)
- R_1 = radius of curvature of the tank wall in a meridian plane, in. (mm)
- R_2 = length, in. (mm), of the normal to the tank wall measured from the wall of the tank to its axis of revolution
- S_c = general symbol for indicating a compressive stress, psi (MPa), which may be either an allowable or computed value, depending on the context in which the symbol is used
- S_{ca} = allowable compressive stress, psi (MPa), which is lower than S_{cs} because of the presence of a coexistent tensile or compressive stress perpendicular to it
- S_{cc} = computed compressive stress, psi (MPa), at the point under consideration

- S_{cs} = maximum allowable longitudinal compressive stress, psi (MPa), for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction, and determined in accordance with ND-3922.3(a) for the thickness-radius ratio involved
- S_t = general symbol for indicating a tensile stress, psi (MPa), which may be either an allowable or computed value, depending on the context in which the symbol is used
- S_{ta} = allowable tensile stress, psi (MPa), which is lower than S_{ts} because of the presence of a coexistent compressive stress perpendicular to it
- S_{tc} = computed tensile stress, psi (MPa), at the point under consideration
- S_{ts} = maximum allowable stress for simple tension, psi (MPa) (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
- t = thickness, in. (mm), of sidewalls, roof, or bottom, including corrosion allowance
- T_1 = meridional unit force in the wall of the tank, lb/in. (N-mm) of latitudinal arc
- T_2 = latitudinal unit force in the wall of the tank, lb/in. (N-mm) of meridional arc

ND-3922.2 Maximum Tensile Stresses. The maximum tensile stresses in the outside walls of a tank, as determined for any loadings or any concurrent combination of such loadings, shall not exceed the applicable stress values determined in accordance with (a) or (b) below.

(a) If both the meridional and latitudinal unit forces T_1 and T_2 are tensile, or if one of these forces is tensile and the other is zero, the computed tensile stress S_{tc} shall not exceed the applicable value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) If the meridional unit force T_1 is tensile and the coexistent latitudinal unit force T_2 is compressive, or if T_2 is tensile and T_1 is compressive, the computed tensile stress S_{tc} shall not exceed a value of S_{ta} obtained by multiplying the applicable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 by the appropriate value of N obtained from Figure ND-3922.1-1 for the value of compressive stress ($S_c = S_{cc}$) and co-related ratio $(t - c)/R$ involved. However, in cases where the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may permit a tensile stress of the magnitude specified in (a) above. Section F.1 of Appendix F of API 620 Feb. 1970 Ed.⁴⁰ gives examples illustrating the determination of allowable tensile stress values S_{ta} . In no event shall the value of S_{ta} exceed the product of the applicable joint efficiency for tension and the allowable stress for simple tension shown in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

ND-3922.3 Maximum Compressive Stresses. Except as provided in ND-3933.4(b), the maximum compressive stresses in the outside walls of a tank, as determined for the loadings, shall not exceed the applicable stress values determined in accordance with (a) through (e) below.

(a) If a cylindrical wall, or portion thereof, is acted upon by a longitudinal compressive force with neither a tensile nor a compressive force acting concurrently in a circumferential direction, the computed compressive stress S_{cc} shall not exceed a value S_{cs} established for the applicable thickness-radius ratio as follows:⁴¹

For $(t - c)/R$ values less than 0.00667

(U.S. Customary Units)

$$S_{cs} = 1,800,000(t - c)/R$$

(SI Units)

$$S_{cs} = 12,400(t - c)/R$$

For $(t - c)/R$ values between 0.00667 and 0.0175

(U.S. Customary Units)

$$S_{cs} = 10,150 + 277,400(t - c)/R$$

(SI Units)

$$S_{cs} = 700 + 19,100(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175

$$S_{cs} = 15,000 \text{ psi (100 MPa)}$$

However, values of S_{cs} calculated as above, but with R taken as equal to R_1 when the compressive unit force under consideration is latitudinal or with R taken as equal to R_2 when the compressive unit force is meridional, form the basis for the rules given in (b), (c), and (d) below which apply to walls of double curvature.

(b) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive and of equal magnitude, the computed compressive stress S_{cc} shall not exceed a value S_{ca} established for the applicable thickness-radius as follows:

For $(t - c)/R$ values less than 0.00667

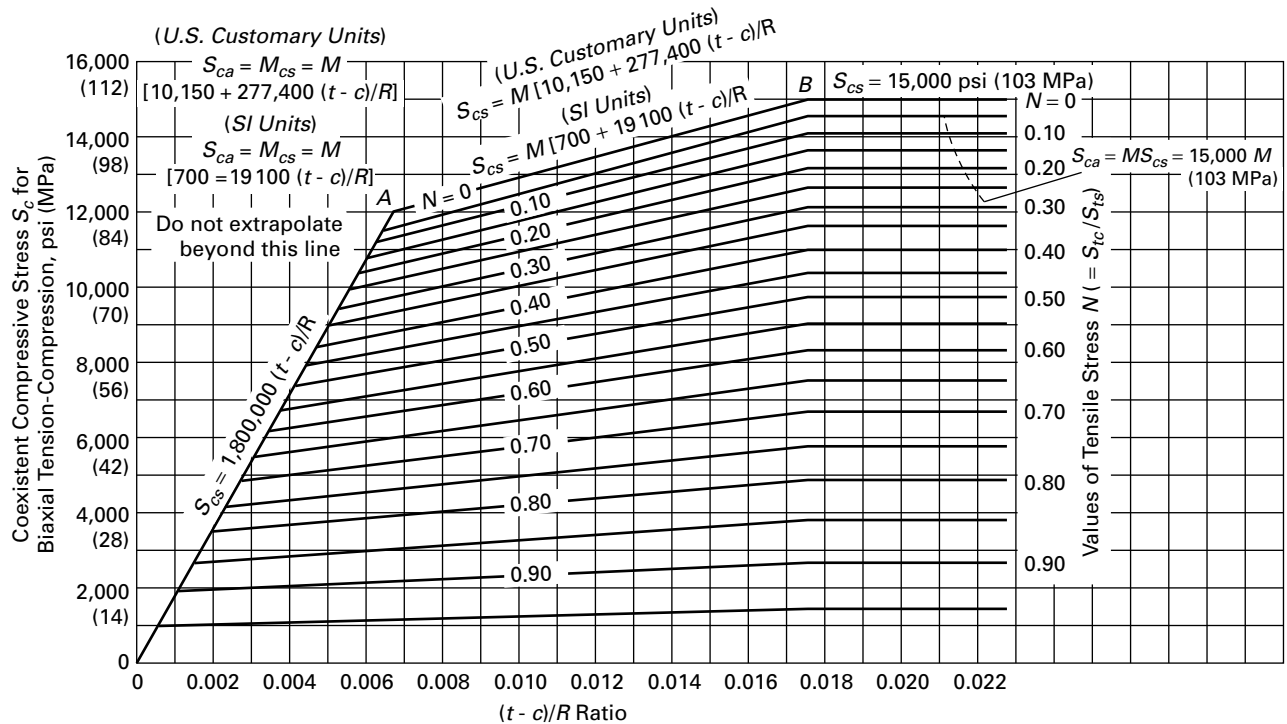
(U.S. Customary Units)

$$S_{ca} = 1,000,000(t - c)/R$$

(SI Units)

$$S_{ca} = 69,000(t - c)/R$$

Figure ND-3922.1-1
Biaxial Stress Chart for Combined Tension and Compression, 30,000 psi to 38,000 psi (205 MPa to 260 MPa) Yield Strength Steels



GENERAL NOTES:

- (a) At no time can a compressive stress for a particular value of $(t - c)/R$ exceed S_{cs} represented by curve OABC. No values of compressive stress or N are permitted to fall to the left or above this curve. (see Fig. ND-3822.1-2 for relationships between factors M and N .)
- (b) If compressive stress is latitudinal, use $R = R_1$.
- (c) If compressive stress is meridional, use $R = R_2$.

For $(t - c)/R$ values between 0.00667 and 0.0175

(U.S. Customary Units)

$$S_{ca} = 5,650 + 154,200(t - c)/R$$

(SI Units)

$$S_{ca} = 390 + 10,600(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175

$$S_{ca} = 8,340 \text{ psi (575 MPa)}$$

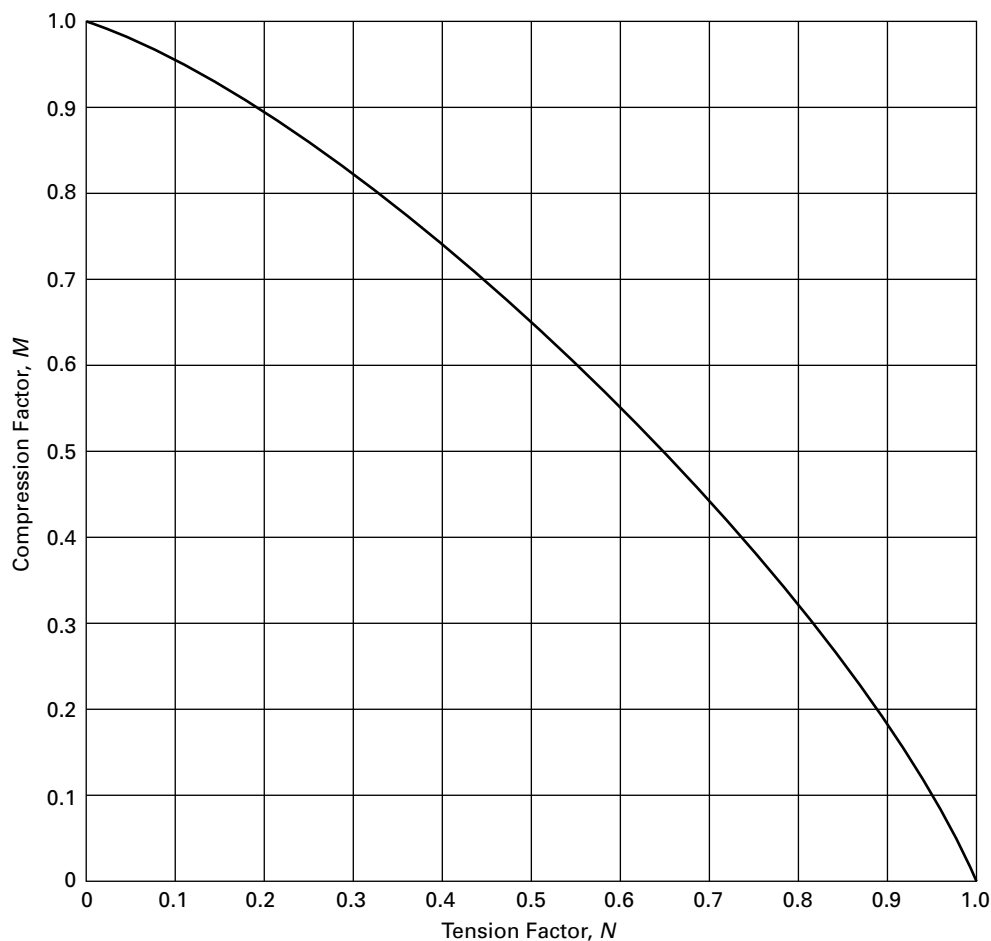
(c) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive but of unequal magnitude, both the larger and the smaller computed compressive stresses shall be limited to values which satisfy the following requirements:⁴²

$$\frac{(\text{larger stress}) + 0.8(\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the larger unit force}} \leq 1.0$$

$$\frac{1.8(\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the smaller unit force}} \leq 1.0$$

(d) If the meridional unit force T_1 is compressive and the coexistent unit force T_2 is tensile or if T_2 is compressive and T_1 is tensile, the computed compressive stress S_{cc} shall not exceed a value of S_{ca} determined from Figure ND-3922.1-1 by entering the computed value of N and the value of $(t - c)/R$ associated with the compressive unit stress and by reading the value of S_c that corresponds to that point. Such value of S_c will be the limiting value of S_{ca} for the given conditions. Section F.1 of Appendix F of API 620, Feb. 1970 Ed. gives examples illustrating the determination of allowable compressive stress values S_{ca} .

Figure ND-3922.1-2
Reduction of Design Stresses Required to Allow for Biaxial Stresses of Opposite Sign



$$N^2 + MN + M^2 = 1$$

or

$$(S_t/S_{ts})^2 + (S_t/S_{ts})(S_c/S_{cs}) + (S_c/S_{cs})^2 = 1$$

where

$$N = S_t/S_{ts}$$

S_t = the tensile stress, psi (MPa), at the point under consideration

S_{ts} = the maximum allowable stress for simple tension, psi (MPa)

$$M = S_c/S_{cs}$$

S_c = the compressive stress, psi (MPa), at the point under consideration

S_{cs} = the maximum allowable longitudinal compressive stress, psi (MPa), for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction; determined in accordance with NC-3922.3(a) for the thickness to radius ratio involved

(e) The allowable compressive stresses previously specified in this subparagraph are predicated on butt welded construction. If one or more of the main joints across which the compressive force acts are of the lap welded type, the allowable compressive stress shall be determined as above except that the maximum compressive stress shall be subject to the limitations of ND-3933.1 and the applicable joint efficiency.

ND-3922.4 Maximum Shear Stresses. The maximum shear stresses in welds used for attaching manways, nozzles, reinforcements, or other attachments to the walls of a tank, and in sections of manway or nozzle necks serving as reinforcement attachment, shall not exceed 80% of the applicable maximum allowable tensile stress value S_{ts} .

ND-3923 Maximum Allowable Stress Values for Structural Members

ND-3923.1 General Stress Limits. Subject to the provisions of ND-3923.2(c) the maximum stresses in internal or external diaphragms, webs, trusses, columns, and other framing, as determined for any loadings shall not exceed the applicable allowable stresses given in Table ND-3923.1-1.

- (13) **ND-3923.2 Slenderness Ratio Limits.** The slenderness ratio (i.e., the ratio of the unbraced length l to the least radius of gyration r) for structural members in compression and for tension members other than rods shall not exceed the following values, except as provided in (a) below.

	Maximum l/r
For main compression members	120
For bracing and other secondary members in compression	200
For main tension members	240
For bracing and other secondary members in tension	300

(a) The slenderness ratio of main compression members inside of a tank may exceed 120, but not 200, provided the member is not ordinarily subject to shock or vibration loads and the unit stress under full Design Loadings does not exceed the following fraction of the stress value given in Table ND-3923.1-1 for the member's actual l/r ratio

$$f = 1.6 - \frac{l}{200r}$$

(b) The gross and net sections of structural members shall be as determined in (1) through (5) below.

(1) The gross section of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net section shall be determined by substituting for the gross width the net width which, in the case of a member having a chain of holes extending across it in any diagonal or zigzag line, shall be

computed by deducting from the gross width the sum of the diameters of all holes in the chain and adding, for each gage space in the chain, the following quantity:

$$\frac{s^2}{4g}$$

where

g = transverse spacing (gage), in. (mm), of the same two holes
 s = longitudinal spacing (pitch), in. (mm), of any two successive holes

(2) In the case of angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angle less the thickness.

(3) In determining the net section across plug or slot welds, the weld metal shall not be considered as adding to the net area.

(4) For splice members, the thickness considered shall be only that part of the thickness of the member that has been developed by the welds or other attachments beyond the section considered.

(5) In pin connected tension members other than forged eyebars, the net section across the pinhole transverse to the axis of the member shall not be less than 135%, and the net section beyond the pinhole parallel to the axis of the member shall not be less than 90% of the net section of the body of the member. The net width of a pin connected member across the pinhole transverse to the axis of the member shall not exceed eight times the thickness of the member at the pin, unless lateral buckling is prevented.

(c) External structural or tubular columns and framing subject to stresses produced by a combination of wind and other applicable loads specified in ND-3921.4 may be proportioned for unit stresses 25% greater than those specified in Table ND-3923.1-1, provided the section thus required is not less than that required for all other applicable loads combined on the basis of the unit stresses specified in Table ND-3923.1-1. A corresponding increase may be applied to the allowable unit stresses in the connecting bolts or welds.

ND-3930 DESIGN PROCEDURE

ND-3931 Design of Tank Walls

(a) Free body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and latitudinal unit forces that will exist in the walls of the tank at critical levels under all the various combinations of gas pressure or partial vacuum and liquid head to be encountered in service that may have a controlling effect on the design. To this end it will sometimes be necessary to make several analyses at a given level of the tank to establish the governing conditions of gas pressure and

Table ND-3923.1-1
Maximum Allowable Stress Values for Structural Members

	Column 1 For Members Not Subject to Pressure-Imposed Loads,		Column 2 For Internal Members Resisting Pressure, ksi (MPa)
	ksi	MPa	
(a) Tension			
Rolled steel, on net section	18.0	124	[Note (1)]
Butt welds, on cross-sectional area in, or at edge of, weld [Note (2)]	18.0	124	[Note (1)]
Bolts and other threaded parts, on net area at root of thread	18.0	124	[Note (1)]
(b) Compression			
For axially loaded structural columns, structural bracing, and structural secondary members, on gross section	$\frac{18}{1 + \frac{l^2}{18,000r^2}}$ but not to exceed 15	$\frac{124}{1 + \frac{l^2}{18,000r^2}}$ 100	Same values as for Column 1
For axially loaded tubular columns, tubular bracing, and tubular secondary members, on gross section [minimum permissible thickness, $\frac{1}{4}$ in. (6.4 mm)]	$\frac{18.0 Y}{1 + \frac{l^2}{18,000r^2}}$ but not to exceed 15 Y	$\frac{124 Y}{1 + \frac{l^2}{18,000r^2}}$ 100 Y	Same values as for Column 1
where			
l = unbraced length of column, in. (mm)			
r = corresponding least radius of gyration of column, in. (mm)			
R = outside radius of tubular column, in. (mm)			
t = thickness of tubular column, in. (mm)			
Y = unity (1.0) for values of t/R equal to or exceeding 0.015			
$= \frac{2}{3} (100t/R) [2 - \frac{2}{3} (100 t/R)]$, for values of t/R less than 0.015			
Butt welds, on least cross-sectional area in, or at edge of, weld (crushing)	18.0	124	15.0 (100)
Plate girder stiffeners, on gross section	18.0	124	15.0 (100)
(c) Bending			
Tension on extreme fibers of rolled sections, plate girders, and built-up members	18.0	124	[Note (1)]
Compression on extreme fibers of rolled sections, plate girders, and built-up members:			
With ld/bt not in excess of 600	18.0	124	Same as tension value [Note (1)]
With ld/bt in excess of 600	$\frac{10,800.0}{ld/bt}$	$\frac{74,400.0}{ld/bt}$	$\frac{600 \times \text{tension value}^1}{ld/bt}$
where			
l = unsupported length of the member, in., except that, for a cantilever beam not fully stayed at its outer end against translation or rotation, l shall be taken as twice the length of the compression flange			
d = depth of the member, in. (mm)			
b = width of its compression flange, in. (mm)			
t = thickness of its compression flange, in. (mm)			
Stress on extreme fibers of pins	27.0	186	20.0 (138)
Members subjected to both axial and bending loads shall be so proportioned that the maximum combined axial and bending stress will not exceed the permissible value for axial loading alone.			

Table ND-3923.1-1
Maximum Allowable Stress Values for Structural Members (Cont'd)

	Column 1 For Members Not Subject to Pressure-Imposed Loads,		Column 2 For Internal Members Resisting Pressure, ksi (MPa)
	ksi	MPa	
(c) Bending (Cont'd)			
Fiber stresses in butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respectively. (Such values for welds in tension must be multiplied by the applicable joint efficiency.)			
(d) Shearing			
Pins and turned bolts in reamed or drilled holes	13.5	93	12.0 (82)
Unfinished bolts	10.0	69	8.0 (55)
Webs of beams and plate girders where h/t is not more than 60, or where web is adequately stiffened, on gross section of web	12.0	83	Two-thirds of tension value [Note (1)]
Webs of beams and plate girders where web is not adequately stiffened and h/t is more than 60, on gross section of web	$\frac{18.0}{1 + \frac{h^2}{7,200t^2}}$	$\frac{124}{1 + \frac{h^2}{7,200t^2}}$	$\frac{\text{Tension value}^1}{1 + \frac{h^2}{7,200t^2}}$
where h = clear distance between web flanges, in. (mm) t = thickness of the web, in. (mm)			
Fillet welds where load is perpendicular to length of weld, on section through throat [Note (2)]	12.6	87	70% of tension value [Note (1)]
Fillet welds where load is parallel to length of weld, on section through throat [Note (2)]	9.0	62	50% of tension value [Note (1)]
Plug welds or slot welds, on effective faying-surface area of weld [Note (2)]	11.7	81	65% of tension value [Note (1)]
Butt welds, on least cross-sectional area in, or at edge of, weld [Note (2)]	14.4	99	80% of tension value [Note (1)]
(e) Bearing			
Pins and turned bolts in reamed or drilled holes:			
Load applied to bolt at only one side of member connected	24.0 (165)		1.33 (tension value) [Note (1)]
Load approximately uniformly distributed across thickness of member connected	30.0 (207)		1.67 (tension value) [Note (1)]
Unfinished bolts:			
Load applied to bolt at only one side of member connected	16.0 (110)		0.9 (tension value) [Note (1)]
Load approximately uniformly distributed across thickness of member connected	20.0 (138)		1.1 (tension value) [Note (1)]

NOTES:

(1) See Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(2) All values for butt welds in tension or shear shall be multiplied by the applicable joint efficiency. These values are obtained by combining the following: a factor of 80% for shear strength of weld metal; an efficiency factor of approximately 85% for fillet welds or 80% for plug welds and slot welds; and a factor of 100% for perpendicular loading or approximately 75% for parallel loading.

liquid head for that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in [ND-3932.3](#).

(b) For tanks having points of marked discontinuity in the direction of the meridional tangent, such as occurs at the juncture between a conical or dished roof or bottom and a cylindrical sidewall or at the juncture between a conical reducer and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of [ND-3933](#).

ND-3932 Design of Sidewalls, Roofs, and Bottoms

ND-3932.1 Nomenclature. The symbols are defined as follows:

- A_T = cross-sectional area of the interior of the tank at the level under consideration, in.² (mm²)
- E = efficiency, expressed as a decimal, of the weakest joint across which the stress under consideration acts
- F = summation, lb (N), of the vertical components of the forces in all internal or external ties, braces, diaphragms, trusses, columns, skirts, or other structural devices or supports acting on the free body. F shall be given the same sign as P when acting in the same direction as the pressure on the horizontal face of the free body and the opposite sign when acting in the opposite direction.
- $P = P_L + P_G$ = total pressure, psi (MPa), acting at a given level of the tank under a particular condition of loading
- P_G = gas pressure, psi (MPa), above the surface of the liquid. The maximum value, a pressure not exceeding 15 psig (100 kPa), is the nominal pressure rating of the tank. P_G is positive except in computations for investigating the ability of a tank to withstand a partial vacuum, where the value is negative.
- P_L = pressure resulting from the liquid head at the level under consideration in the tank, psi (MPa)
- R_1 = radius of curvature of the tank wall in a meridian plane, at the level under consideration, in. (mm) R_1 is to be considered negative when it is on the opposite side of the tank wall from R_2 except as provided in [ND-3932.2\(f\)](#).
- R_2 = length, in. (mm), of the normal to the tank wall at the level under consideration, measured from the wall of the tank to its axis of revolution. R_2 is always positive except as provided in [ND-3932.2\(f\)](#).
- S_{ca} = allowable compression stress, psi (MPa), as required in [ND-3922.3](#)
- S_{cc} = computed compression stress, psi (MPa), at the point under consideration
- S_{ta} = allowable tension stress, psi (MPa), as required in [ND-3922.2\(b\)](#)
- S_{tc} = computed tension stress, psi (MPa), at the point under consideration

S_{ts} = maximum allowable stress for simple tension, psi (kPa) (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)

T_1 = meridional unit force in the wall of the tank at the level under consideration, lb/in. (N-mm) of latitudinal arc. T_1 is positive when in tension.

T_2 = latitudinal unit force in the wall of the tank at the level under consideration, lb/in. (N-mm) of meridional arc. T_2 is positive when in tension. In cylindrical sidewalls the latitudinal unit forces are circumferential unit forces.

W = total weight, lb (kg), of that portion of the tank and its contents either above the level under consideration, as in [Figure ND-3932.1-1](#) sketch (b), or below such level, as in [Figure ND-3932.1-1](#) sketch (a) which is treated as a free body in the computations for such level. W shall be given same sign as P when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.

ND-3932.2 Computation of Unit Forces.

(a) At each level of the tank selected for free body analysis as specified in [ND-3931](#) ([Figure ND-3932.1-1](#)) and for each condition of gas and liquid loading that must be investigated at such level, the magnitude of the meridional and latitudinal unit forces in the wall of the tank shall be computed from eqs. ⁴³ (1) and (2) below, except as provided in [ND-3932.6](#) or [ND-3933](#).

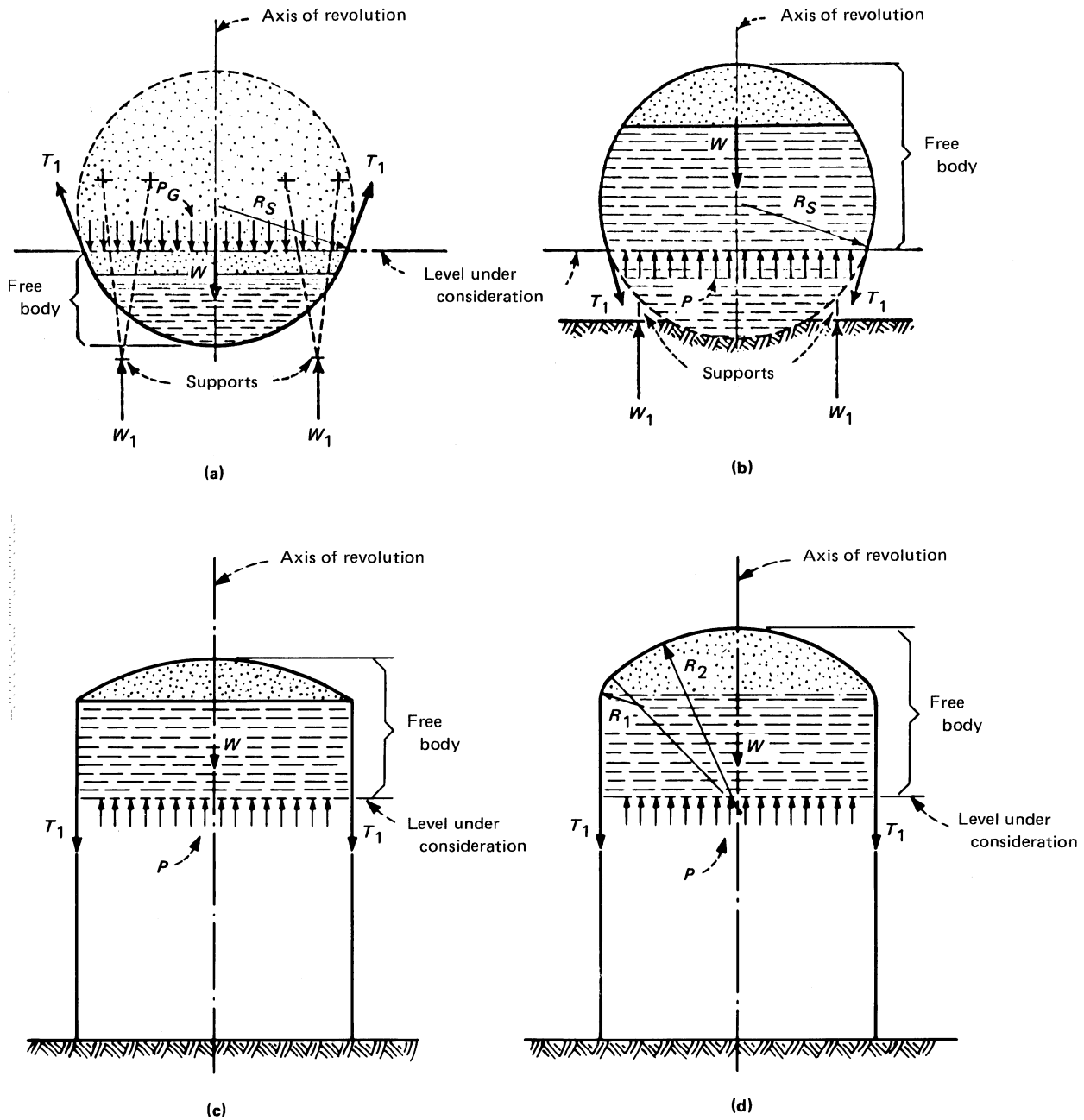
$$T_1 = \frac{R_2}{2} \left(P + \frac{W + F}{A_T} \right) \quad (1)$$

$$\begin{aligned} T_2 &= R_2 \left(P - \frac{T_1}{R_1} \right) \\ &= R_2 \left[P \left(1 - \frac{R_2}{2R_1} \right) - \frac{R_2}{2R_1} \left(\frac{W + F}{A_T} \right) \right] \end{aligned} \quad (2)$$

(b) Positive values of T_1 and T_2 indicate tensile forces, and negative values indicate compressive forces.

(c) It will usually be necessary to make such analyses at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. Moreover, the maximum total pressure, liquid head plus gas pressure that can exist at a given level will not necessarily be the governing condition for that level; sufficient analyses shall be made at each level to establish that combination of liquid head and gas pressure or partial vacuum which, in conjunction with the allowable tensile and compressive stresses, will control the design at such level. Even though a tank may normally be operated at a fixed height of liquid contents, it shall be made safe for any conditions that might develop in filling or emptying the tank.

Figure ND-3932.1-1
Some Typical Free Body Diagrams for Certain Shapes of Tanks



(d) The values for a point at a horizontal distance x from the vertical axis of a roof or bottom in which the length of the horizontal semiaxis a is two times the length of the vertical semiaxis b may be determined by multiplying the length a by the factor from Table ND-3932.2(d)-1. Values for ellipsoidal shapes of other proportions shall be calculated from the following equations:

$$R_1 = \frac{b^2}{a^4} \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{3/2} = \frac{b^2 (R_2)^3}{a^4} \quad (3)$$

$$R_2 = \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{1/2} \quad (4)$$

(e) Equations (a)(1) and (a)(2) are general equations applicable to any tank having a single vertical axis of revolution and to any free body that is isolated by a horizontal plane which intersects the walls of the tank in only one circle [(f)]. For shapes most commonly used, these equations reduce to the simplified equations given in (1) through (3) below for the respective shapes indicated.

**Table ND-3932.2(d)-1
Factors for Determining Values of R_1 and R_2
for 2:1 Ellipsoidal Roofs and Bottoms**

x/α	$u = R_1 / \alpha$	$v = R_2 / \alpha$
0.00	2.000	2.000
0.05	1.994	1.998
0.10	1.978	1.993
0.15	1.950	1.983
0.20	1.911	1.970
0.25	1.861	1.953
0.30	1.801	1.931
0.35	1.731	1.906
0.40	1.651	1.876
0.45	1.562	1.842
0.50	1.465	1.803
0.55	1.360	1.759
0.60	1.247	1.709
0.65	1.129	1.653
0.70	1.006	1.591
0.75	0.879	1.521
0.80	0.750	1.442
0.85	0.620	1.354
0.90	0.492	1.253
0.95	0.367	1.137
1.00	0.250	1.000

GENERAL NOTE:

x = horizontal distance from point in roof or bottom to axis of revolution

α = horizontal semiaxis of elliptical cross section

$R_1 = u\alpha$

$R_2 = v\alpha$

(1) For a Spherical Tank or Spherical Segment of a Tank. $R_1 = R_2 = R_s$, the spherical radius of the tank or segment, and eqs. (a)(1) and (a)(2) become

$$T_1 = \frac{R_s}{2} \left(P + \frac{W + F}{A_T} \right) \quad (5)$$

$$T_2 = R_s P - T_1 \quad (6)$$

If the sphere is for gas pressure only and if $(W + F)/A_T$ is negligible as compared with P_G , eqs. (5) and (6) reduce to

$$T_1 = T_2 = \frac{1}{2} P_G R_s \quad (7)$$

(2) For a Conical Roof or Bottom

$$R_1 = \text{infinity}$$

and

$$R_2 = \frac{R_3}{\cos \alpha}$$

where

R_3 = horizontal radius of the base of the cone at the level under consideration, in. (mm)

α = one-half the included apex angle of the conical roof or bottom

For this condition, eqs. (a)(1) and (a)(2) reduce to

$$T_1 = \left(\frac{R_3}{2 \cos \alpha} \right) \left(P + \frac{W + F}{A_T} \right) \quad (8)$$

$$T_2 = \frac{P R_3}{\cos \alpha} \quad (9)$$

(3) For Cylindrical Sidewalls of a Vertical Tank. $R_1 = \text{infinity}$ and $R_2 = R_c$, the radius of the cylinder, and eqs. (a)(1) and (a)(2) become

$$T_1 = \frac{R_c}{2} \left(P + \frac{W + F}{A_T} \right) \quad (10)$$

$$T_2 = P R_c \quad (11)$$

If the cylinder is for gas pressure only and if $(W + F)/A_T$ is negligible as compared with P_G , eqs. (10) and (11) reduce to

$$T_1 = \frac{1}{2} P_G R_c \quad (12)$$

$$T_2 = P_G R_c \quad (13)$$

(f) In the case of a torispherical head shown in Figure ND-3932.1-1(d), applicable equations for the meridional and latitudinal unit forces in the walls of the segment are as follows:

$$T_1 = (\text{in preparation}) \quad (14)$$

$$T_2 = (\text{in preparation}) \quad (15)$$

- (13) **ND-3932.3 Required Thickness.** The thickness of the tank wall at any given level shall be not less than the largest value of t as determined for the level by the methods prescribed in (a) through (d) below. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible partial vacuum enumerated in ND-3921.4, and if the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of ND-3933.

(a) If the unit forces T_1 and T_2 are both positive for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, the larger of the two shall be used for computing the thickness required at such level, as follows:

$$t = \frac{T_1}{S_{ts}E} + c \quad \text{or} \quad t = \frac{T_2}{S_{ts}E} + c \quad (16)$$

(b) If the unit force T_1 is positive and T_2 is negative for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank or if T_2 is positive and T_1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the calculated tension stress S_{tc} and the calculated compression stress S_{cc} satisfy the requirements of ND-3922.2(b) and ND-3922.3(d), respectively. The determination of this thickness will be facilitated by using a graphical solution such as illustrated in Appendix F, Section F.2 of API Standard 620, Feb. 1970 Edition. If the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may determine the thickness required for this condition by using the method specified in (a) above.

NOTE: The value of the joint efficiency factor E will not enter into this determination unless the magnitude of the allowable tensile stress S_{ta} is governed by the product ES_{ts} as provided in ND-3922.2(b).

(c) If the unit forces T_1 and T_2 are both negative and are of equal magnitude for the governing condition of loading at a given level of the tank, the thickness of tank wall required shall be calculated as follows:

$$t = \frac{T_1}{S_{ca}} + c = \frac{T_2}{S_{ca}} + c \quad (17)$$

where S_{ca} has the appropriate value for the thickness-radius ratio involved, as required in ND-3922.3(b) and ND-3922.3(e).

(d) If the unit forces T_1 and T_2 are both negative but of unequal magnitude for the governing condition of loading at a given level, the thickness of tank wall required for this condition shall be the largest of those thickness values, calculated by the following procedure, which show a proper correlation with the respective thickness-radius ratios involved in their computation (Steps 2 and 4).

Step 1. Calculate the values of

$$t = \frac{\sqrt{(T' + 0.8 T'')R'}}{1342} + c \quad (18)$$

and

$$t = \frac{\sqrt{T''R''}}{1000} + c \quad (19)$$

using values of T' equal to the larger of the two coexistent unit forces and T'' equal to the smaller of the two unit forces, and taking R' and R'' as equal to R_1 and R_2 , respectively, if the larger unit force is latitudinal; but, conversely, taking R' and R'' as equal to R_2 and R_1 , respectively, if the larger unit force is meridional.

Step 2. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 1 and check the thickness-radius ratio $(t - c)/R$ for each based on the value of R used in Step 1, eq. (18) or eq. (19). If both such thickness-radius ratios are less than 0.00667, the larger of the two thicknesses calculated in Step 1 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 3.

Step 3. If one or both thickness-radius ratios determined in Step 2 exceed 0.00667, calculate the values of

$$t = \frac{T' + 0.8 T''}{15,000} + c \quad (20)$$

and

$$t = \frac{T''}{8340} + c \quad (21)$$

Step 4. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 3 and check the thickness-radius ratio $(t - c)/R$ for each using a value of R equal to R' as defined in Step 1 in connection with the thickness determined from Step 3, eq. (20) and a value

of R equal to R'' in connection with the thickness determined from Step 3, eq. (21). If both such thickness-radius ratios are greater than 0.0175, the larger of the two thicknesses calculated in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 5. If one or more of the thickness-radius ratios determined in Steps 2 and 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Step 1, eq. (18) or Step 3, eq. (20), find a thickness which satisfies the following equation:

$$\frac{10,150(t - c) + 277,400(t - c)^2}{R'} = T' + 0.8T'' \quad (22)$$

or, if the thickness involved was calculated by Step 1, eq. (19) or Step 3, eq. (21), find a thickness which satisfies the following equation:

$$\frac{5,650(t - c) + 154,200(t - c)^2}{R''} = T'' \quad (23)$$

Step 6. Make a selection of thickness from the values calculated. Calculate the values of S_{cc} for both T_1 and T_2 and check that values of S_{cc} satisfy the requirements of ND-3922.3(c).

NOTE: The procedure described in (d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to compute the values of S_{cc} for both T_1 and T_2 and then check to see that these values satisfy the requirements of ND-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix F of API Standard 620, Feb. 1970 Edition, for examples illustrating the application of (a)].

ND-3932.4 Least Permissible Thickness. In no event shall the net thickness after fabrication of any plate subject to pressure imposed membrane stresses be less than $3/16$ in. (5 mm), exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft (18.3 m) up to but not including 120 ft (36.6 m), such thickness for sidewall plates shall not be less than $1/4$ in. (6 mm) exclusive of corrosion allowance.

ND-3932.5 External Pressure Limitations. The thickness computed by the equations and procedures specified in ND-3932, using a negative value of P_G equal to the partial vacuum for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius R_1 is equal to or less than R_2 or does not exceed R_2 by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking, and it is not intended that the equations and procedures be used for evaluating the stability of such surfaces or of cylindrical surfaces against

external pressure. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storage of liquids⁴⁴ with the thickness of upper courses not less than specified in ND-3932.4 for the size of tank involved and with increasing thicknesses from top to bottom as required for the combined gas and liquid loadings may safely be subjected to a partial vacuum in the gas or vapor space not exceeding 1 oz/sq in. (0.4 kPa)⁴⁵ with the operating liquid level in the tank at any stage from full to empty.

ND-3932.6 Special Considerations Applicable to Bottoms Resting Directly on Foundations.

(a) *Uplift Considerations.* In the case of tanks with cylindrical sidewalls and flat bottoms, the uplift⁴⁶ from the pressure acting on the underside of the roof must not exceed the weight of the sidewalls plus the weight of that portion of the roof that is carried by the sidewalls when no uplift exists, unless such excess is counteracted by increasing the magnitude of the downward acting forces. This shall be a matter of agreement between the Certificate Holder and Owner. Similar precautions must be taken with flat bottom tanks of other shapes. All weights used in such calculations shall be based on net thicknesses of the materials, exclusive of corrosion allowance.

(b) *Foundation Considerations.* The type of foundation used for supporting the tank shall be taken into account in the design of bottom plates and welds. For recommended practice for construction of foundations, see API Standard 620, Feb. 1970 Edition, Appendix C.

ND-3933 Design of Roof and Bottom Knuckle Regions, and Compression Ring

ND-3933.1 Nomenclature. The symbols used are defined as follows:

- A_c = net area, in.² (mm²), of the vertical cross section of metal required in the compression ring region, exclusive of all corrosion allowances
- E = efficiency, expressed as a decimal, of meridional joints in the compression ring region in the event that Q should have a positive value, indicating tension
- Q = total circumferential force, lb (N) acting on a vertical cross section through the compression ring region
- R_c = horizontal radius, in. (mm), of the cylindrical sidewall at its juncture with the roof or bottom
- R_2 = length, in. (mm), of the normal to the roof or bottom at the juncture between the roof or bottom and the sidewalls, measured from the roof or bottom to the tank's vertical axis of revolution
- S_{ts} = maximum allowable stress value for simple tension, psi (MPa) (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
- t_c = corresponding thickness, in. (mm), of the cylindrical sidewalls at and near such juncture

- t_h = thickness, in. (mm), of the roof or bottom plate at and near the juncture of the roof or bottom and sidewalls, including corrosion allowance
- T_1 = meridional unit force in the roof or bottom of the tank at its juncture with the sidewall, lb/in. (N·mm) of circumferential arc
- T_2 = corresponding latitudinal unit force in the roof or bottom, lb/in. (N·mm) of meridian arc
- T_{2s} = circumferential unit force⁴⁷ in the cylindrical sidewall of the tank at its juncture with the roof or bottom, lb/in. (N·mm), measured along an element of the cylinder
- w_c = corresponding width, in. (mm), of the participating sidewall plate
- w_h = width, in. (mm), of the roof or bottom plate considered to participate in resisting the circumferential force acting on the compression ring region
- α = angle between the direction of T_1 and a vertical line. In a conical surface it is also one-half of the total vertex angle of the cone.

ND-3933.2 General Requirements. When the roof or bottom of a tank is a cone or partial sphere and is attached to cylindrical sidewalls, the membrane stresses in the roof or bottom act inward on the periphery of the sidewalls. This results in circumferential compressive forces at the juncture, which shall be resisted either by a knuckle curvature in the roof or bottom or by a limited zone at the juncture of the intersecting roof or bottom plates and sidewall plates, supplemented in some cases by an angle, a rectangular bar, or a ring girder.

ND-3933.3 Requirements for Knuckle Regions.

(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%, of the diameter of the sidewalls.⁴⁸ Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of ND-3932.

(b) Application of the equations in ND-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a common meridional tangent, as at the juncture between the knuckle region and the spherically dished portion of a torispherical roof, will result in the calculation of two latitudinal unit forces, differing in magnitude and perhaps in sign, at the same point. The latitudinal unit force at such a point will be between the two calculated values, depending on the geometry of the tank wall in that area.

ND-3933.4 Requirements for Compression Rings.

(a) If a curved knuckle is not provided, the circumferential compressive forces shall be resisted by other means in the compression ring region of the tank walls. The zone of the tank walls at the juncture between the roof or bottom and the sidewalls includes that width of plate on each side

of the juncture that is considered to participate in resisting these forces [Figure ND-3933.4(a)-1]. The thickness of the wall plate on either side of the juncture shall not be less than the thickness needed to satisfy the requirements of ND-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

$$w_h = 0.6 \sqrt{R_2(t_h - c)} \quad (24)$$

$$w_c = 0.6 \sqrt{R_c(t_c - c)} \quad (25)$$

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

$$Q = T_2 w_h + T_{2s} w_c - T_1 R_c \sin \alpha \quad (26)$$

and the net cross-sectional area provided in the compression ring region shall not be less than that found to be required by the following equation:

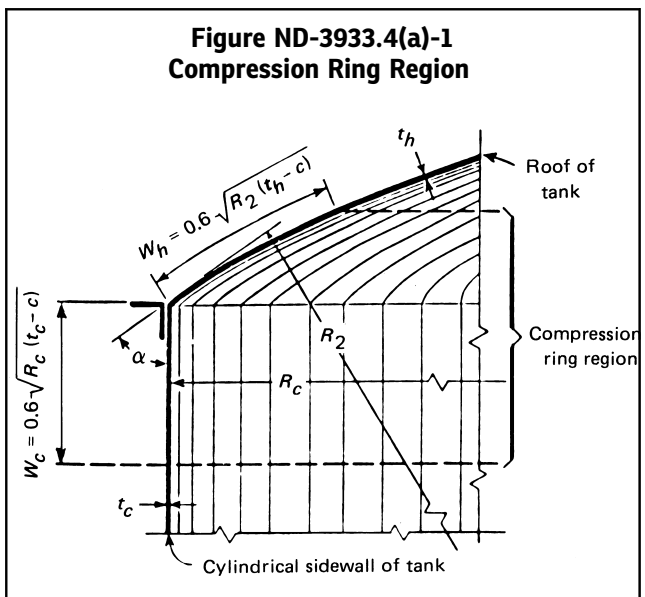
(U.S. Customary Units)

$$A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{ts}E} \quad (27)$$

(SI Units)

$$A_c = \frac{Q}{66,700}$$

depending on whether the value of Q as determined by eq. (26) is negative⁴⁹ or positive.



ND-3933.5 Details of Compression Ring Regions.

(a) If the force Q is negative, indicating compression, the horizontal projection of the effective compression ring region shall have a width in a radial direction not less than 0.015 times the horizontal radius of the tank wall at the level of the juncture between the roof or bottom and the sidewalls. If such projected width does not meet this requirement, appropriate corrective measures shall be taken as specified in this subparagraph.

(b) Whenever the circumferential force Q determined in accordance with ND-3933.4 is of such magnitude that the area required by eq. ND-3933.4(b)(27) is not provided in a compression ring region with plates of the minimum thicknesses established by the requirements of ND-3932, or when Q is compressive and the horizontal projection of the width w_h is less than specified in (a), the compressional ring region shall be reinforced either by thickening the roof or bottom and sidewall plates as required to provide a compressional ring region having the necessary cross-sectional area and width as determined on the basis of the thicker plates,⁵⁰ or by adding an angle, a rectangular bar, or a ring girder at the juncture of the roof or bottom and sidewall plates, or by a combination of these alternatives.

(c) Such an angle, bar, or ring girder, if used, may be located either inside or outside of the tank⁵¹ and shall have a cross section of such dimensions that

(1) its area makes up the deficiency between the area A_c required by eq. ND-3933.4(b)(27) and the cross-sectional area provided by the compression ring region in the walls of the tank;

(2) the horizontal width of the angle, bar, or ring girder is not less than 0.015 times the horizontal radius R_c of the tank wall at the level of the juncture of the roof or bottom and the sidewalls, except that, when the cross-sectional area to be added in an angle or bar is not more than one-half the total area required by eq. ND-3933.4(b)(27), the width requirement for this member may be disregarded, provided the horizontal projection of the width w_h of participating roof or bottom plates alone is equal to or greater than $0.015R_c$ or, with an angle or bar located on the outside of a tank, the sum of the projection of the width w_h and the horizontal width of the added angle or bar is equal to or greater than $0.015R_c$;

(3) when bracing must be provided as specified in (h), the moment of inertia of the cross section about a horizontal axis shall be not less than that required by eq. (h)(28).

(d) When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. However, if this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make good contact with the wall of the tank around the entire circumference and, except as provided in (e) below, shall be attached

along both the top and bottom edges by continuous fillet welds. These welds shall be of sufficient size to transmit to the compression ring angle, bar, or girder that portion of the total circumferential force Q , assuming, in the case of welds separated by the width of a leg or flange of a structural member as shown in Figure ND-3933.5(d)-1 sketches (a), (g), and (j), that only the weld nearest the roof or bottom is effective. The part thicknesses and weld sizes in Table ND-4247.6(d)-1 relate to dimensions in the as-welded condition before deduction of corrosion allowances, but all other part thicknesses and weld sizes referred to in this subparagraph relate to dimensions after deduction of corrosion allowance.

(e) If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent provided:

(1) the summation of their lengths is not less than one-half the circumference of the tank;

(2) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance;

(3) the welds are of such size as needed for strength but in no case smaller than specified in Table ND-4247.6(d)-1.

(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

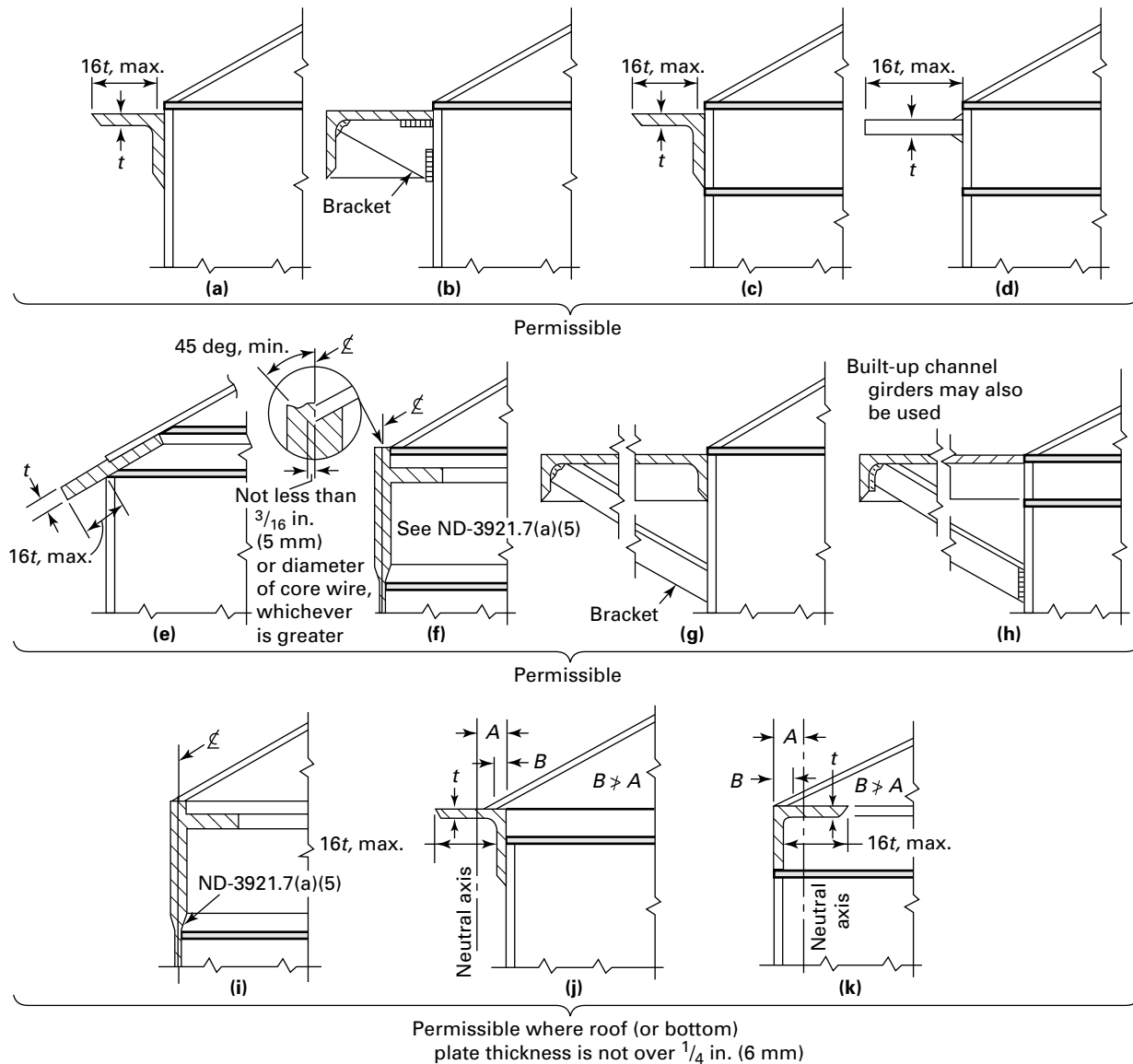
(g) If a compression ring on either the inside or outside of a tank is of such shape that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if the shape of a compression ring on the inside of a tank is such that gas would be trapped on the underside thereof when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than $\frac{3}{4}$ in. (19 mm) diameter.

(h) The projecting part of a compression ring without an outer vertical flange need not be braced, provided the width of such projecting part in a radial vertical plane does not exceed 16 times its thickness. With this exception, the horizontal part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other suitable members securely attached to both the ring and the tank wall to prevent such part of the ring from buckling laterally. When such bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that calculated to be required by the following equation:⁵²

(U.S. Customary Units)

$$I_1 = \frac{1.44Q_p R_c^2}{29,000,000k} = 5 \frac{Q_p R_c^2}{k} \times 10^{-8} \quad (28)$$

Figure ND-3933.5(d)-1
Permissible Details of Compression Ring Construction



GENERAL NOTES:

- (a) See ND-3350 for limitations concerning locations where various types of welded joints may be used.
 (b) For sketches (j) and (k), dimension B shall not exceed A.

(SI Units)

$$I_1 = \frac{1.12 Q_p R_c^2}{29\,000\,000k} = 5 \frac{Q_p R_c^2}{k} \times 10^{-8}$$

where

I_1 = required moment of inertia, in.⁴ (mm⁴), for the cross section of a steel compression ring with respect to a horizontal axis through the centroid of the section, not taking credit for any portion of the tank wall except that, in the case of an angle ring whose vertical leg is attached to or forms a part of the tank wall, the moment of inertia of only the horizontal leg shall be considered, and it shall be figured with respect to a horizontal axis through the centroid of such leg⁵²

k = a constant whose value depends on the magnitude of the angle θ , subtended at the central axis of the tank by the space between adjacent brackets or other supports, which value shall be determined from the tabulation in Table ND-3933.5(h)-1, in which n is the number of brackets or other supports evenly spaced around the circumference of the tank

Q_p = that portion of the total circumferential force Q , lb (N), [eq. ND-3933.4(b)(26)] which is carried by the compression ring angle, bar, or girder, as computed from the ratio of the cross-sectional area of the compression ring to the total area of the compression zone

R_c = horizontal radius, in. (mm), of the cylindrical side-wall of the tank at its juncture with the roof or bottom

ND-3934 Nozzle Piping Transitions

The stress limits of Table ND-3921.8-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in ND-3334, except as provided in ND-3935. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

Table ND-3933.5(h)-1
Some Values for k Based on n, θ

n	30	24	20	18	15	12
θ , deg	12	15	18	20	24	30
k	186.6	119.1	82.4	66.6	45.0	29.1
N	10	9	8	6	5	4
θ , deg	36	40	45	60	72	90
k	20.0	16.0	12.5	6.7	4.4	2.6

GENERAL NOTE: In no case shall θ be larger than 90 deg.

ND-3935 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table ND-3921.8-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3921.8-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table ND-3921.8-1, for a given condition.

ND-3940 ALTERNATE RULES FOR AXIAL COMPRESSIVE MEMBRANE STRESSES IN THE CYLINDRICAL WALLS OF 0 PSI TO 15 PSI STORAGE TANKS

The rules of this subsubarticle provide an alternative to the allowable compressive stress rules of ND-3922.3 for loadings associated with Service Limits A, B, C, and D. The remaining rules of the Subarticle are still applicable.

ND-3941 Limits of Application

The application of this subsubarticle is subject to the following limitations:

(a) The rules apply to the right circular cylindrical walls of tanks otherwise designed to the rules of ND-3900.

(b) The specific criteria given herein are for the establishment of allowable axial membrane compressive stresses for those locations on the cylindrical walls where the corresponding total internal radial pressure (e.g., hydrostatic pressure + vapor over pressure + hydrodynamic pressures from loading such as earthquake) is equal to or greater than the external pressure. Except as noted in (c), no specific provisions are given for locations on the cylindrical walls where the internal pressure is less than the external pressure.

(c) These provisions do not provide criteria for hoop compressive membrane stresses. If applicable, the design specification shall provide for such conditions. However, the use of this subsubarticle requires that eqs. ND-3946(40a), ND-3946(40b), ND-3946(40c), and ND-3946(40d) be satisfied for those locations where the hoop stress is compressive and the axial stress is tensile.

(d) This subsubarticle applies for tanks where the height of the cylindrical wall, H , divided by the radius of the midsurface of wall, R , is equal to or less than 0.95 times the square root of the ratio of the radius to the thickness of the wall [i.e., $(H/R) \leq 0.95\sqrt{R/t}$]. See ND-3942 for definitions of H , R , and t .

(e) This subsubarticle is not applicable to tanks where the main joints are lap welded.

(f) This subsubarticle does not address long column buckling.

(g) All other requirements of ND-3900 shall be satisfied.

ND-3942 Nomenclature

The symbols used in this subsubarticle have the following definitions:

- DF = design factor applied to $\sigma_{a,u}$ in order to establish $\sigma_{a,allow}$; dimensionless (see ND-3945)
- E = modulus of elasticity of the cylindrical wall material, at the corresponding temperature, given in the appropriate Table TM, Section II, Part D, Subpart 2; ksi (MPa)
- H = height of the right circular cylindrical wall portion of the tank; in. (mm)
- L_x = length of measurement over which construction tolerance deviations are measured; in. (mm) (see ND-3947)
- p = net internal radial pressure, i.e., internal radial pressure minus external pressure; ksi (MPa) [see ND-3941(b)]
- R = nominal radius of the midsurface of the cylindrical wall; in. (mm)
- S = allowable tensile stress of the cylindrical wall material, at the corresponding temperature, given in the appropriate Table 1A or 1B, Section II, Part D, Subpart 1; ksi (MPa)
- S_y = yield strength of the cylindrical wall material, at the corresponding temperature, given in Table Y-1 of Section II, Part D, Subpart 1; ksi (MPa)
- t = nominal (supplied) thickness of the cylindrical wall minus any allowances established in the design specification for corrosion, erosion, etc.; in. (mm)
- α_0 = buckling capacity reduction factor for a cylindrical wall with no net internal radial pressure; dimensionless [see eqs. ND-3943(29a) and ND-3943(29b)]
- α_p = buckling capacity reduction factor that includes the effect of net internal radial pressure; dimensionless [see eq. ND-3943(b)(31)]
- β = nondimensional parameter used in the formulation of axial compressive stress criteria; dimensionless [see eq. ND-3943(g)(35)]
- Δ_x = geometric imperfection; in. (mm) (see ND-3947)
- λ_p = slenderness parameter that includes the effect of net internal radial pressure; dimensionless [see eq. ND-3943(g)(36)]

ν = Poisson's ratio of the cylindrical wall material given in Table NF-1, Section II, Part D, Subpart 2; dimensionless. If no value is given for the material, use $\nu = 0.3$

ρ = parameter involving internal pressure; dimensionless [see eq. ND-3943(a)(30)]

σ_a = axial membrane compressive stress (compressive stress is positive); ksi (MPa) (see ND-3946)

$\sigma_{a,allow}$ = allowable value of the axial membrane compressive stress (compressive stress is positive); ksi (MPa) [see eq. ND-3944(b)(39)]

$\sigma_{a,u}$ = lower bound for the axial membrane buckling stress (compressive stress is positive); ksi (MPa) (see ND-3943)

σ_{cl} = classical linear elastic (bifurcation) buckling stress (compressive stress is positive) for a cylinder of perfect geometry ideal boundary conditions; ksi (MPa) [see eq. ND-3943(d)(32)]

σ_{eff} = lower bound for the total effective membrane buckling or collapse stress; ksi (MPa) (see ND-3943)

σ_h = hoop membrane stress (tensile stress is positive); ksi (MPa) [see eq. ND-3943(e)(33)]

ND-3943 Axial Compressive Stress Criteria

The allowable axial membrane compressive stress is expressed as a function of the lower bound value of stress at which buckling could be expected to occur, $\sigma_{a,u}$, and a design factor. The design factor is specified in ND-3945 for different service levels. The quantity $\sigma_{a,u}$ is established from the criteria set forth in this paragraph. A buckling capacity reduction factor, α_0 , is defined by eq. (29a) or eq. (29b).

$$\alpha_0 = \frac{0.83}{\sqrt{1.0 + 0.01 R/t}} \quad \text{for } R/t \leq 212 \quad (29a)$$

$$\alpha_0 = \frac{0.70}{\sqrt{0.1 + 0.01 R/t}} \quad \text{for } R/t > 212 \quad (29b)$$

(a) This buckling capacity factor, α_0 , corresponds to a cylinder subjected to axial compression with no net internal radial pressure. The influence of a net internal radial pressure acting on the cylindrical walls is expressed with the aid of a dimensionless parameter, ρ , defined by eq. (30).

$$\rho = \frac{p}{E} \left(\frac{R}{t} \right)^2 \quad (30)$$

(b) A value of the buckling capacity reduction factor that acknowledges the benefit of a net internal radial pressure, α_p , is determined from eq. (31).

$$\alpha_p = \alpha_o + (1 - \alpha_o) \frac{\rho}{\rho + 0.007} \quad (31)$$

(c) For the purpose of establishing the allowable axial compressive stress at any location on the cylindrical wall, the value of the net internal radial pressure that exists at that location, coincident with the compressive stress, shall be used to establish ρ and hence α_p . When more than one value of net internal pressure may accompany a given axial stress, it shall be demonstrated that the controlling combination of internal pressure and axial stress has been established. This is accomplished by implementing the procedures established in this subsubarticle using both the minimum and the maximum values of the net internal pressures that may exist for the condition being evaluated.

(d) The classical linear elastic buckling stress for a cylinder of perfect geometry subjected to compressive axial loads is given by eq. (32).

$$\sigma_{cl} = \frac{E}{\sqrt{3} (1 - \nu^2)} \left(\frac{t}{R} \right) \quad (32)$$

(e) The hoop tensile stress from internal pressure that accompanies the axial compressive stress shall be established from membrane theory in accordance with eq. (33).

$$\sigma_h = p \frac{R}{t} \quad (33)$$

(f) Here the value of the net internal radial pressure acting on the wall, p , shall be the same as that used to compute ρ in eq. (a)(30). Hoop tensile stress is considered positive.

(g) With the values of the parameters established above, the required quantity $\sigma_{a,u}$ is one of four unknowns ($\sigma_{a,u}$, σ_{eff} , β , and λ_p) in the four simultaneous equations given as eqs. (34), (35), (36), (37a), and (37b).

$$\sigma_{eff} = \sqrt{\sigma_{a,u}^2 + \sigma_h^2 + \sigma_{a,u}\sigma_h} \quad (34)$$

$$\beta = \frac{\sigma_{a,u}}{\sigma_{eff}} \quad (35)$$

$$\lambda_p = \sqrt{\frac{\beta S_y}{\alpha_p \sigma_{cl}}} \quad (36)$$

$$\frac{\sigma_{eff}}{S_y} = \frac{0.75}{\lambda_p^2} \text{ for } \lambda_p \geq 1.414 \quad (37a)$$

$$\frac{\sigma_{eff}}{S_y} = (1.0 - 0.4123\lambda_p^{1,2}) \text{ for } \lambda_p < 1.414 \quad (37b)$$

(h) When the hoop stress is zero, these equations can be solved explicitly for $\sigma_{a,u}$. In the more general case, a method such as outlined in ND-3944 must be used.

ND-3944 Allowable Axial Membrane Compressive Stresses

Any method of solving the system of equations given in ND-3943 is satisfactory. Provided herein is one acceptable method. Note that eq. ND-3943(g)(34) can be rearranged as shown in eq. (38).

$$\sigma_{a,u} = \sqrt{(\sigma_{eff}^2 - 0.75 \sigma_h^2)} - 0.5 \sigma_h \quad (38)$$

(a) The algorithm proceeds as follows:

Step 1. Compute parameters α_o , ρ , α_p , σ_{cl} , and σ_h for the set of conditions being evaluated.

Step 2. Estimate a value of β [note eq. ND-3943(g)(35)] and call the value β' .

Step 3. Compute λ_p from eq. ND-3943(g)(36) using β' for β .

Step 4. Compute σ_{eff} from eqs. ND-3943(g)(37a) and ND-3943(g)(37b).

Step 5. Compute $\sigma_{a,u}$ from eq. (38).

Step 6. Compute β from eq. ND-3943(g)(35).

Step 7. Compare the computed value of β (Step 6) with the estimated value of β' . If the computed value of β is close to the estimated value of β' (i.e., within $\pm 2\%$), note the value of $\sigma_{a,u}$ obtained from Step 5 for use as described below. If not, select a revised β estimate, β' , and return to Step 3.

(b) The allowable value of the axial compressive membrane stress, $\sigma_{a,allow}$, shall be established from eq. (39).

$$\sigma_{a,allow} = \frac{\sigma_{a,u}}{DF} \quad (39)$$

(c) In eq. (b)(39), the minimum values of the design factors against buckling, DF, are provided in ND-3945 for the different service levels.

(d) As an alternative to solving the equations of ND-3943 by methods as described above, the plotted curves provided in Figs. ND-3944-1 through ND-3944-6 (ND-3944-1M through ND-3944-6M) may be used for ferrous materials of various yield strengths at temperatures not exceeding 300°F (150°C).

These curves establish the allowable axial membrane compressive stress at a location on the tank wall where the net internal radial pressure is equal to or greater than zero. Linear interpolation between the curves is permitted. To establish the allowable axial membrane compressive stress for a given service level, the value read from the ordinate of the curve shall be divided by the appropriate design factor, DF, consistent with the service level assigned by the design specification to the loading combination being evaluated. The value of S_y shall be the

yield strength of the material at the corresponding temperature, obtained from Table Y-1, of Section II, Part D, Subpart 1.

The value of ρ [see eq. ND-3943(a)(30)] shall be computed from the pressure at the location of interest and under the same loading conditions as those that produce the axial membrane compressive stress being evaluated.

Note that the tabular representation of the data in Figs. ND-3944-1 through ND-3944-6 (ND-3944-1M through ND-3944-6M) are for ferrous materials at temperatures equal to or less than 300°F (150°C). Other Code temperature limits may also apply.

ND-3945 Axial Compressive Stress Design Factors

The design factors, DF, for use in establishing the allowable values of axial membrane compressive stress with eq. ND-3944(b)(39) shall be as follows:

Service Level	Design Factors, DF
A	2
B	2
C	$\frac{5}{3}$
D	$\frac{4}{3}$

ND-3946 Corresponding Allowable Hoop Membrane Stresses

When the allowable axial membrane compressive stress is established by the use of this subsubarticle, the requirements of this paragraph, expressed in eqs. (40a) through (40d), shall also be satisfied. The hoop membrane stress may be computed by use of eq. ND-3943(e)(33), or results from more detailed stress analyses may be used, but the largest value of coincident pressure shall be considered for each value of corresponding axial stress. For designs qualified by use of this subsubarticle, the requirements

of eqs. (40a) through (40d) shall also apply for those situations where the cylindrical wall is in a state of hoop membrane compression in combination with axial membrane tension. With the value of S established from the appropriate Table 1A, or Table 1B from Section II, Part D, Subpart 1, the following requirements expressed as eqs. (40a), (40b), (40c), and (40d) shall be satisfied:

$$|\sigma_a| + |\sigma_h| \leq 1.0 S, \text{ for Service Level A} \quad (40a)$$

$$|\sigma_a| + |\sigma_h| \leq 1.1 S, \text{ for Service Level B} \quad (40b)$$

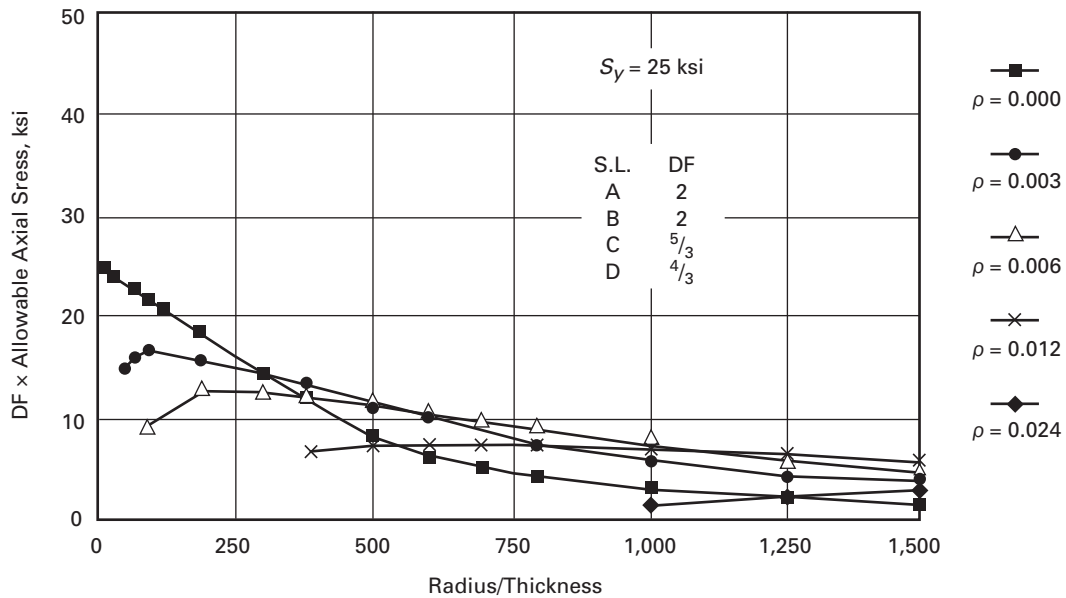
$$|\sigma_a| + |\sigma_h| \leq 1.5 S, \text{ for Service Level C} \quad (40c)$$

$$|\sigma_a| + |\sigma_h| \leq 2.0 S, \text{ for Service Level D} \quad (40d)$$

ND-3947 Construction Tolerances

In addition to the applicable requirements established in ND-4220, a tolerance shall apply on bulges or flat spots in the cylindrical walls that result from vertical elements of the cylinder being other than straight lines. This tolerance is expressed in terms of the quantities illustrated in Fig. ND-3947-1. A straight rod is to be positioned either inside or outside the tank, as appropriate, for the deviation being evaluated. The length of the rod, L_x , shall be $4\sqrt{Rt} \pm 10\%$. The amplitude of the deviation, Δ_x , shall not exceed 1% of L_x . These tolerance requirements, which are in addition to those given in ND-4220, apply only to regions of the cylindrical walls where allowable compressive stresses are established by the rules of this subsubarticle.

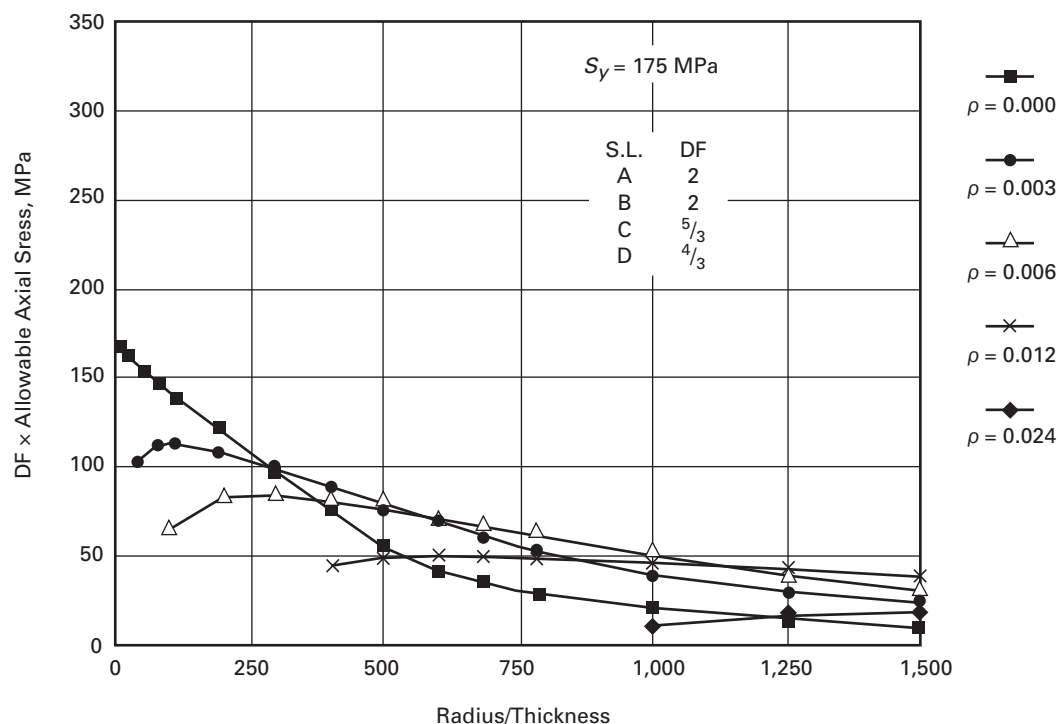
Figure ND-3944-1
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 25 ksi at Temperatures $\leq 300^{\circ}\text{F}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	24.05	...	...	...	...
25	23.30	...	...	...	...
50	22.28	14.72	...	...	...
75	21.36	15.83	...	...	...
100	20.50	16.17	9.16	...	...
200	17.29	15.60	11.96	...	...
300	14.01	14.21	12.07	...	...
400	10.79	12.73	11.56	6.27	...
500	7.88	11.30	10.87	6.97	...
600	6.00	9.94	10.11	7.23	...
700	4.77	8.67	9.34	7.26	...
800	3.91	7.50	8.60	7.16	...
1,000	2.80	5.77	7.23	6.76	1.53
1,250	2.01	4.45	5.77	6.13	2.42
1,500	1.53	3.61	4.73	5.48	2.87

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

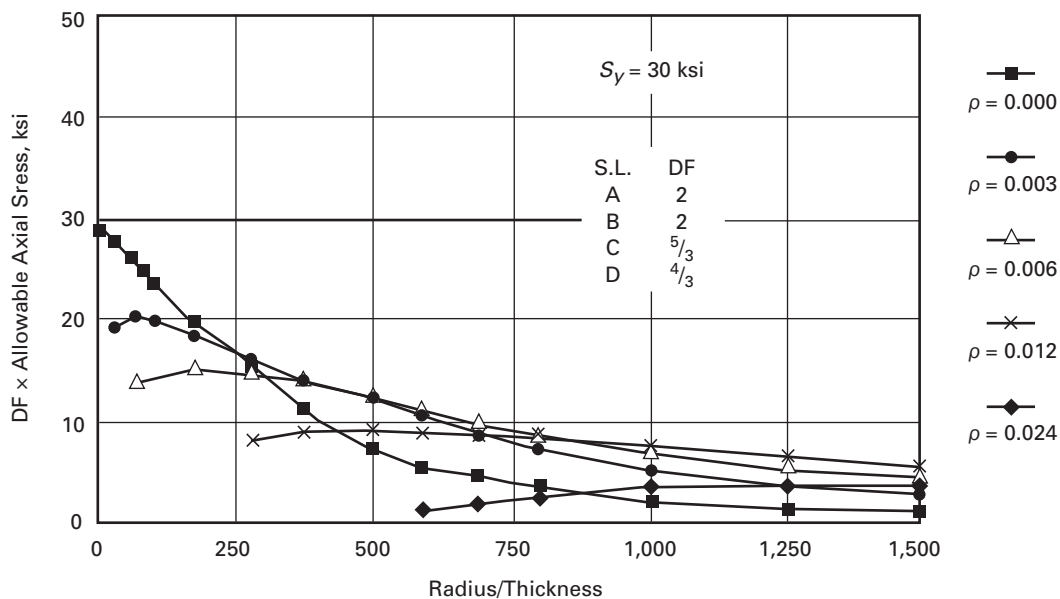
Figure ND-3944-1M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 175 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	165.825	...	...	...	...
25	160.654	...	...	...	...
50	153.621	101.494	...	...	...
75	147.277	109.148	...	...	...
100	141.348	111.492	63.158	...	...
200	119.215	107.562	82.464	...	...
300	96.599	97.978	83.223	...	...
400	74.397	87.773	79.706	43.232	...
500	54.333	77.914	74.949	48.058	...
600	41.370	68.536	69.708	49.851	...
700	32.889	59.780	64.399	50.058	...
800	26.959	51.713	59.297	49.368	...
1,000	19.306	39.784	49.851	46.610	10.549
1,250	13.859	30.683	39.784	42.266	16.686
1,500	10.549	24.891	32.613	37.785	19.789

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

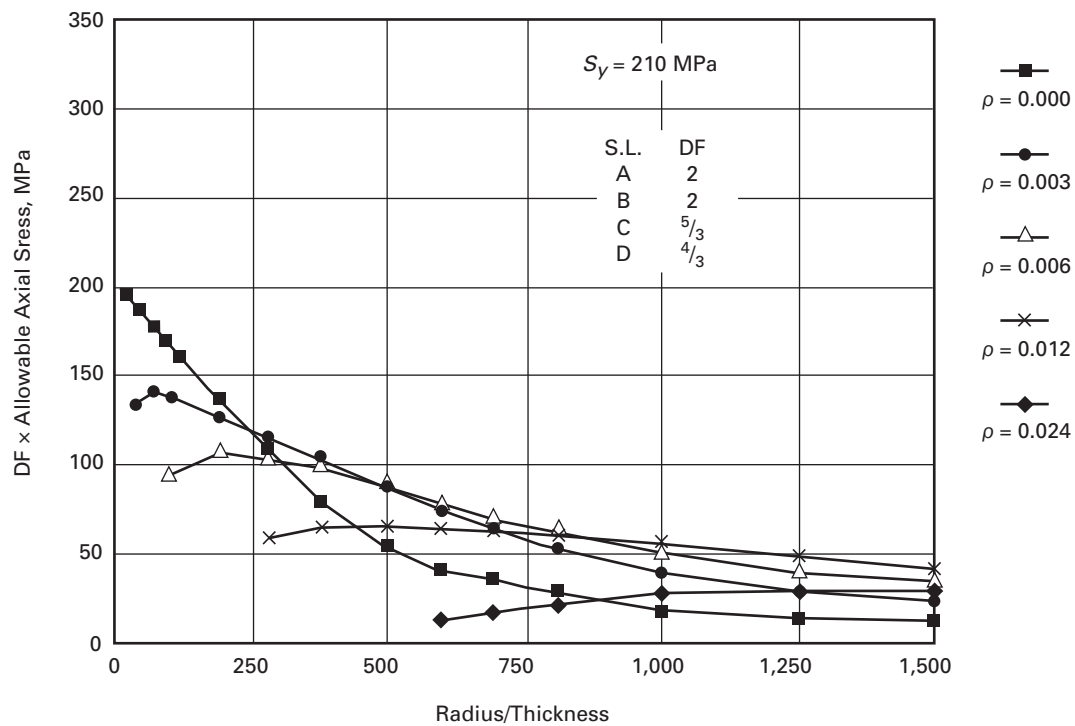
Figure ND-3944-2
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 30 ksi at Temperatures $\leq 300^{\circ}\text{F}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	28.73	...	...	...	...
25	27.72	...	...	...	...
50	26.35	19.31	...	...	...
75	25.13	20.02	...	...	...
100	23.97	20.06	13.82	...	...
200	19.69	18.59	15.47	...	...
300	15.28	16.45	14.84	8.55	...
400	10.98	14.32	13.76	9.47	...
500	7.88	12.31	12.57	9.64	...
600	6.00	10.45	11.39	9.49	1.07
700	4.77	8.79	10.27	9.17	2.14
800	3.91	7.50	9.22	8.77	2.92
1,000	2.80	5.77	7.37	7.88	3.82
1,250	2.01	4.45	5.77	6.80	4.28
1,500	1.53	3.61	4.73	5.48	4.36

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

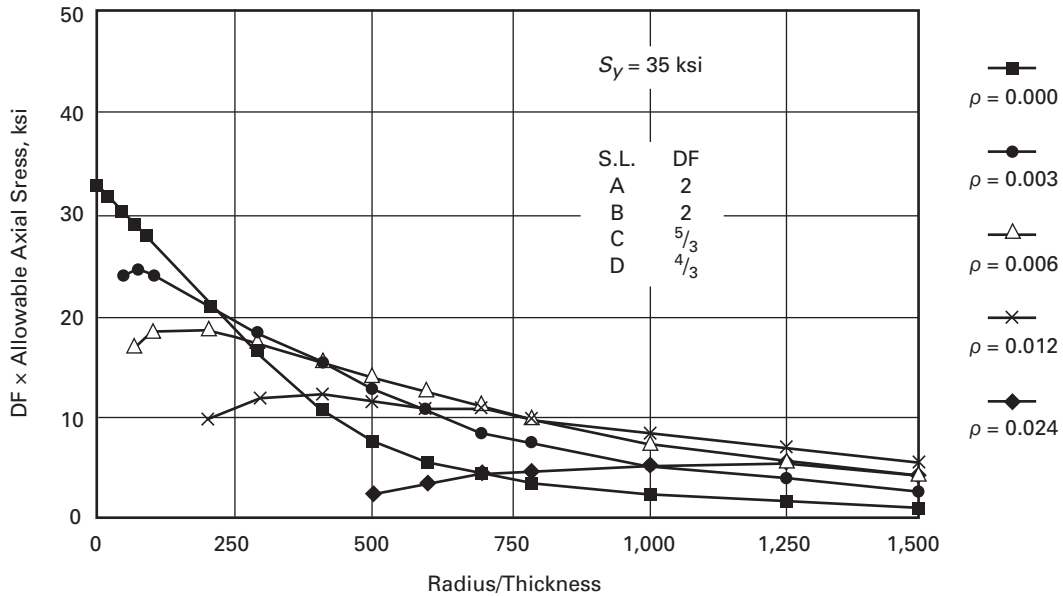
Figure ND-3944-2M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 210 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	198.093	...	...	...	...
25	191.129	...	...	...	...
50	181.683	133.142	...	...	...
75	173.271	138.038	...	...	...
100	165.273	138.314	95.289	...	...
200	135.763	128.178	106.666	...	...
300	105.356	113.423	102.322	58.952	...
400	75.707	98.736	94.875	65.296	...
500	54.333	84.877	86.670	66.468	...
600	41.370	72.053	78.534	65.434	7.378
700	32.889	60.607	70.812	63.227	14.755
800	26.959	51.713	63.572	60.469	20.133
1,000	19.306	39.784	50.816	54.333	26.339
1,250	13.859	30.683	39.784	46.886	29.511
1,500	10.549	24.891	32.613	37.785	30.062

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

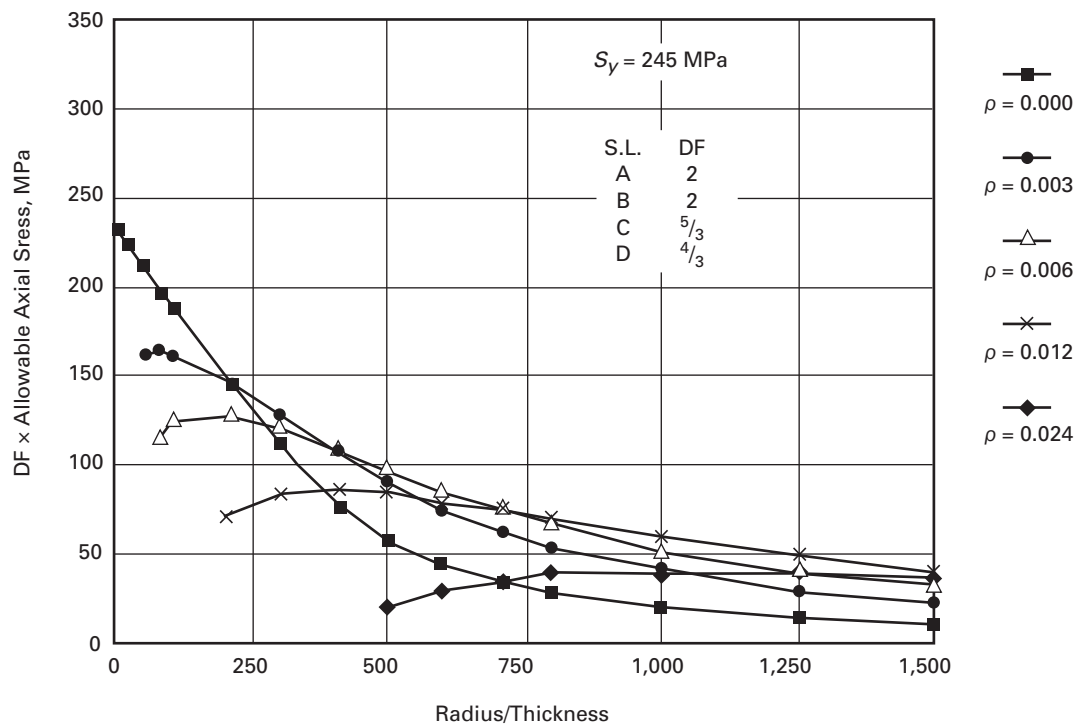
Figure ND-3944-3
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 35 ksi at Temperatures $\leq 300^{\circ}\text{F}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	33.38	...	...	...	...
25	32.08	...	...	...	...
50	30.33	23.68	...	...	...
75	28.77	24.02	16.71	...	...
100	27.29	23.76	18.08	...	...
200	21.80	21.32	18.65	9.98	...
300	16.17	18.36	17.27	11.90	...
400	10.98	15.52	15.57	12.16	...
500	7.88	12.91	13.88	11.84	2.54
600	6.00	10.56	12.27	11.27	3.91
700	4.77	8.79	10.78	10.61	4.76
800	3.91	7.50	9.43	9.91	5.26
1,000	2.80	5.77	7.37	8.57	5.69
1,250	2.01	4.45	5.77	7.11	5.67
1,500	1.53	3.61	4.73	5.91	5.40

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

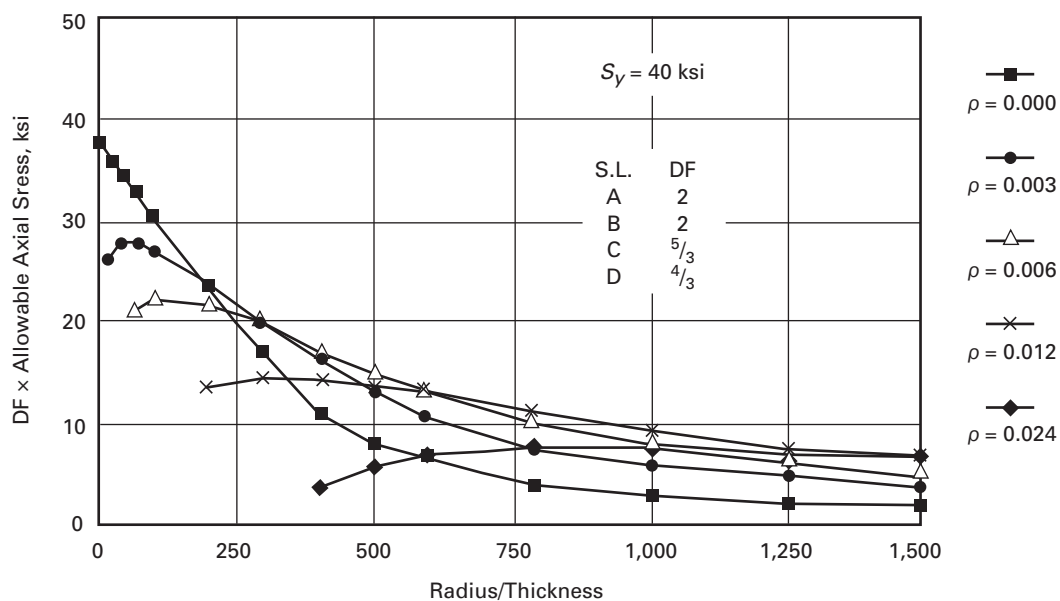
Figure ND-3944-3M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 245 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	230.155	...	...	...	...
25	221.192	...	...	...	...
50	209.125	163.274	...	...	...
75	198.369	165.618	115.215	...	...
100	188.165	163.825	124.662	...	...
200	150.311	147.001	128.592	68.812	...
300	111.492	126.592	119.077	82.051	...
400	75.707	107.010	107.355	83.843	...
500	54.333	89.014	95.703	81.637	17.513
600	41.370	72.811	84.602	77.707	26.959
700	32.889	60.607	74.328	73.156	32.820
800	26.959	51.713	65.020	68.329	36.268
1,000	19.306	39.784	50.816	59.090	39.233
1,250	13.859	30.683	39.784	49.023	39.095
1,500	10.549	24.891	32.613	40.749	37.233

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

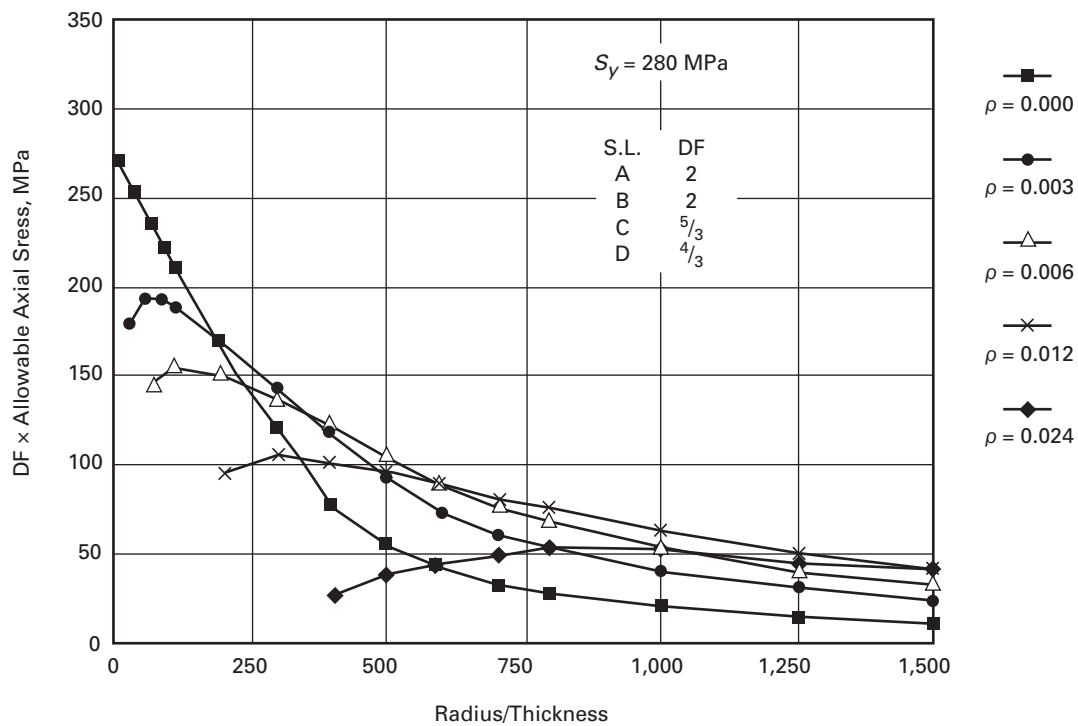
Figure ND-3944-4
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 40 ksi at Temperatures $\leq 300^{\circ}\text{F}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	38.00	...	...	...	...
25	36.39	25.91	...	...	...
50	34.22	27.90	...	...	...
75	32.28	27.86	21.10	...	...
100	30.45	27.28	22.06	...	...
200	23.66	23.82	21.56	13.80	...
300	16.68	19.98	19.40	14.83	...
400	10.98	16.38	17.06	14.46	3.62
500	7.88	13.14	14.83	13.64	5.53
600	6.00	10.56	12.78	12.67	6.49
700	4.77	8.79	10.95	11.67	6.99
800	3.91	7.50	9.44	10.70	7.20
1,000	2.80	5.77	7.37	8.94	7.14
1,250	2.01	4.45	5.77	7.16	6.68
1,500	1.53	3.61	4.73	5.91	6.10

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

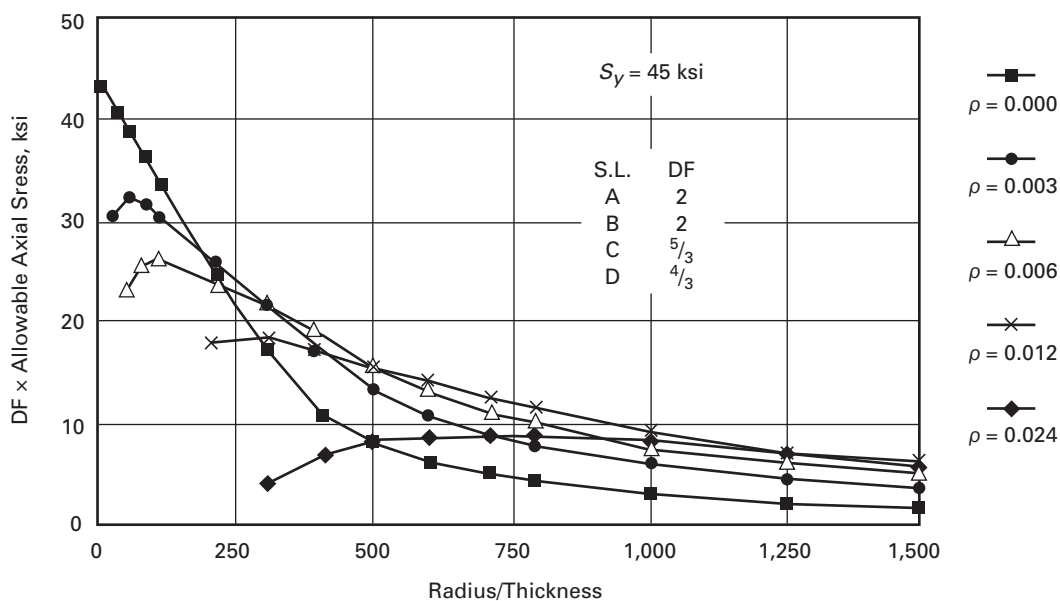
Figure ND-3944-4M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 280 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	262.010	...	...	...	...
25	250.909	178.649	...	...	...
50	235.947	192.371	...	...	...
75	222.571	192.095	145.485	...	...
100	209.953	188.096	152.104	...	...
200	163.136	164.239	148.656	95.151	...
300	115.009	137.762	133.763	102.253	...
400	75.707	112.940	117.629	99.702	24.960
500	54.333	90.600	102.253	94.048	38.129
600	41.370	72.811	88.118	87.360	44.749
700	32.889	60.607	75.500	80.465	48.196
800	26.959	51.713	65.089	73.777	49.644
1,000	19.306	39.784	50.816	61.641	49.230
1,250	13.859	30.683	39.784	49.368	46.059
1,500	10.549	24.891	32.613	40.749	42.060

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

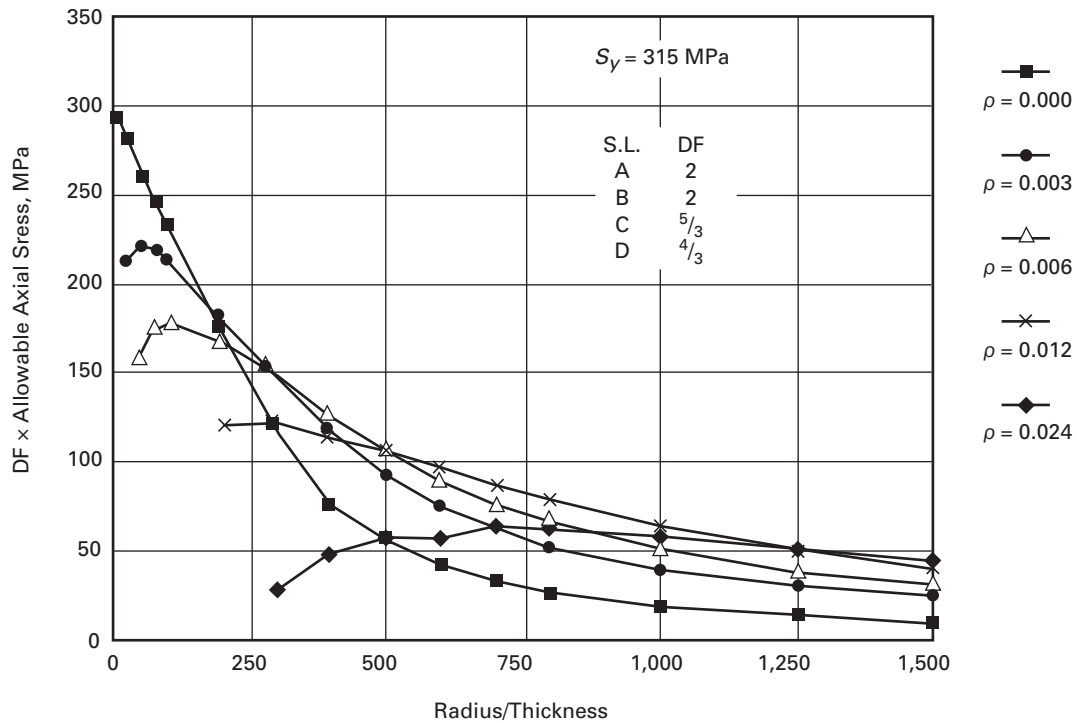
Figure ND-3944-5
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 45 ksi at Temperatures $\leq 300^{\circ}\text{F}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	42.58	...	...	...	...
25	40.64	30.56	...	...	...
50	38.02	32.00	23.10	...	...
75	35.68	31.56	25.24	...	...
100	33.47	30.66	25.81	...	...
200	25.27	26.11	24.24	17.26	...
300	16.84	21.32	21.25	17.43	3.73
400	10.98	16.93	18.25	16.43	6.76
500	7.88	13.14	15.48	15.12	8.13
600	6.00	10.56	13.00	13.74	8.13
700	4.77	8.79	10.95	12.41	8.85
800	3.91	7.50	9.44	11.18	8.76
1,000	2.80	5.77	7.37	9.06	8.24
1,250	2.01	4.45	5.77	7.16	7.39
1,500	1.53	3.61	4.73	5.91	6.54

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

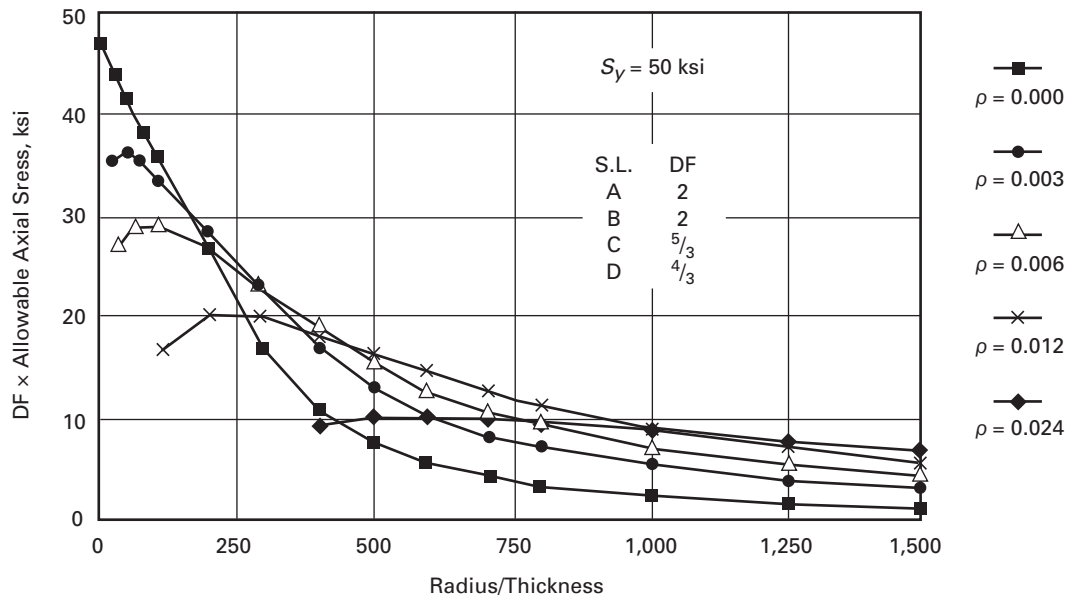
Figure ND-3944-5M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for
Ferrous Materials With Yield Strengths of 315 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values					
R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	293.589	...	...	...	...
25	280.213	210.711	...	...	...
50	262.148	220.640	159.275	...	...
75	246.014	217.606	174.030	...	...
100	230.776	211.401	177.960	...	...
200	174.237	180.028	167.135	119.008	...
300	116.112	147.001	146.519	120.180	25.718
400	75.707	116.732	125.834	113.285	46.610
500	54.333	90.600	106.735	104.252	56.056
600	41.370	72.811	89.635	94.737	56.056
700	32.889	60.607	75.500	85.567	61.021
800	26.959	51.713	65.089	77.086	60.400
1,000	19.306	39.784	50.816	62.469	56.815
1,250	13.859	30.683	39.784	49.368	50.954
1,500	10.549	24.891	32.613	40.749	45.093

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

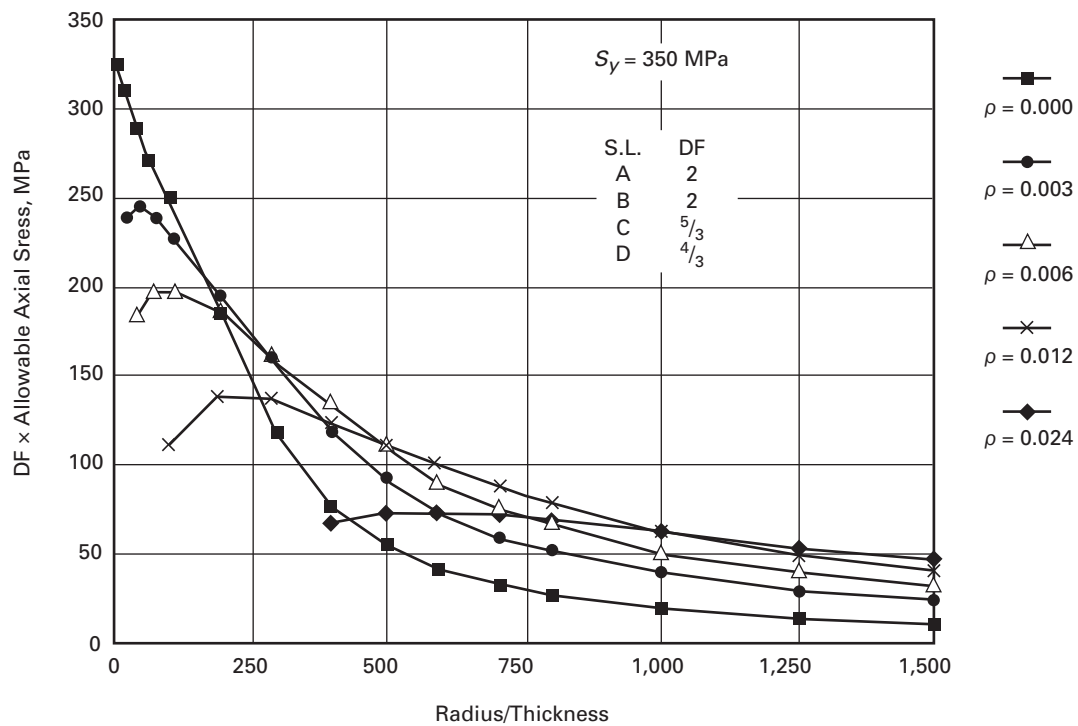
Figure ND-3944-6
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 50 ksi at Temperatures $\leq 300^{\circ}\text{F}$



R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	47.14	...	...	...	...
25	44.84	35.09	...	...	...
50	41.74	35.98	27.58	...	...
75	38.97	35.15	29.20	...	...
100	36.35	33.89	29.39	16.19	...
200	26.64	28.19	26.71	20.42	...
300	16.84	22.41	22.87	19.74	...
400	10.98	17.19	19.17	18.12	9.56
500	7.88	13.14	15.85	16.30	10.42
600	6.00	10.56	13.01	14.53	10.57
700	4.77	8.79	10.95	12.89	10.38
800	3.91	7.50	9.44	11.42	10.01
1,000	2.80	5.77	7.37	9.06	9.06
1,250	2.01	4.45	5.77	7.16	7.86
1,500	1.53	3.61	4.73	5.91	6.79

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 300^{\circ}\text{F}$; other code temperature limits may also apply.

Figure ND-3944-6M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 350 MPa at Temperatures $\leq 150^{\circ}\text{C}$



Tabular Values

R/t	$\rho = 0.000$	$\rho = 0.003$	$\rho = 0.006$	$\rho = 0.012$	$\rho = 0.024$
10	325.030	...	...	...	...
25	309.172	241.946	...	...	...
50	287.797	248.082	190.164	...	...
75	268.698	242.359	201.334	...	...
100	250.633	233.672	202.644	111.630	...
200	183.683	194.370	184.165	140.796	...
300	116.112	154.517	157.689	136.107	...
400	75.707	118.525	132.177	124.937	65.916
500	54.333	90.600	109.286	112.389	71.846
600	41.370	72.811	89.704	100.184	72.880
700	32.889	60.607	75.500	88.877	71.570
800	26.959	51.713	65.089	78.741	69.019
1,000	19.306	39.784	50.816	62.469	62.469
1,250	13.859	30.683	39.784	49.368	54.195
1,500	10.549	24.891	32.613	40.749	46.817

GENERAL NOTE: Curves are for ferrous materials, temperature $\leq 150^{\circ}\text{C}$; other code temperature limits may also apply.

ARTICLE ND-4000 FABRICATION AND INSTALLATION

ND-4100 GENERAL REQUIREMENTS

ND-4110 INTRODUCTION

(a) Components, parts, and appurtenances shall be fabricated and installed in accordance with the rules of this Article and shall be manufactured from materials that meet the requirements of [ND-2000](#).

(b) Atmospheric and 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks shall be fabricated in accordance with the rules of this Article.

ND-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

ND-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with NCA-8000, that the material used complies with the requirements of [ND-2000](#) and that the fabrication or installation complies with the requirements of this Article.

ND-4121.1 Certification of Treatments, Tests, and Examinations. If a Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

ND-4121.2 Repetition of Tensile or Impact Tests. If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons ([ND-2200](#)) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of [ND-2000](#).

ND-4121.3 Repetition of Surface Examination After Machining. During the fabrication or installation of an item if materials for pressure containing parts are machined, the Certificate Holder shall reexamine the surface of the material in accordance with [ND-2500](#) when

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with [ND-2500](#); and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3 mm) or 10% of the minimum required thickness of the part.

ND-4122 Material Identification

(a) Material for pressure retaining parts shall carry identification markings that will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the same marks shall either be transferred to the parts cut or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding and brazing material, shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed which ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked upon establishing positive identification.

ND-4122.1 Marking Material. Material shall be marked in accordance with [ND-2150](#).

ND-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of [ND-4000](#), may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to [ND-5100](#) and [ND-5500](#), respectively, unless so specified.

ND-4125 Testing of Welding and Brazing Material

All welding and brazing material shall meet the requirements of ND-2400.

ND-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of ND-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of ND-2500 for the applicable product form, except that

(a) the limitation on the depth of the weld repair does not apply; and

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with ND-5120;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less;

(d) radiographic examination is not required for welded repairs in material used in components, provided that the welded joints in these materials are not required to be radiographed, the extent of the welded repair does not exceed 10 in.² (6 500 mm²) of the surface area, and the magnetic particle or liquid penetrant examination of the repair is made as required by ND-2539.4.

ND-4200 FORMING, FITTING, AND ALIGNING

ND-4210 CUTTING, FORMING, AND BENDING

ND-4211 Cutting

Materials may be cut to shape and size by mechanical means such as machining, shearing, chipping, or grinding, or by thermal cutting.

ND-4211.1 Preheating Before Thermal Cutting. When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

ND-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure retaining material, including weld metal, provided the required dimensions are attained (see ND-4214 and ND-4220), and provided the impact properties of the materials, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties

as outlined in ND-4213. When required, the process shall be qualified to meet thickness requirements as outlined in ND-4223.1.

ND-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications a procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of ND-2300 are met after straining.

ND-4213.1 Exemptions. Procedure qualification tests are not required for materials listed in (a) through (f) below:

(a) hot formed material, such as forging, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material which does not require impacts in accordance with ND-2300;

(d) material which has a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing required by ND-2300 is performed on each heat and lot, as applicable, after forming.

ND-4213.2 Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of ND-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

For cylinders

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

R = nominal bending radius to the center line of the pipe
 r = nominal radius of the pipe
 R_f = final radius to center line of shell
 R_o = original radius (equal to infinity for a flat part)
 t = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient Charpy V-notch test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both the lateral expansion and energy level data (ND-2300). In addition, drop weight tests shall be made when required by ND-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either of (1) or (2) below:

(1) the maximum change in NDT temperature along with

(-a) the maximum change of lateral expansion and energy at the temperature under consideration, or

(-b) the maximum change in temperature at the lateral expansion and energy levels under consideration; or

(2) where lateral expansion is the acceptance criteria (ND-2300), either the maximum change in temperature or the maximum change in lateral expansion.

ND-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

ND-4213.4 Requalification. A new procedure qualification test is required when any of the following changes in (a), (b), or (c) below are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified considering ND-2211; if the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment;

(b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;

(c) where preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

ND-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of ND-2124 and ND-3000, the material may be repaired in accordance with ND-4130.

ND-4220 FORMING TOLERANCES

ND-4221 Tolerance for Vessel Shells

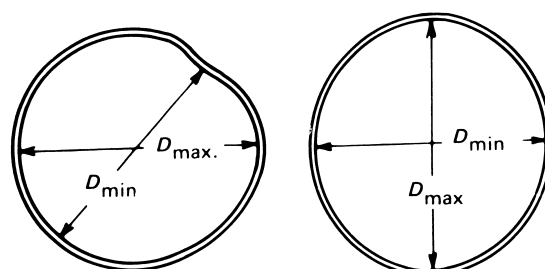
Cylindrical, conical, or spherical shells of a completed vessel except formed heads covered by ND-4222 shall meet the requirements of the following subparagraphs at all cross sections.

ND-4221.1 Maximum Difference in Cross-Sectional Diameters. The difference in inches (mm) between the maximum and minimum diameters at any cross section shall not exceed the smaller of $(D + 50)/200$ [$(D + 1250)/200$] and $D/100$, where D is the nominal inside diameter in inches (mm) at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Figure ND-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening. For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

ND-4221.2 Maximum Deviation From True Theoretical Form for External Pressure. Vessels designed for external pressure shall meet the following tolerances:

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible

Figure ND-4221.1-1
Maximum Difference in Cross-Sectional Diameters



deviation obtained from Figure ND-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Figure ND-4221.2(a)-2. For Figure ND-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Figure ND-4221.2(a)-2, the arc length need not be greater than $0.3D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t in inches (mm) at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness. For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is $(t + e)$.

(c) The value of L in Figures ND-4221.2(a)-1 and ND-4221.2(a)-2 is determined by (1) through (3) below.

(1) For cylinders, L is as given in ND-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o , in. (mm).

(d) The dimensions of a completed vessel may be brought within the requirements by any process that will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

ND-4221.3 Deviations From Tolerances. Deviations from the tolerance requirements stipulated in ND-4221.1 and ND-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

Figure ND-4221.2(a)-1
Maximum Permissible Deviation e From a True Circular Form

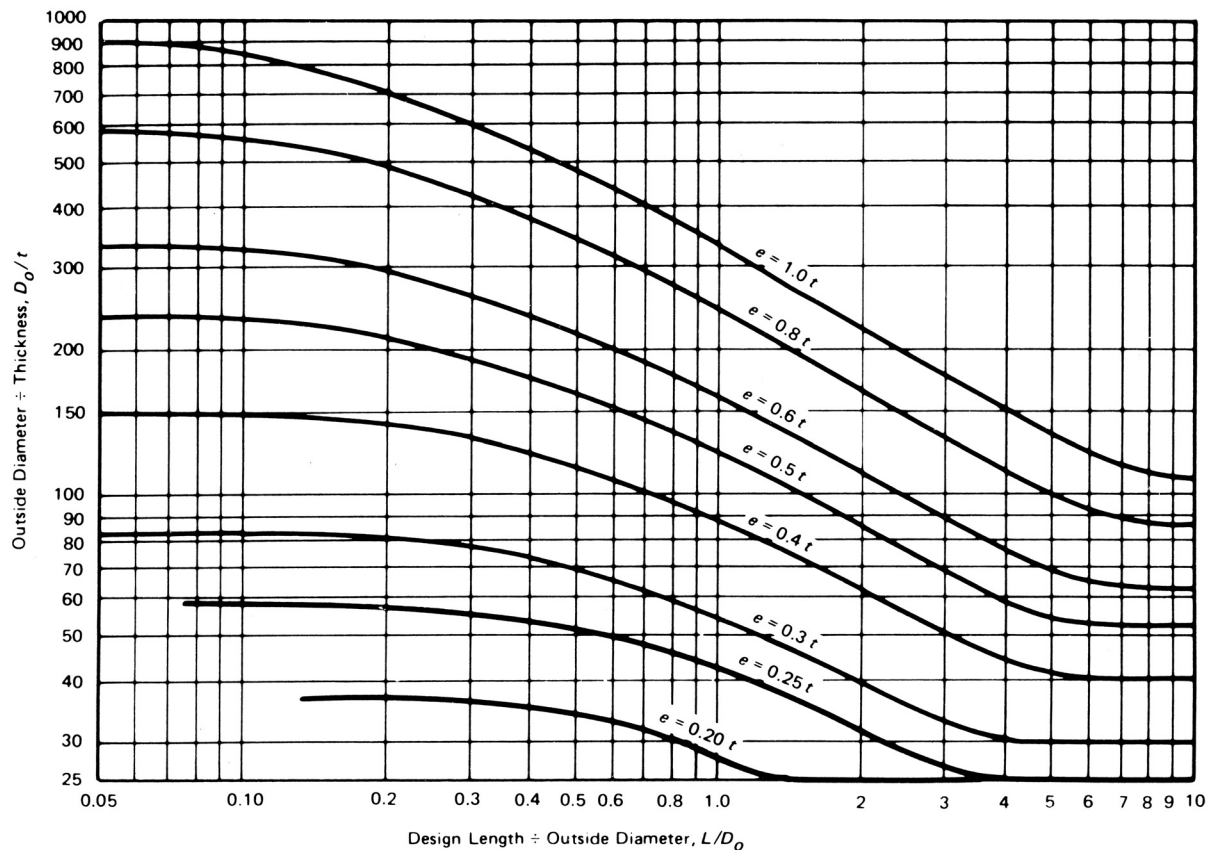
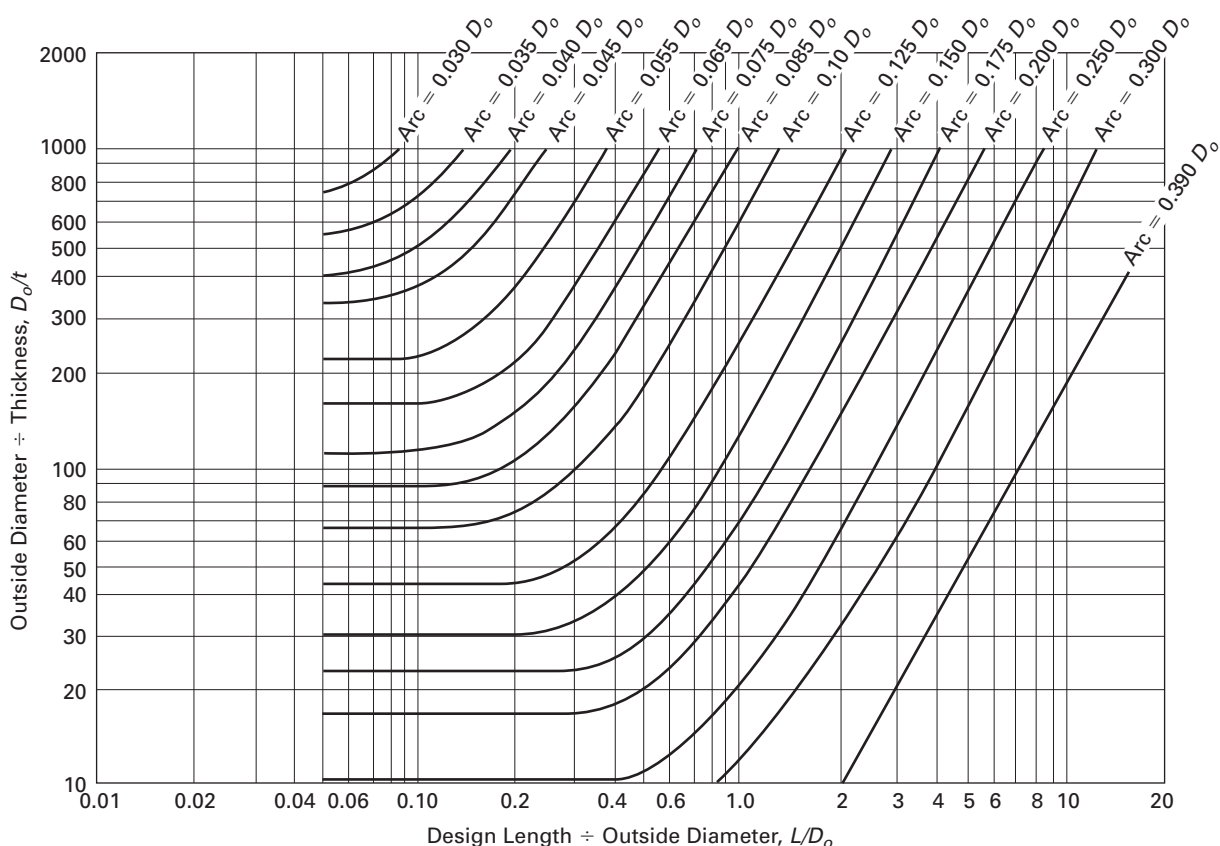


Figure ND-4221.2(a)-2
Maximum Arc Length for Determining Plus or Minus Deviation



ND-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe. Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

(U.S. Customary Units)

$$\frac{D + 50}{200} \text{ and } \frac{D + 12}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \text{ and } \frac{D + 300}{100}$$

ND-4221.5 Localized Thin Areas. Localized thin areas are permitted if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in [ND-3330](#).

where D is the nominal inside diameter in inches (mm) and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in [ND-4232](#).

ND-4222 Tolerances for Formed Vessel Heads

The tolerances for formed vessel heads shall be as set forth in the following subparagraphs.

ND-4222.1 Maximum Difference in Cross-Sectional Diameters. The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches (mm) between the maximum and minimum diameters does not exceed the lesser of

ND-4222.2 Deviation From Specified Shape.

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , nor inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in ND-4221.2, using L as the outside spherical radius in inches (mm) and D_o as two times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

ND-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

ND-4223.1 Minimum Wall Thickness.

(a) In order to assure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

(b) As an alternative to (a) above, the requirements of Table ND-3642.1(c)-1 shall be followed.

ND-4223.2 Ovality Tolerance. Unless otherwise justified by the design calculations, the ovality of piping after bending shall not exceed 8% as determined by

$$100 \times (D_{\max} - D_{\min}) / D_o$$

where

D_{\max} = the maximum outside diameter after bending or forming

D_{\min} = the minimum outside diameter after bending or forming

D_o = the nominal pipe outside diameter

ND-4224 Tolerances for Storage Tanks

The horizontal circular cross section of storage tanks shall be sufficiently true to round so that the difference between the maximum and minimum diameters measured inside or outside at any section in a cylindrical wall shall not exceed 1% of the average diameter or 12 in. (300 mm), whichever is less, measured 6 ft (2 m) or one plate width from the top or bottom juncture, respectively, if these junctures are of a type that offers serious restraint when the tank is filled or under the specified maximum vapor pressure. At any section in a sidewall having double curvature, this difference in diameter shall not exceed $\frac{1}{2}\%$ of the average diameter or 6 in. (150 mm), whichever is less.

ND-4224.1 Maximum Difference in Cross-Sectional Diameters for Tanks of Double Curvature. For tanks of double curvature, the meridian curvature of the plate surface shall not deviate from the design shape by more than $\frac{1}{2}\%$ of the radius, measured radially, and shall not show abrupt changes. Plate surfaces shall merge smoothly into the adjoining surfaces in all directions. Local inward deviations, such as flat spots, shall be limited by ND-4224.2.

ND-4224.2 Local Inward Deviations. Local inward deviations, such as flat spots, if present on wall or bottom surfaces having double curvature, shall not be greater than the plate thickness and shall not have a diameter d greater than $\sqrt{8Rt}$, where R is the radius of the tank and t is the thickness of the plate involved. R shall be taken as R_1 , with d being the chord in a meridional direction, and as R_2 , with d being the chord in a latitudinal direction.

ND-4224.3 Tolerance Measurements. The tolerance measurements are given for a tank while empty and shall be taken with a steel tape, making corrections for temperature, sag, and wind.

ND-4230 FITTING AND ALIGNING

ND-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

ND-4231.1 Tack Welds. Tack welds used to secure alignment either shall be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

ND-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections that are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table ND-4232(a)-1, where t is the nominal thickness of the thinner section at the joint.

**Table ND-4232(a)-1
Maximum Allowable Offset in Final Welded Joints**

Section Thickness, in. (mm)	Direction of Joints	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$ (13), incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$ (13 to 19), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{8}t$
Over 2 (50)	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in. (10 mm)	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in. (19 mm)

(b) Joints in spherical vessels and joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table ND-4232(a)-1 for longitudinal joints.

ND-4232.1 Fairing of Offsets. Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

ND-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with ND-4232, alignment of sections shall meet the requirements of (1) and (2) below.

(1)

(-a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result as shown in Figure ND-4233-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $\frac{3}{32}$ in. (2.5 mm) as shown in Figure ND-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations that do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of ND-4250 are met.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $\frac{3}{32}$ in. (2.5 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of ND-4232.

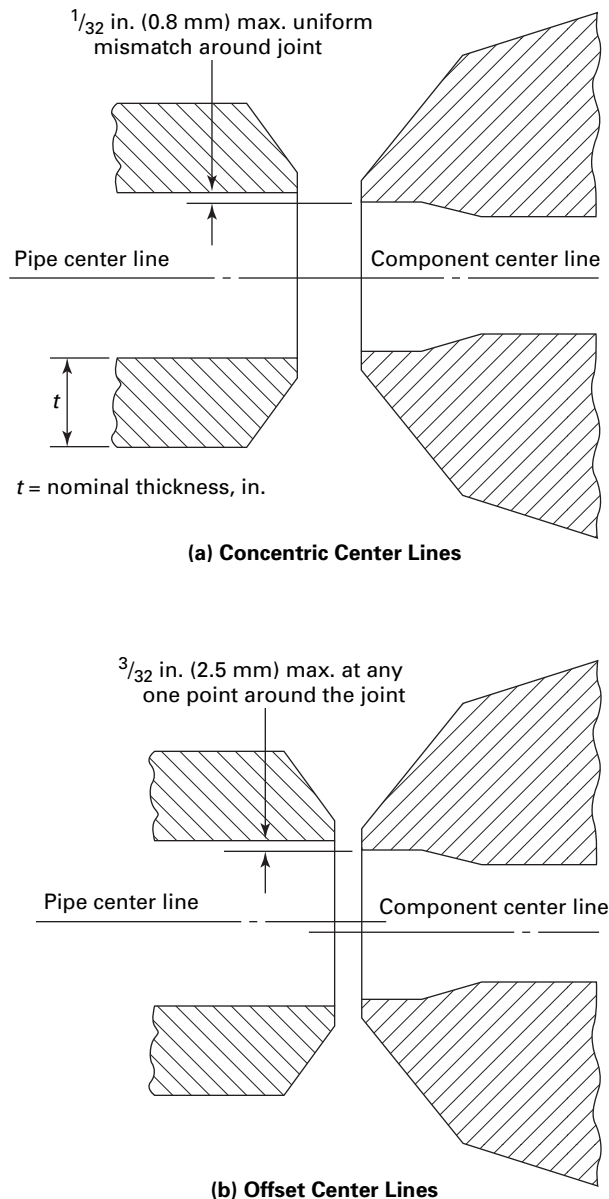
ND-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS⁵³

ND-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

All Category A weld joints in vessels and longitudinal weld joints in other components shall meet the requirements of (a), (b), and (c) below.

(a) When the design is based on a joint efficiency permitted by ND-3352.1(a) or ND-3352.1(b), all Category A welds in vessels and longitudinal joints in other components shall be Type 1 or Type 2 as described in ND-4245.

Figure ND-4233-1
Butt Weld Alignment and Mismatch Tolerances
for Unequal I.D. and O.D. When Components Are
Welded From One Side and Fairing Is Not
Performed



GENERAL NOTE: The weld end transitions are typical and are not intended as requirements. Refer to ND-4250 for weld end transition requirements.

(b) When the design is based on a joint efficiency permitted by ND-3352.1(c), any joint Type as described in ND-4245 may be used, provided the limitations of the joint are followed.

(c) When the component is constructed of P-No. 11A, Group 1 material, Type 1 joints as described in [ND-4245](#) shall be used.

ND-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall meet the requirements of (a) and (b) below, except that piping NPS 2 (DN 50) and smaller may be socket welded.

(a) When the design is based on a joint efficiency permitted by [ND-3352.1\(a\)](#) or [ND-3352.1\(b\)](#), or when P-No. 11A, Group 1 materials are joined, all Category B welds in pressure vessels and circumferential joints in other components shall be Type 1 or Type 2 as described in [ND-4245](#).

(b) When the design is based on a joint efficiency permitted by [ND-3352.2\(c\)](#), any joint Type as described in [ND-4245](#) may be used, provided the limitations of the joint are followed.

ND-4243 Category C Weld Joints in Vessels and Similar Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall meet the requirements of (a), (b), and (c) below, except that socket welded flanges NPS 2 (DN 50) and less and slip-on flanges may be used.

(a) Category C and similar weld joints shall be Type 1 or Type 2 as described in [ND-4245\(a\)](#) when a butt weld detail is used and the provisions of [ND-3352.1\(a\)](#) or [ND-3352.2\(b\)](#) apply. These joints must be Type 1 or Type 2 butt welds when the joint is required to be radiographed.

(b) Typical Category C corner joints are shown in [Figure ND-4243-1](#) and Appendix XI.

(c) All category C joints in P-No. 11A, Group 1 material shall be full penetration welds extending through the entire section of the joint.

ND-4243.1 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in [Figure ND-4243.1-1](#), shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen, subsize if necessary, taken in this direction and as close to the hub as is practical.⁵⁴ In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.

ND-4244 Category D Weld Joints in Vessels and Branch Connection Weld Joints in Other Components

Category D weld joints in vessels and branch connection weld joints in other components shall be welded using one of the details of (a) through (g) below except that joints in P-No. 11A, Group 1 material shall be full penetration welds extending through the entire thickness of the component wall or nozzle wall as shown in [Figures ND-4244\(a\)-1](#), [ND-4244\(b\)-1](#), and [ND-4244\(c\)-1](#).

(a) *Butt Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component nozzle or branch as shown in [Figure ND-4244\(a\)-1](#). Backing strips, if used, may be left in place.

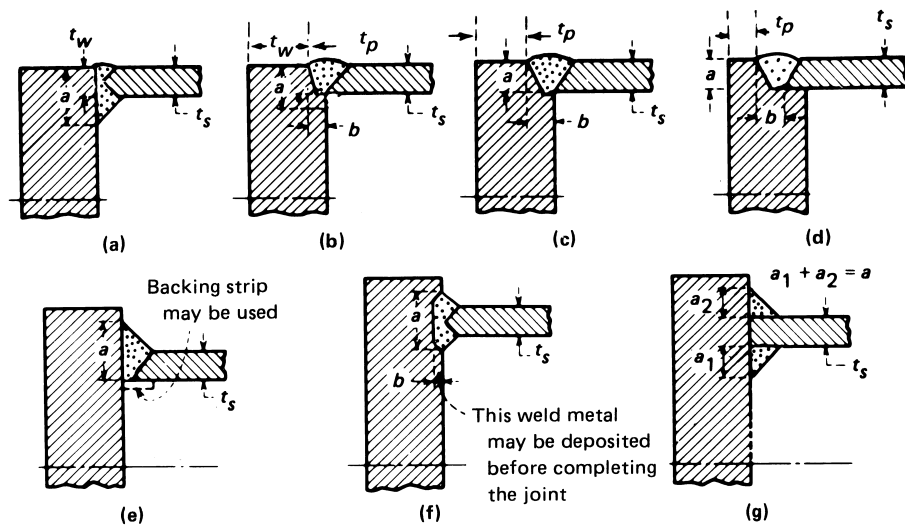
(b) *Corner Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in [Figure ND-4244\(b\)-1](#). When complete joint penetration cannot be verified by visual examination or other means permitted, backing strips or equivalent shall be used with full penetration welds deposited from only one side. Backing strips, if used, may be left in place.

(c) *Deposited Weld Metal of Opening for Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in [Figure ND-4244\(c\)-1](#). Backing strips, if used, may be left in place. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) *Partial Penetration Welded Nozzle and Branch Piping Connections.* Partial penetration welds in components and branch piping connections shall meet the weld design requirements of [ND-3352.4\(d\)](#) and [ND-3359](#). Nozzles shall be attached as shown in [Figure ND-4244\(d\)-1](#). Reinforcing plates of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole, maximum size $\frac{1}{4}$ in. (6 mm) pipe tap, that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds that seal off the inside of the vessel. These telltale 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.

(e) *Attachment of Fittings With Internal Threads.*⁵⁵ Internally threaded fittings shall be attached by a full penetration groove weld or, for NPS 3 (DN 80) and less, by two fillet or partial penetration welds, one on each face of the vessel wall, or by a fillet groove weld from the outside only as shown in [Figure ND-4244\(e\)-1](#), sketch (c-3). Internally

Figure ND-4243-1
Attachment of Pressure Parts to Plates to Form a Corner Joint



Typical Unstayed Flat Heads and Side Plates of Rectangular Vessels [Notes (1), (2)]

NOTES [sketches (a) through (g)]:

(1) For unstayed flat heads, see ND-3325.

(2) t_s , t_p , and t_w are defined in ND-3325.1.

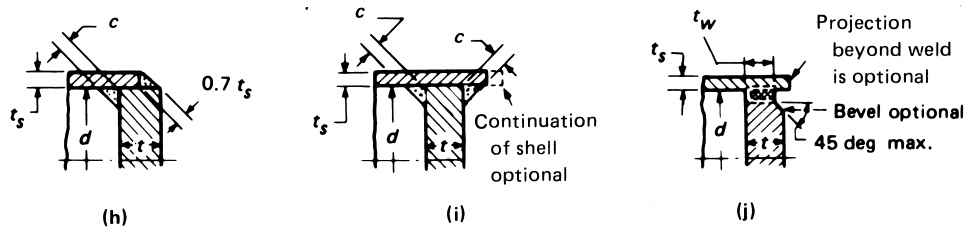
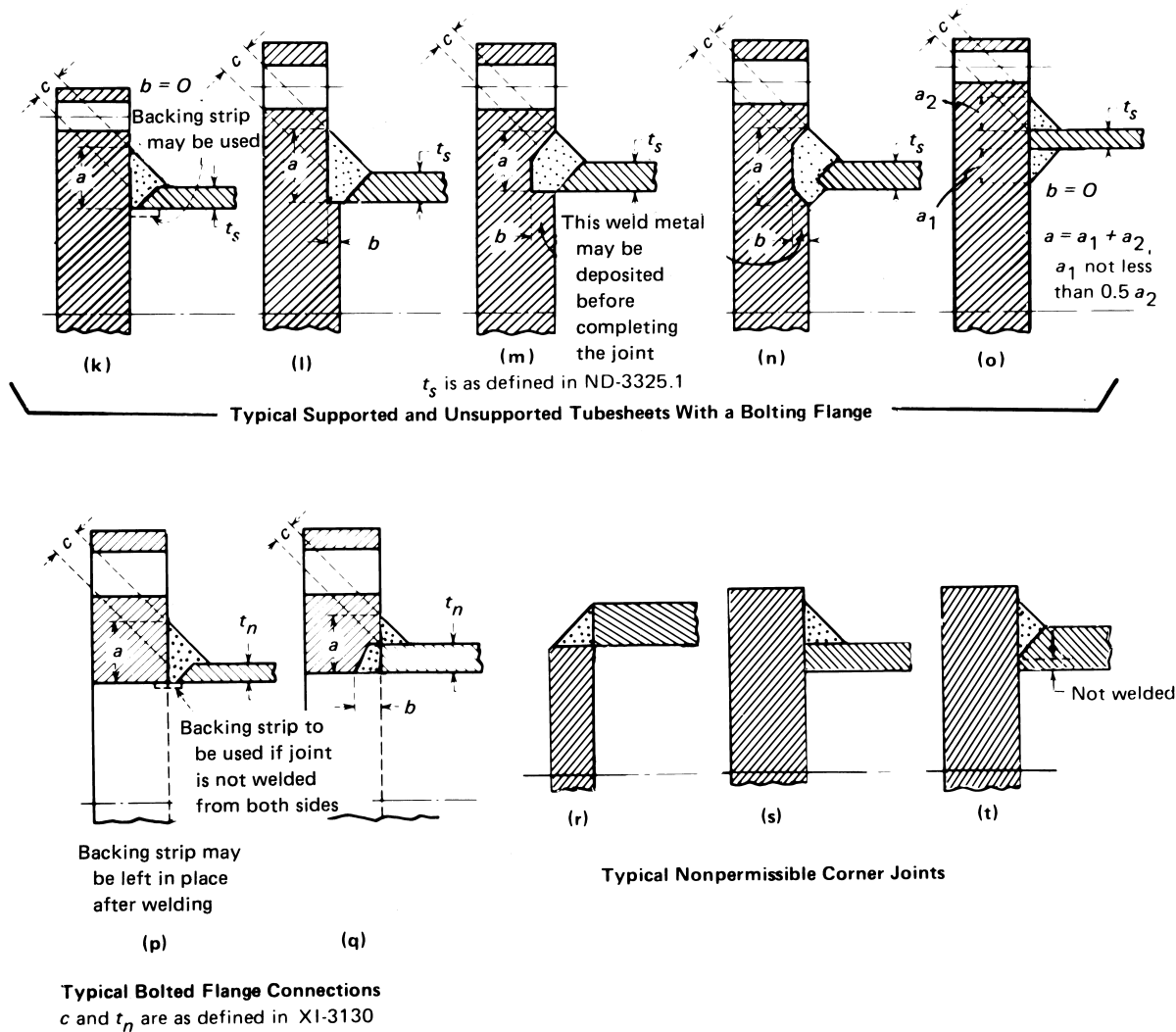


Figure ND-4243-1
Attachment of Pressure Parts to Plates to Form a Corner Joint (Cont'd)

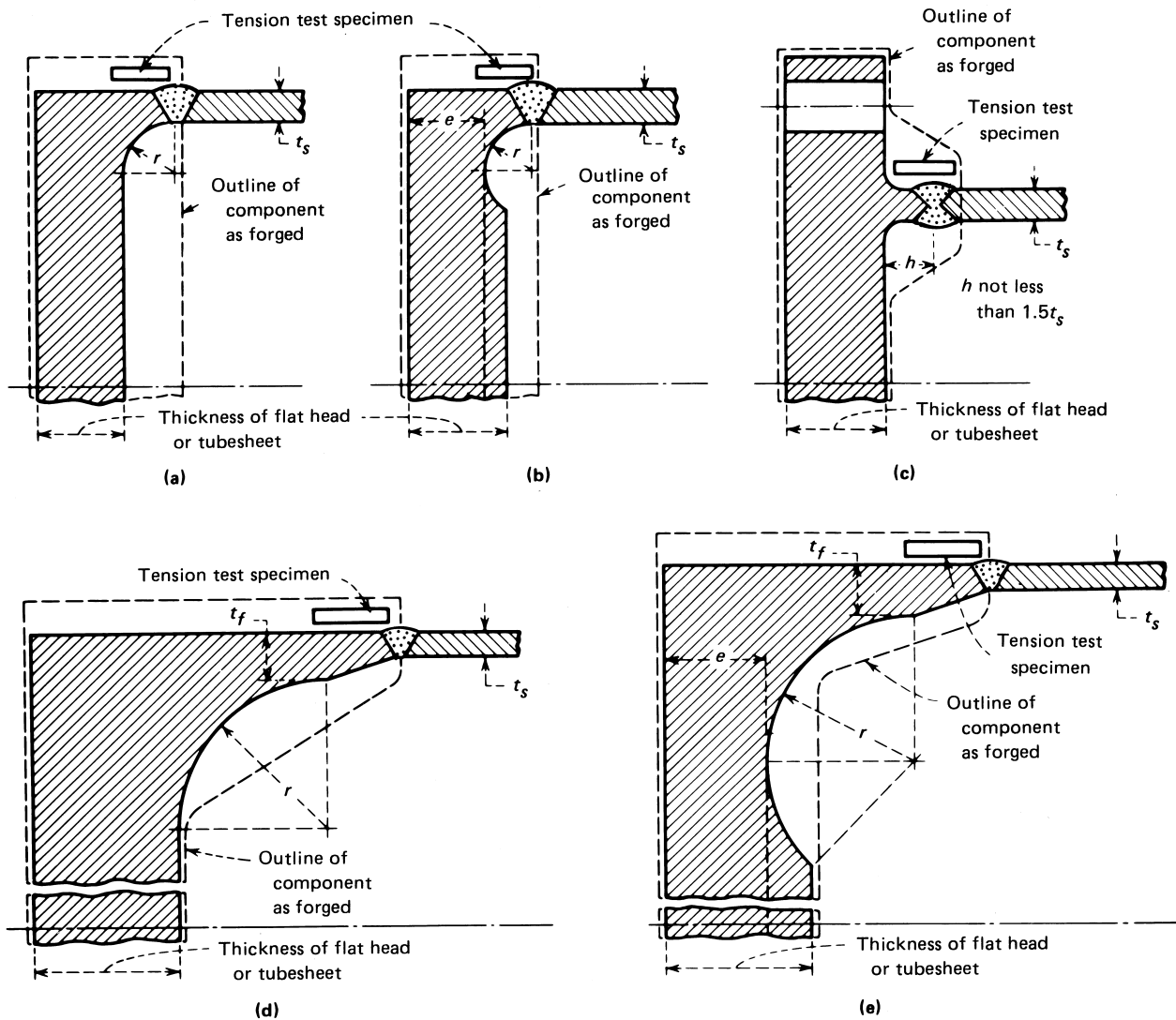


threaded fitting and bolting pads not exceeding NPS 3 (DN 80), as shown in [Figure ND-4244\(e\)-2](#), may be attached to components having a wall thickness not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld, deposited from the outside only. The design requirements of [ND-3352.4\(e\)](#) shall be met for all components.

(f) *Tubed Connections.* Nozzles or tubes recessed into thick-walled components or parts may be welded from only one side, provided the requirements of [ND-3352.4\(f\)](#) are met. Typical connections are shown in [Figure ND-4244\(f\)-1](#).

(g) *Nozzles With Integral Reinforcing.* Nozzles and other connections having integral reinforcing in the form of external necks or saddle type pads shall be attached by full penetration welds or by means of a fillet weld along the outer attachment having a wall, single bevel, or single J-weld along the inner attachment. Typical connections are shown in [Figure ND-4244\(g\)-1](#).

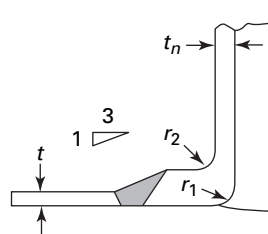
Figure ND-4243.1-1
Typical Flat Heads, and Supported and Unsupported Tubesheets With Hubs



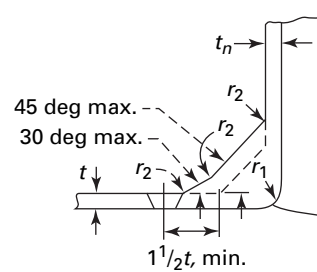
GENERAL NOTE:

Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

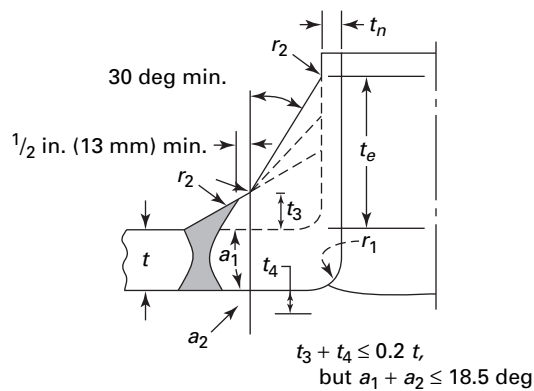
Figure ND-4244(a)-1
Nozzles, and Branch and Piping Connections Joined by Full Penetration Butt Welds



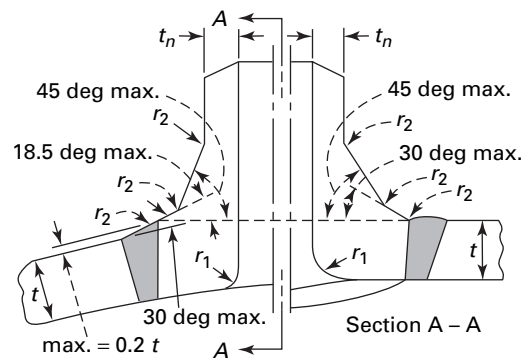
(a)



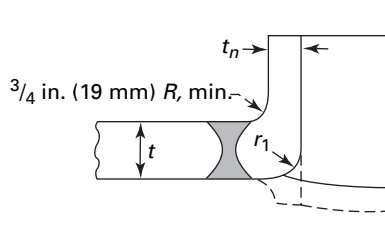
(b)



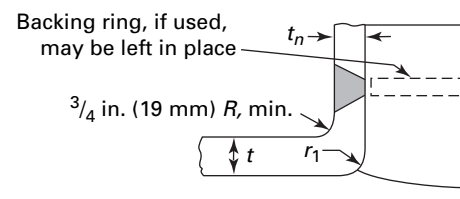
(c)



(d) [Note (1)]



(e)



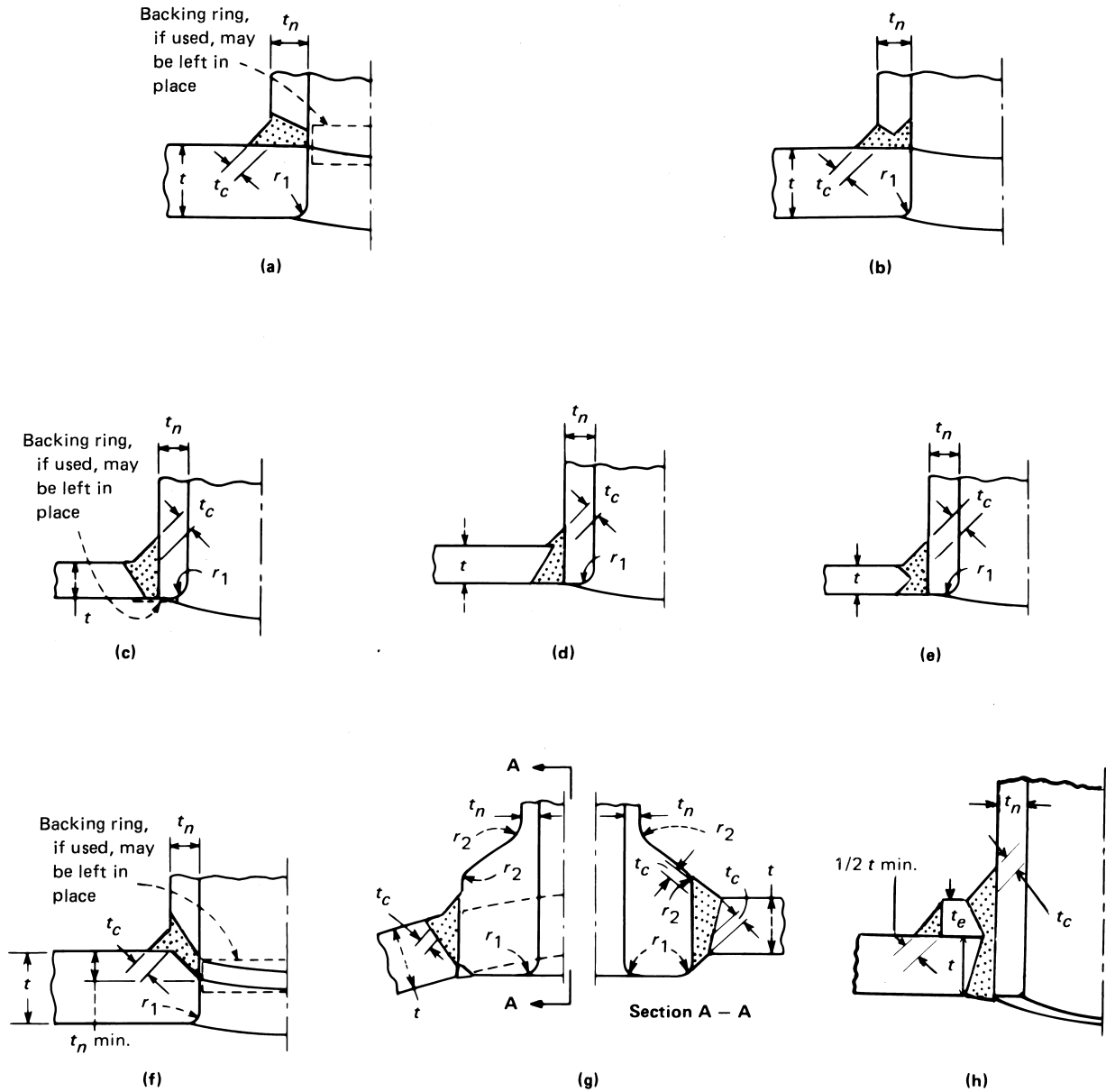
(f)

GENERAL NOTE: For definition of symbols, see ND-3352(a).

NOTE:

(1) Sections are perpendicular and parallel to the cylindrical component's axis.

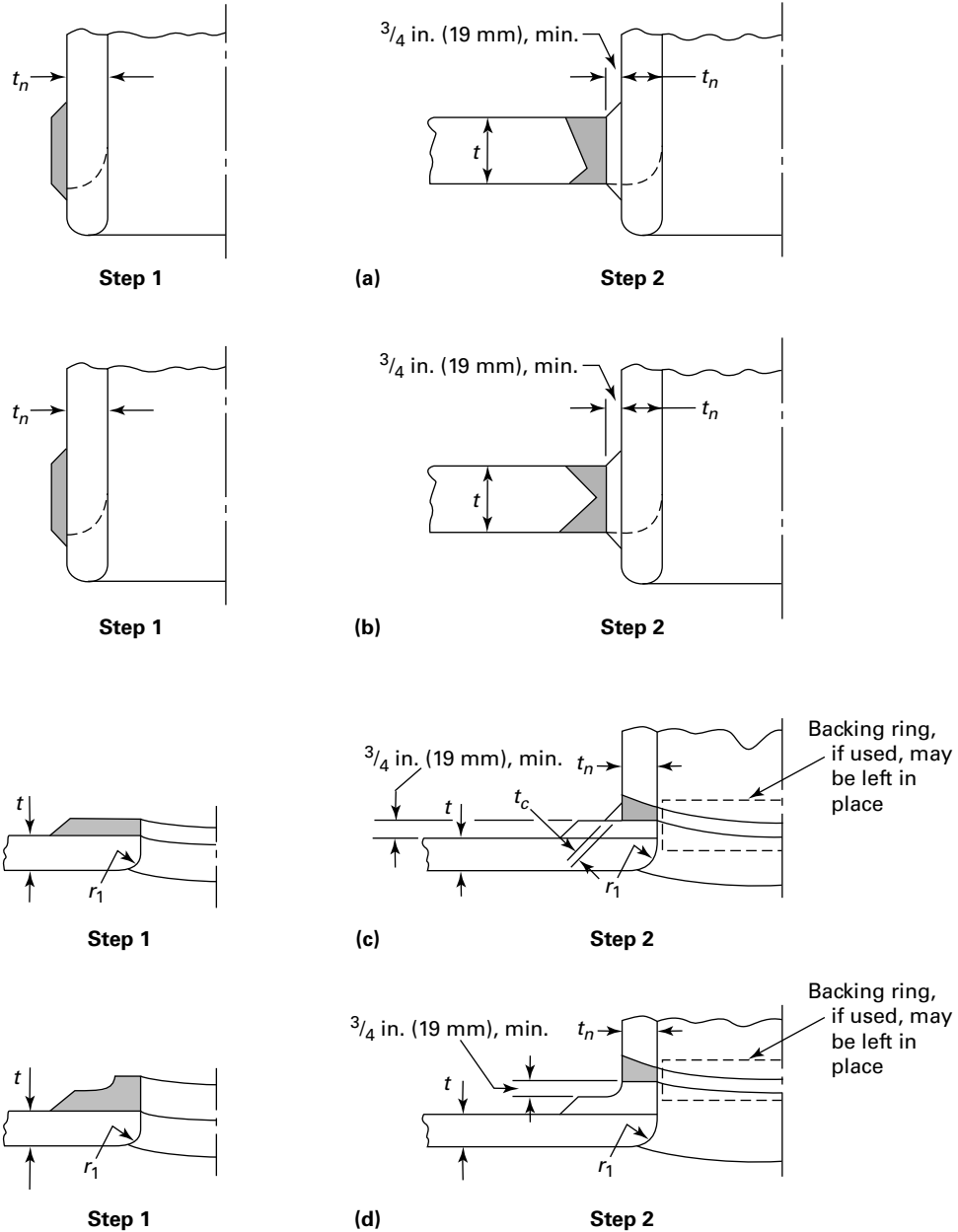
Figure ND-4244(b)-1
Nozzles, and Branch and Piping Connections Joined by Full Penetration Corner Welds



Sections perpendicular and parallel to the cylindrical component axis

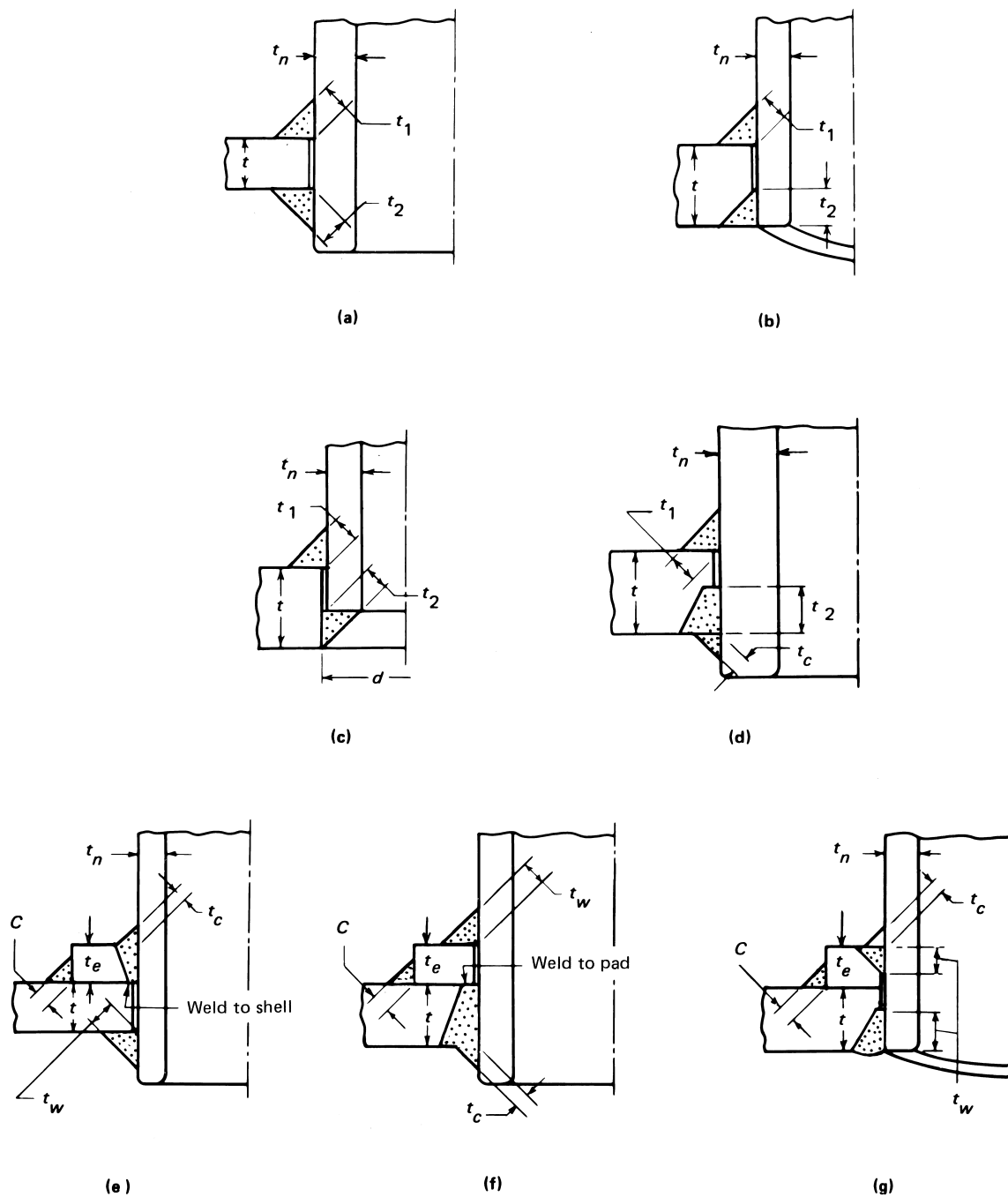
GENERAL NOTE: For definition of symbols, see ND-3352.4(b).

Figure ND-4244(c)-1
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles, and Branch and Piping Connections



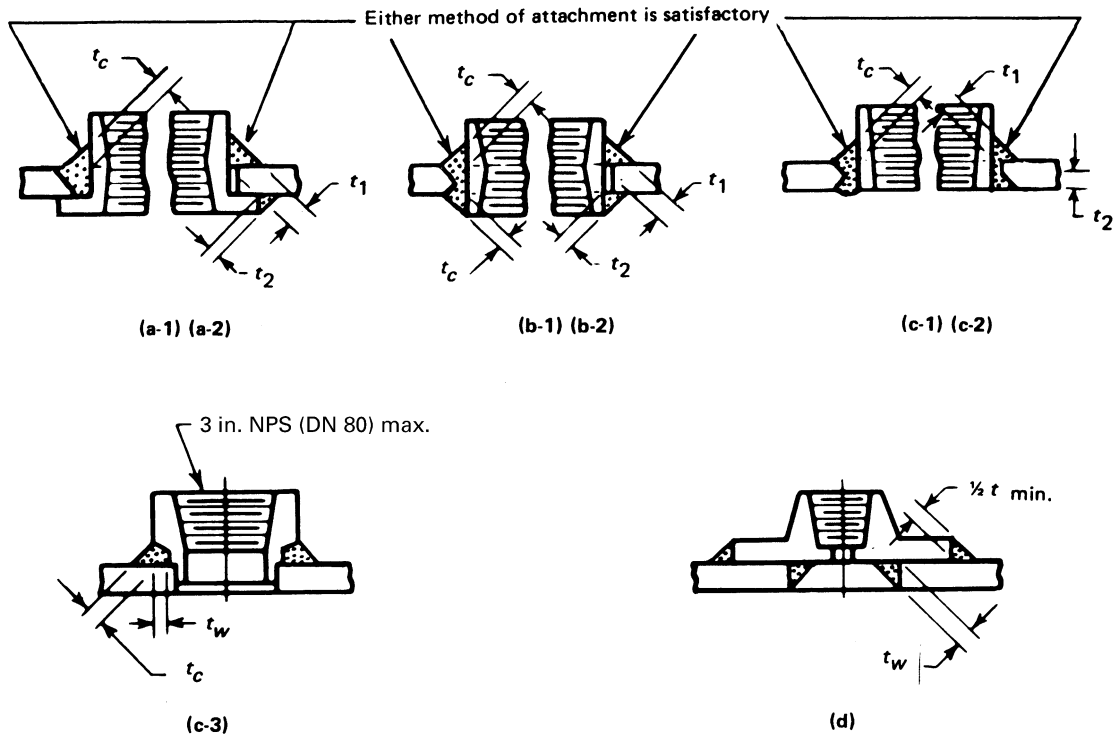
GENERAL NOTE: For definition of symbols, see [ND-3352.4\(c\)](#).

Figure ND-4244(d)-1
Some Acceptable Types of Welded Nozzles, and Branch and Piping Connections



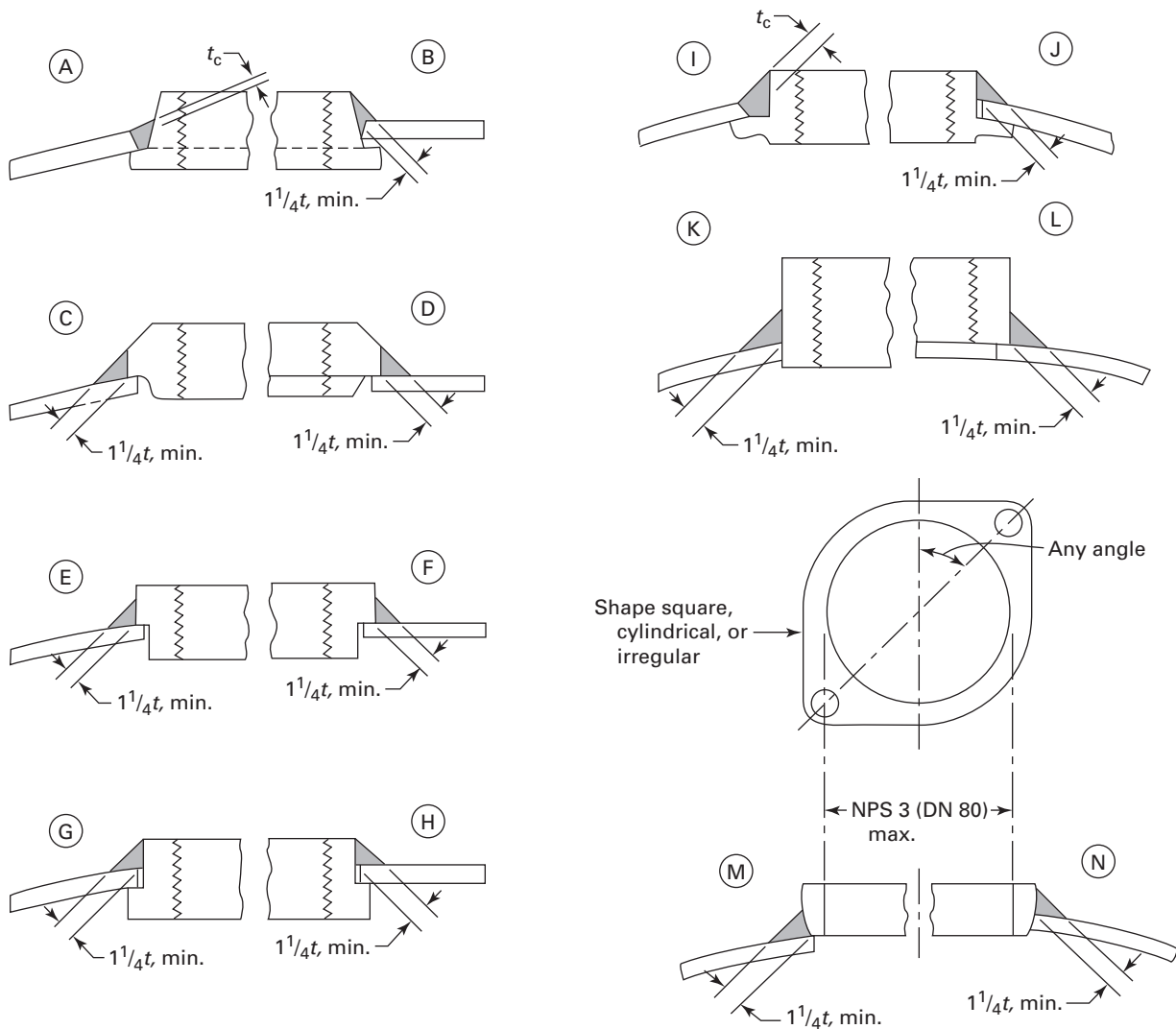
GENERAL NOTE: For definition of symbols, see ND-3352.4(d).

Figure ND-4244(e)-1
Some Acceptable Types of Welded Nozzles



GENERAL NOTE: For definition of symbols, see [ND-3352.4\(e\)](#).

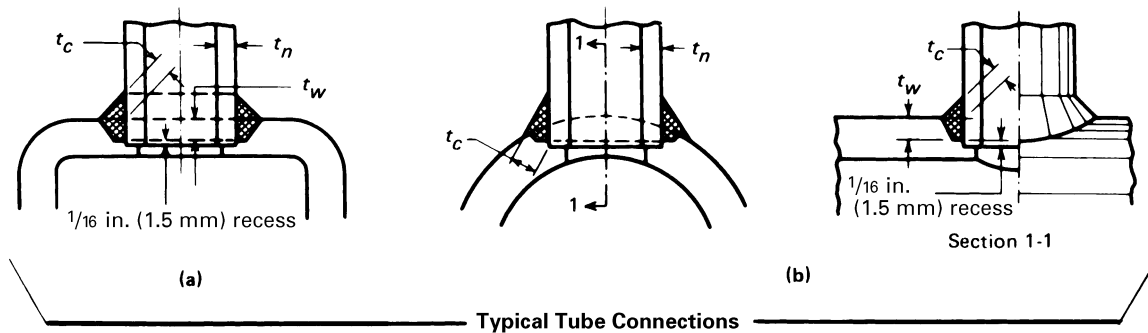
Figure ND-4244(e)-2
Some Acceptable Types of Small Fittings



GENERAL NOTES:

- (a) For definition of symbols, see [ND-3352.4\(e\)](#).
- (b) Maximum shell thickness = $\frac{3}{8}$ in. (10 mm).
- (c) Maximum internal thread diameter = $3\frac{1}{2}$ in. (89 mm).
- (d) Maximum dimension of opening in shell = no greater than $5\frac{3}{8}$ in. (135 mm) or $0.5 \times$ shell diameter.

**Figure ND-4244(f)-1
Tube Connections**



GENERAL NOTES:

- (a) For definitions of symbols, see ND-3352.4(f).
 (b) When used for other than square, round, or oval headers, round off corners.

ND-4245 Description and Limitations of Joint Types

(a) For components the description of the joint types are as follows:

Type	Description
1	Butt joints as attained by double welded or by other means will obtain the same quality of deposit weld metal on the inside and outside surface to agree with the requirements of ND-4426. Welds using metal backing strips that remain in place are excluded.
2	Single welded butt joints with backing strips other than those included in Type 1
3	Single welded butt joints without the use of a backing strip
4	Double full fillet lap joints
5	Single full fillet lap joints with plug welds conforming to ND-3356.2
6	Single full fillet lap joints without plug welds

(b) The limitations for each Type of weld are as outlined below. Some typical configurations are shown in Figure ND-4245-1.

Type	Limitations
1	The use of this joint Type is not limited.
2	The use of this joint Type is not limited, except for butt welds with one plate offset which can be used for circumferential joints only and are limited by the provisions of ND-3358.5 [Figure ND-4245-1 sketch (k)].
3	This joint Type is limited to circumferential joints only, which are not over $\frac{5}{8}$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter.
4	This joint Type is limited to longitudinal joints not over $\frac{3}{8}$ in. (10 mm) thick and circumferential joints not over $\frac{5}{8}$ in. (16 mm) thick.
5	This joint Type is limited to circumferential joints for attachments of heads other than hemispherical not over 24 in. (600 mm) outside diameter to shells not over $\frac{1}{2}$ in. (13 mm) thick. This joint Type cannot be used for attaching hemispherical heads to shells.

Table continued

Type	Limitations
6	This joint Type is limited to attachment of heads convex to pressure to shells not over $\frac{5}{8}$ in. (16 mm) required thickness, using fillet welds on the inside of the shell or for the attachment of heads having pressure on either side, to shells not over 24 in. (600 mm) inside diameter and not over $\frac{1}{4}$ in. (6 mm) required thickness with the fillet welds on the outside of the head flange only.

ND-4246 Atmospheric Storage Tank Special Joints

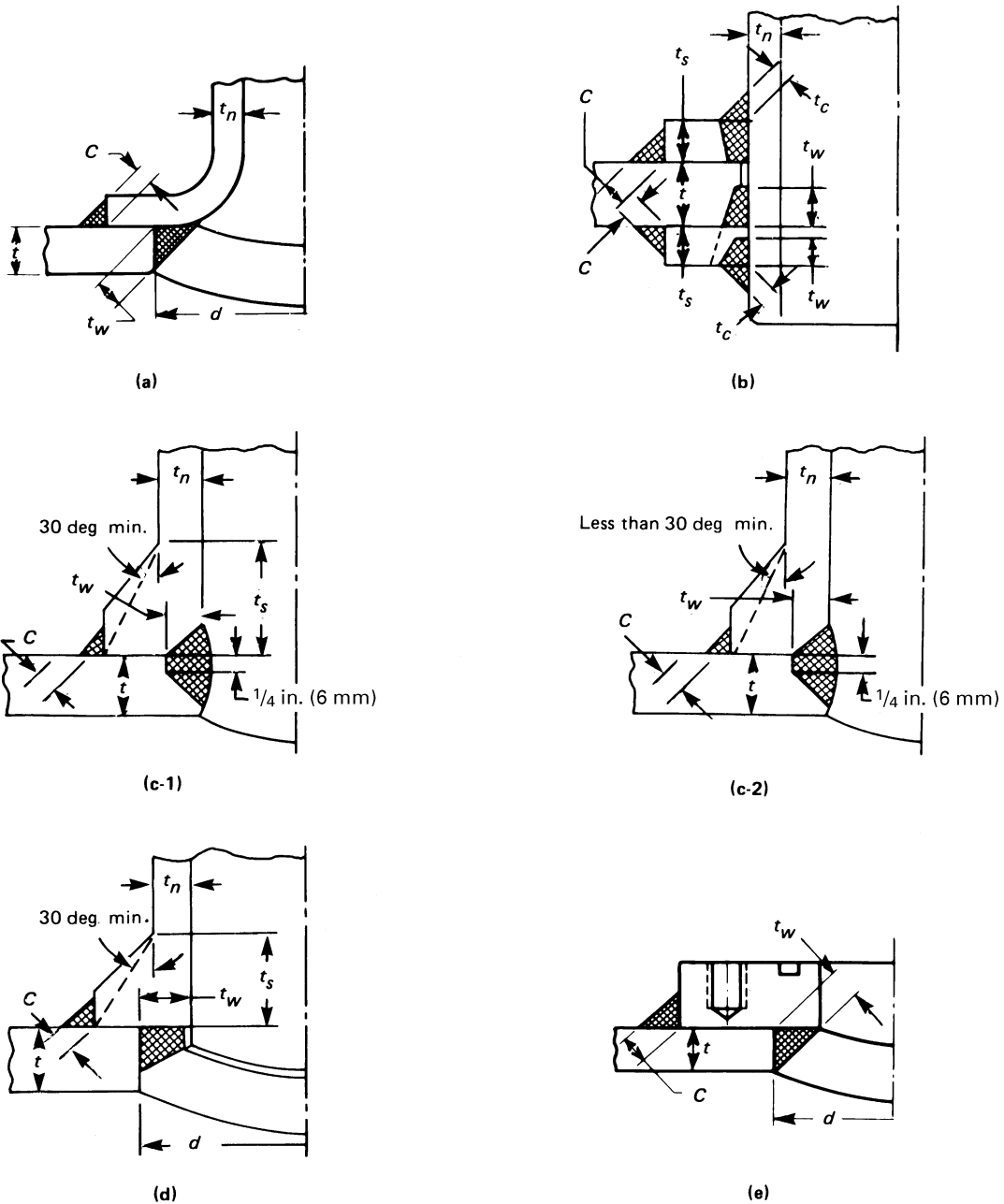
Requirements for special joints for atmospheric storage tanks are given below.

ND-4246.1 Bottom Plates. Bottoms shall be built to either one of the alternative methods of construction given in (a) and (b) below.

(a) Lap welded bottom plates shall be reasonably rectangular and square edged. Three plate laps in tank bottoms shall not be closer than 12 in. (300 mm) from each other and also from the tank shell. Bottom plates need be welded on the top side only, with a continuous full fillet weld on all seams [Figure ND-4246.1(a)-1]. The plates under the bottom ring shell connection shall have the outer ends of the joints fitted and lap welded to form a smooth bearing for the shell plates, as shown in Figure ND-4246.1(a)-1.

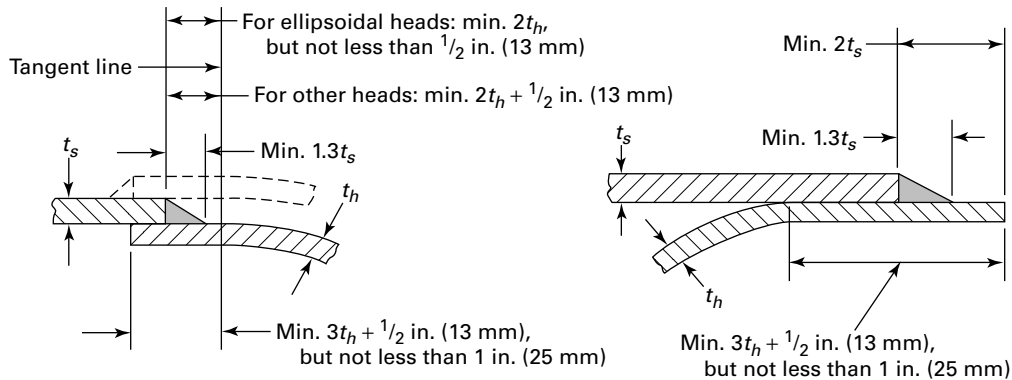
(b) Butt welded bottom plates shall have the parallel edges prepared for butt welding with either square or V-grooves. If square grooves are employed, the root opening shall be not less than $\frac{1}{4}$ in. (6 mm). The butt welds shall be made by applying a backing strip $\frac{1}{8}$ in. (3 mm) thick or heavier by tack welding to the underside of the plate [Figure ND-4246.1(a)-1]. A metal spacer shall be used, if necessary, to maintain the root opening between the adjoining plate edges. The Certificate Holder may

Figure ND-4244(g)-1
Some Acceptable Types of Welded Nozzles, and Branch and Piping Connections

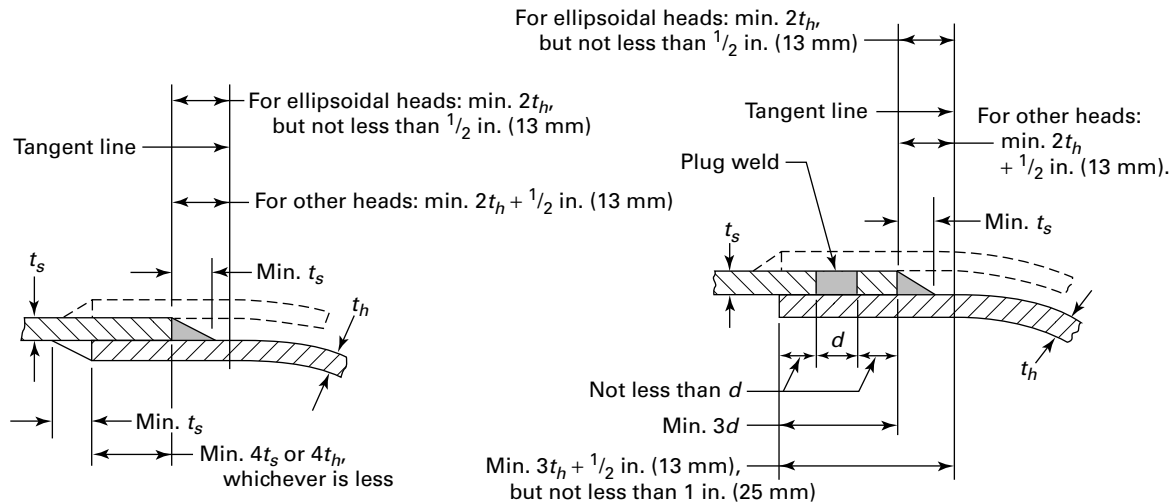


GENERAL NOTE: For definition of symbols, see [ND-3352.4\(g\)](#).

Figure ND-4245-1
Attachment Welds

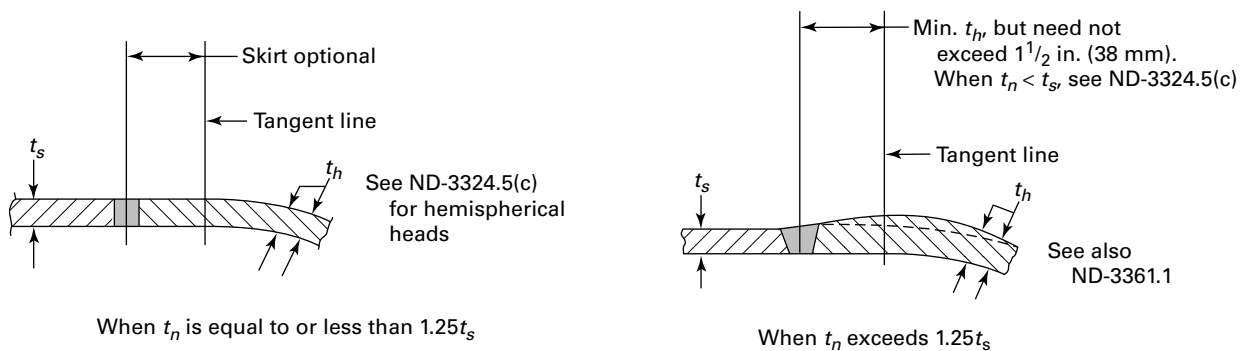


(a) Single Fillet Lap Weld



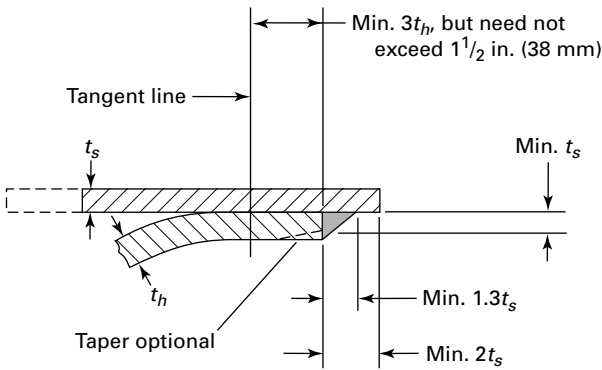
(b) Double Fillet Lap Weld

(c) Single Fillet Lap Weld With Plug Welds

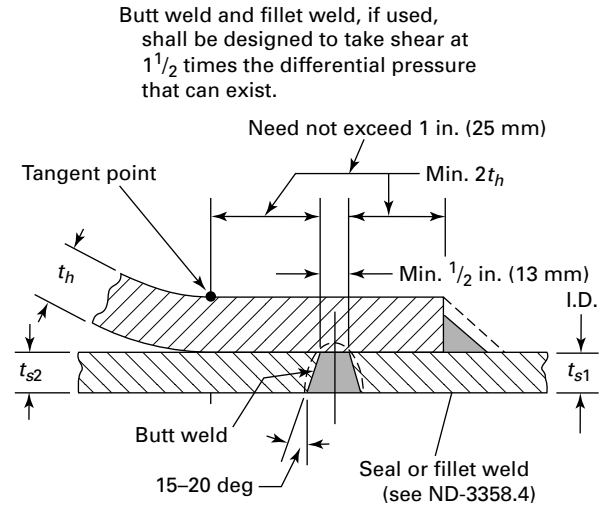


(d) Butt Weld

Figure ND-4245-1
Attachment Welds (Cont'd)

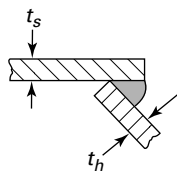


(e) Single Fillet Lap Weld

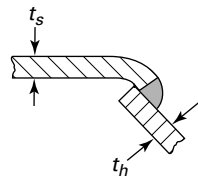


(f) Intermediate Head

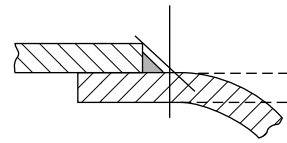
t_{s1} and t_{s2} may be different



(g)

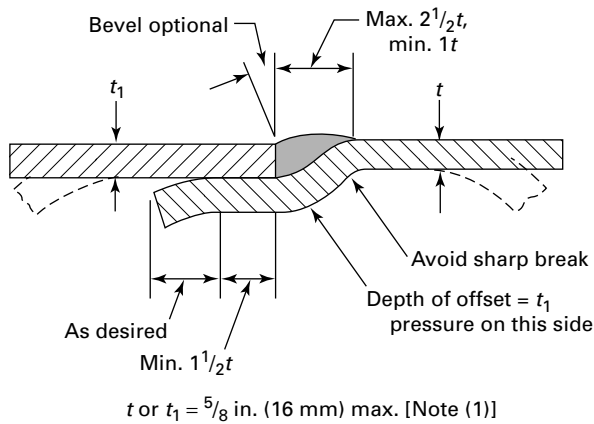


(h)



(i)

Sketches (g), (h), and (i) are not permissible



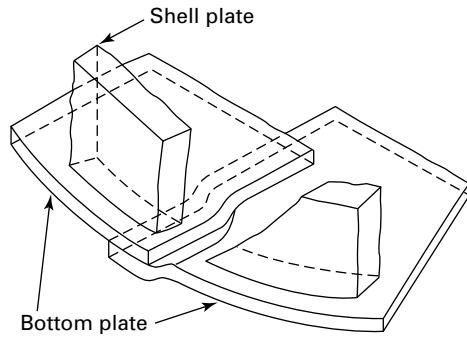
(k) Butt Weld With One Plate Edge Offset

NOTE [sketch (k)]:

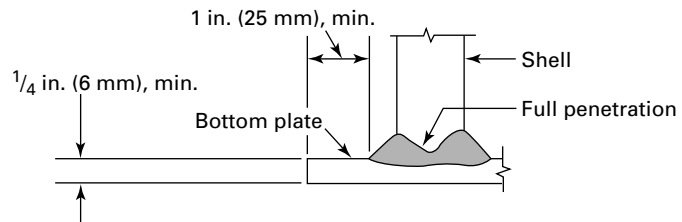
(1) For joints connecting hemispherical heads to shells, the following shall apply:

- (a) t or $t_1 = 3/8$ in. (10 mm) max.;
- (b) Max. difference in thickness between t and $t_1 = 3/32$ in. (2.5 mm)
- (c) Use of this figure for joints connecting hemispherical heads to shells shall be noted in the "Remarks" part of the Data Report Form.

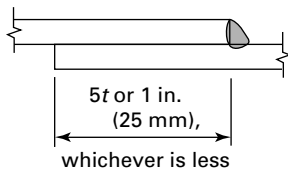
Figure ND-4246.1(a)-1
Typical Bottom and Bottom-to-Shell Joints



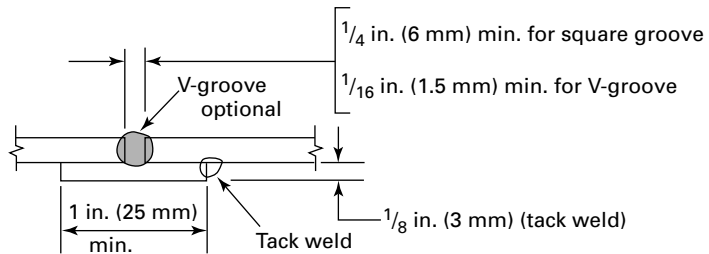
(a) Method for Preparing Lap Welded Bottom Plates Under Tank Shell



(b) Bottom-to-Shell Joint



(c) Single Welded Full Fillet Lap Joint



(d) Single Welded Butt Joint With Backing Strip

submit other methods of butt welding the bottom for the Owner's approval. Three plate joints in tank bottoms shall not be closer than 12 in. (300 mm) from each other and also from the tank shell.

ND-4246.2 Shell-to-Bottom Attachment. The attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous full wall thickness weld with a cover fillet on each side of shell plate [Figure ND-4246.1(a)-1], or for tanks not exceeding 35 ft (10.7 m) in diameter the bottom plates may be flanged and butt welded to the bottom shell course. The flanged tank bottom plates shall be butt welded and have a thickness equal to the thickness of the bottom shell course. The inside radius of the bend shall be not less than $1.75t$ nor more than $3t$.

ND-4246.3 Roof-to-Sidewall Attachment. Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side only [Figure ND-4246.3-1]. Roof plates of supported cone roofs shall not be attached to the supporting members. For cone roofs the fillet weld shall be $\frac{3}{16}$ in. (5 mm) or smaller.

ND-4246.4 Roof Plates. Roof plates shall be attached at least by a continuous full fillet lap joint on the top side [Figure ND-4246.3-1]. The top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

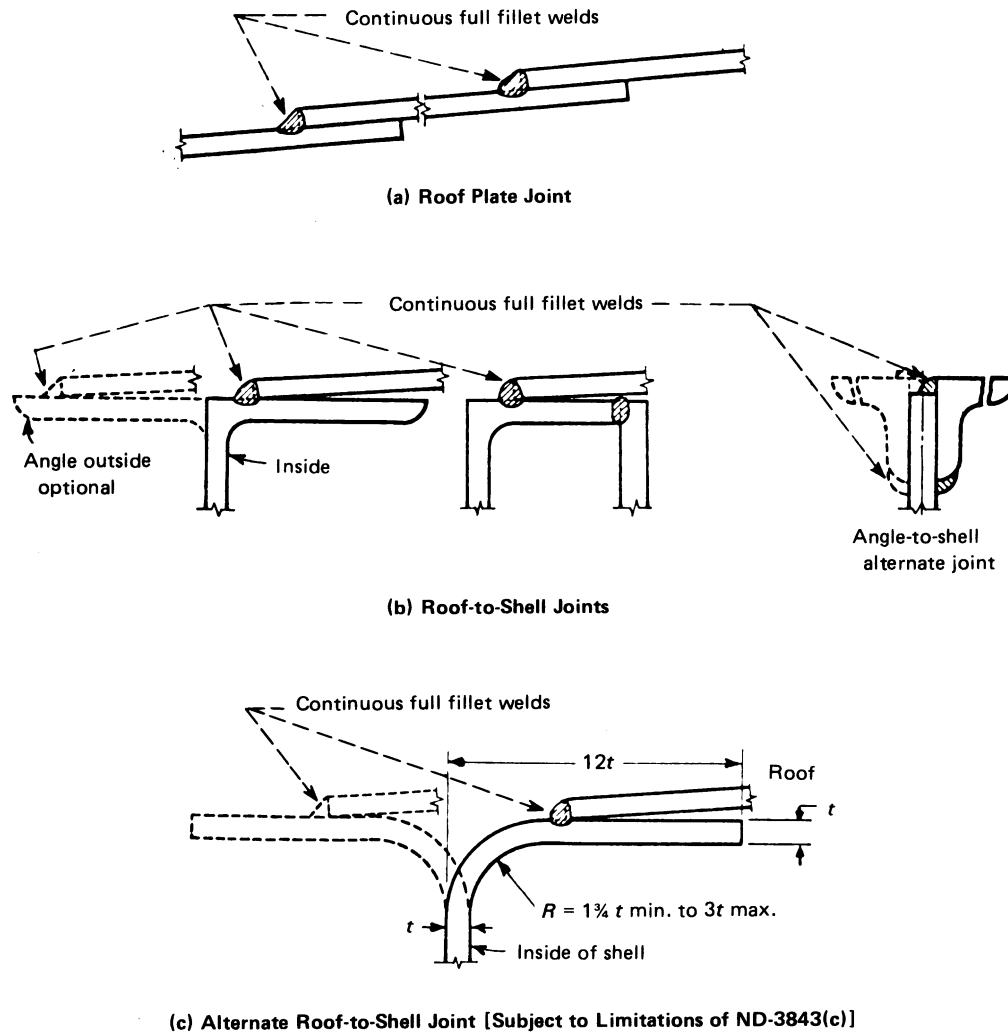
ND-4246.5 Nozzle-to-Tank Joints. Nozzles, man-holes, and outlets shall be attached by full fillet welds as shown in Figures ND-4246.5-1, ND-4246.5-2, ND-4246.5-3, and ND-4246.5-4.

ND-4246.6 Special Requirements. Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (5 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (5 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (5 mm).

(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (50 mm), and in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

Figure ND-4246.3-1
Typical Roof and Roof-to-Shell Joints



(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $\frac{1}{8}$ in. (3 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Figure ND-3361.1-1). The length of the required taper may include the width of the weld.

(d) Top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

ND-4246.7 Other Weld Joints. The fabrication requirements for weld joints not specifically covered by ND-4246, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in ND-4240 for Category A, B, and C weld joints for vessels.

ND-4247 Zero psi to 15 psi (0 kPa to 100 kPa) Storage Tank Special Joints

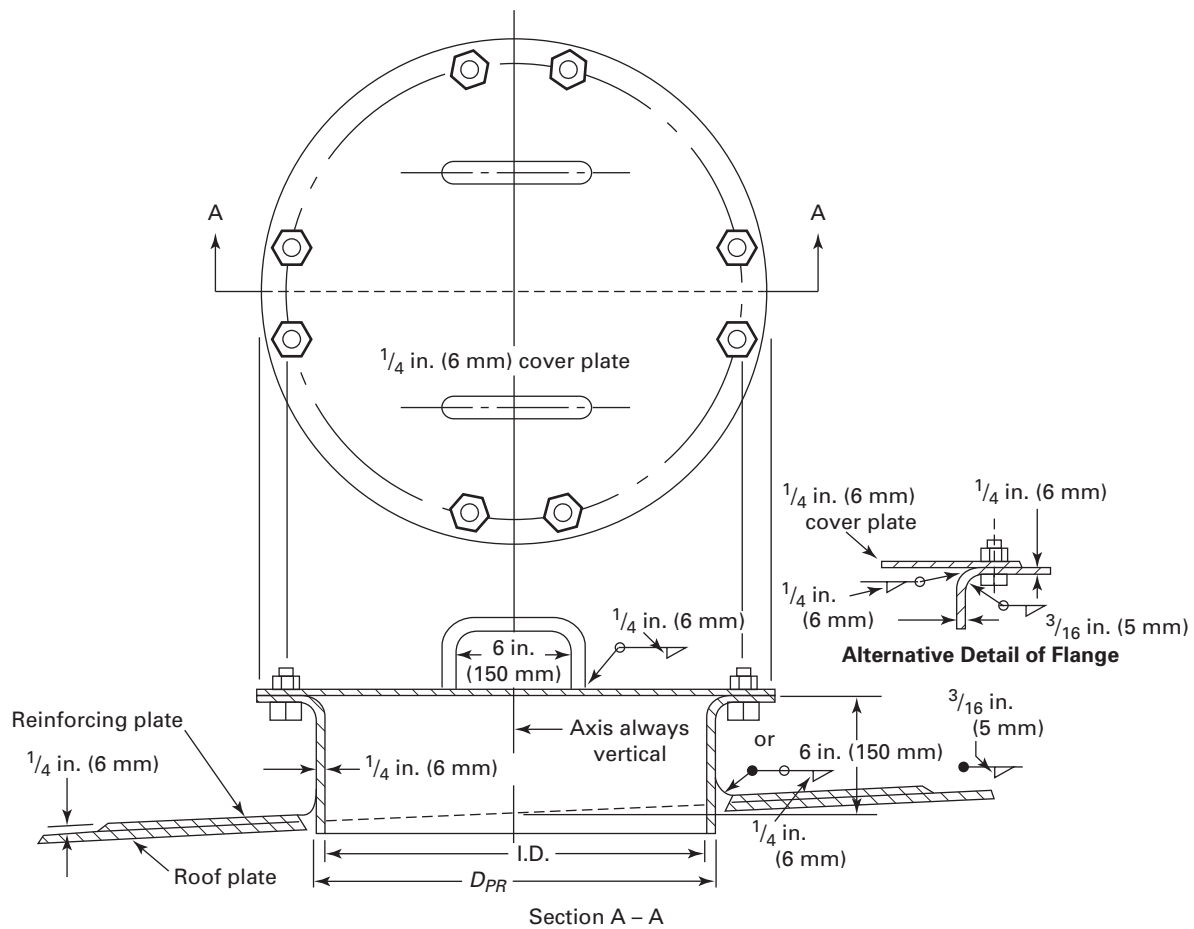
Requirements for special joints for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks are given below.

ND-4247.1 Bottoms. All welds in flat bottoms supported directly on foundations shall be single full fillet lap joints as a minimum. For other bottoms, all welds shall be butt welds.

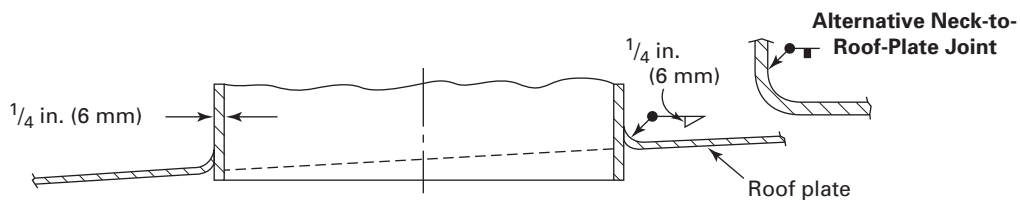
ND-4247.2 Bottom-to-Sidewall. All welds shall meet the design requirements of ND-3933. Flat bottoms shall be attached to sidewalls by full penetration welds and fillet welds on each side as a minimum.

ND-4247.3 Roof-to-Sidewall. Roof-to-sidewall joints shall be in accordance with the design requirements of ND-3933. The joints shall have continuous full fillet welds as a minimum.

Figure ND-4246.5-1
Roof Manholes

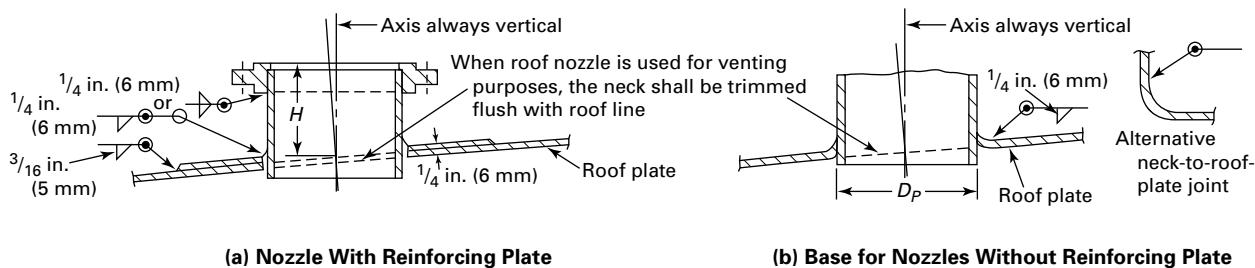


(a) Roof Manhole With Reinforcing Plate



(b) Base for Roof Manhole Without Reinforcing Plate

**Figure ND-4246.5-2
Flanged Roof Nozzles**



GENERAL NOTES:

- (a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
- (b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

ND-4247.4 Roofs. Roofs shall be in accordance with the design requirements of [ND-3933](#) and shall meet the requirements of [ND-4241](#).

ND-4247.5 Nozzles. Nozzle welds shall meet the requirements of [ND-4244](#).

ND-4247.6 Special Requirements. Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (5 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (5 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (5 mm)

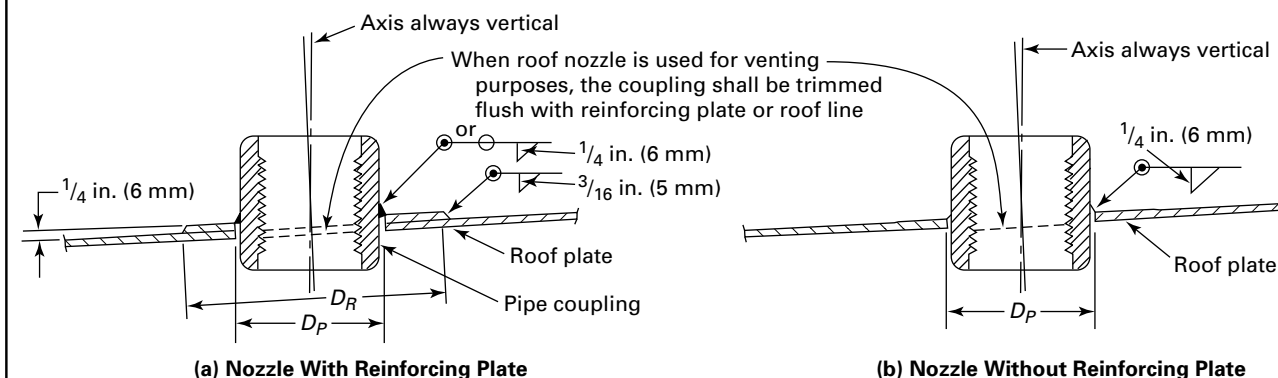
(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints

the lap need not exceed 2 in. (50 mm), and in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

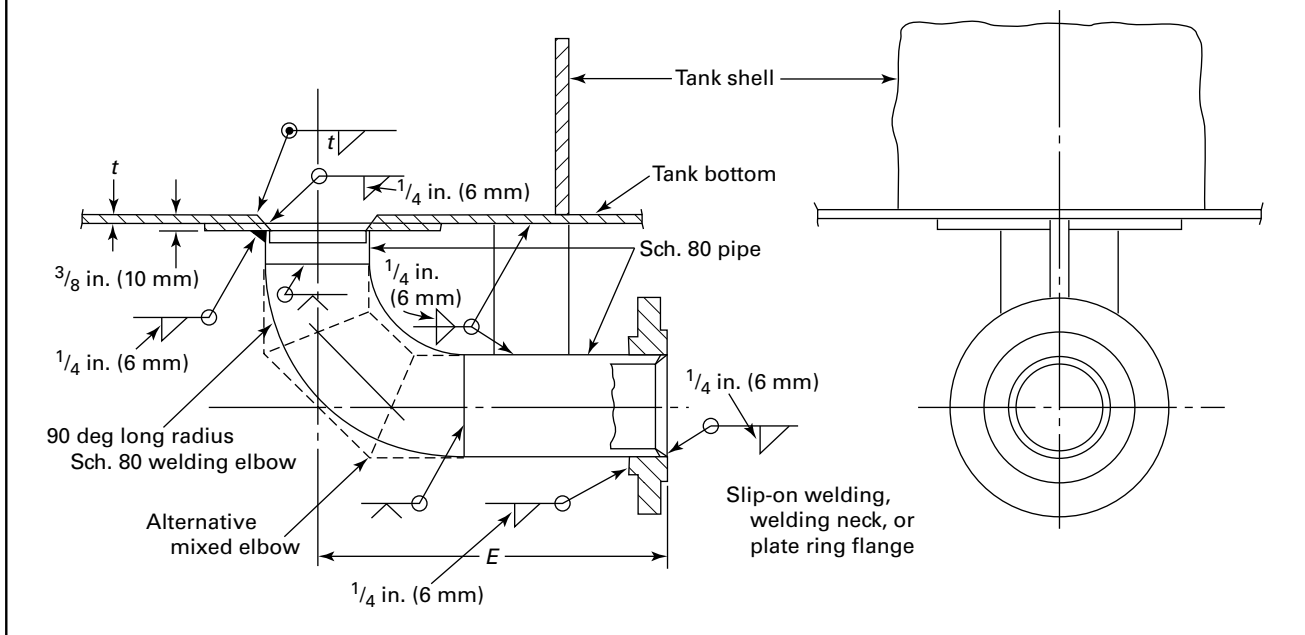
(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates that are to be butt welded together differs more than $\frac{1}{8}$ in. (3 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness ([Figure ND-3361.1-1](#)). The length of the required taper may include the width of the weld.

(d) The size of any weld along either edge of a compression ring shall not be less than the thickness of the thinner of the two parts joined or $\frac{1}{4}$ in. (6 mm), whichever is less, nor shall the size of the corner welds between the shell and a girder bar, such as shown in sketches (d) and (e) in [Figure ND-3933.5\(d\)-1](#), or between the horizontal and

**Figure ND-4246.5-3
Screwed or Socket Weld Roof Nozzles**



**Figure ND-4246.5-4
Welded Bottom Outlet Elbow**



vertical members of a compression ring assembly, such as shown in sketches (f) and (i), be less than the applicable value specified in [Table ND-4247.6\(d\)-1](#).

ND-4247.7 Other Weld Joints. The fabrication requirements for weld joints not specifically covered by [ND-4247](#), such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in [ND-4240](#) for Category A, B, and C weld joints for vessels.

ND-4250 WELDING END TRANSITIONS — MAXIMUM ENVELOPE

The welding ends of items shall provide a gradual change in thickness from the item to the adjoining items. Any welding end transition that lies entirely within the envelope shown in [Figure ND-4250-1](#) is acceptable, provided that

(a) the wall thickness in the transition region is not less than the minimum wall thickness of the adjoining item; and

(b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg, the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{\min}$.

ND-4300 WELDING QUALIFICATIONS

ND-4310 GENERAL REQUIREMENTS

ND-4311 Types of Processes Permitted

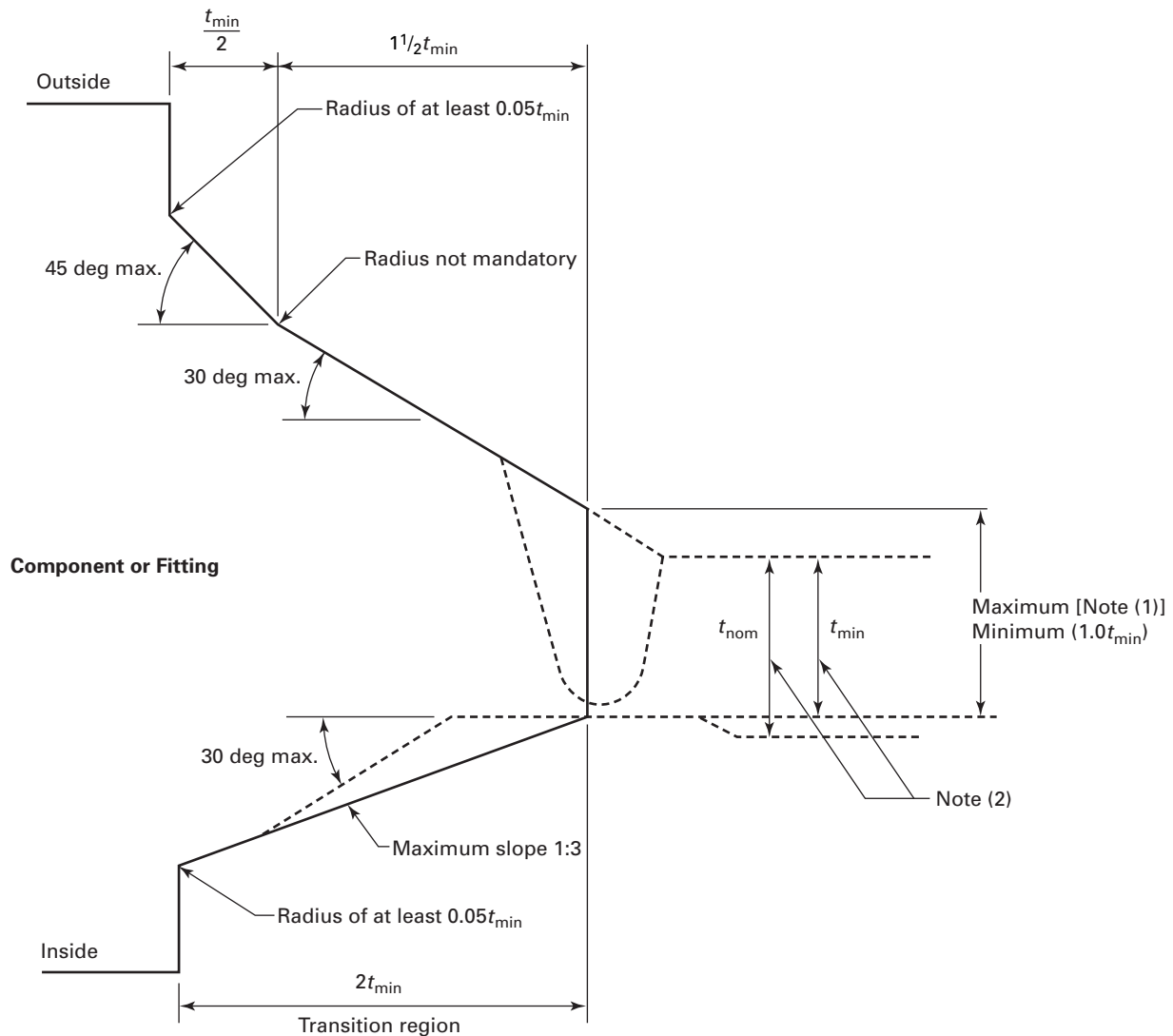
Only those welding processes that are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure retaining material or attachments thereto. Any process used shall be such that the records required by [ND-4320](#) can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

ND-4311.1 Stud Welding Restrictions. Stud welding is acceptable only for nonstructural and temporary attachments ([ND-4435](#)). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and 3/4 in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall

**Table ND-4247.6(d)-1
Minimum Size for Fillet Welds**

Thickness of the Thicker of the Two Parts Joined, in. (mm)	Minimum Size of Fillet Weld, in. (mm)
Not over 1/4 (6)	3/16 (5)
Over 1/4 through 3/4 (6 through 19)	1/4 (6)
Over 3/4 through 1 1/4 (19 through 32)	5/16 (8)
Over 1 1/4 (32)	3/8 (10)

Figure ND-4250-1
Welding End Transitions Maximum Envelope



GENERAL NOTES:

- Weld bevel is shown for illustration only.
- The weld reinforcement permitted by ND-4426 may lie outside the maximum envelope.

NOTES:

- The maximum thickness at the end of the component is:
 - the greater of $t_{min} + 0.15$ in. (3.8 mm) or $1.15t_{min}$ when ordered on a minimum wall basis;
 - the greater of $t_{min} + 0.15$ in. (3.8 mm) or $1.0 t_{nom}$ when ordered on a nominal wall basis.
- The value of t_{min} is whichever of the following is applicable:
 - the minimum ordered wall thickness of the pipe;
 - 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness that has an under tolerance of 12.5%;
 - the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.

comply with [ND-4600](#), except that time at temperature need not exceed $\frac{1}{2}$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

ND-4311.2 Capacitor Discharge Welding. Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided

(a) temporary attachments are removed in accordance with the provisions of [ND-4435\(b\)](#);

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

ND-4311.4 Inertia and Continuous Drive Friction Welding.

(a) Inertia and continuous drive friction welding shall not be used for the fabrication of piping.

(b) The weld between the two members shall be a full penetration weld.

ND-4312 Production Test Plates

If a vessel of welded unalloyed titanium construction incorporates weld joints of Categories A or B, a production test plate of the same specification, grade, and thickness shall be made of sufficient size to provide at least one face and one root bend specimen. Where longitudinal joints are involved, the test plate shall be attached to one end of the longitudinal joint and welded continuously with the joint. Where circumferential joints only are involved, the test plate need not be attached but shall be welded along with the joint. One test plate is required for each vessel by each welder or welding operator working on the vessel, provided not over 100 ft (30 m) of Category A or B weld joints are involved. An additional test plate, meeting the same requirement as outlined above, shall be made for each additional 100 ft (30 m) of Category A or B weld joints involved. The bend specimens shall be tested in accordance with Section IX. Failure of either bend specimen constitutes rejection of the weld.

ND-4313 Unalloyed Titanium

Unalloyed titanium shall not be welded to other material.

ND-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

ND-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization and shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Authorization.

ND-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Authorized Nuclear Inspector.

ND-4322.1 Identification of Joints by Welder or Welding Operator.

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing and tube-to-tubesheet welds, are

made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

ND-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with ND-4320 and Section IX shall be used.

ND-4324 Transferring Qualifications

The welding procedure qualifications and performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures, and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

ND-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

ND-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

ND-4333 Heat Treatment of Qualification Welds for Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of ND-4600 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

ND-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

ND-4334.1 Coupons Representing the Weld Deposits. Impact test specimens and testing methods shall conform to ND-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in ND-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld.

ND-4334.2 Coupons Representing the Heat-Affected Zone. Where impact tests of the heat-affected zone are required by ND-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of ND-2321. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat-affected zone values with base material values [ND-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base

material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material.

ND-4335 Impact Test Requirements

When materials are required to be impact tested per ND-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemption from impact testing under ND-2311(a)(8) does not apply to weld metal unless the specific weld metal used is included in Table ND-2331(a)-1. Exemption from impact testing of the heat affected zone of those base materials exempted by ND-2311(a)(8) is not permitted. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of ND-2330 and ND-4334. Retests in accordance with the provisions of ND-2350 are permitted.

ND-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with ND-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with ND-2310, regardless of the depth of the repair. Exemption from impact testing under ND-2311(a)(8) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base material repairs unless the specific weld metal used is included in Table ND-2311-1. Weld metal exemptions are being developed.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in ND-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding, and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection. Use of this alternative shall be identified on the Welding Procedure Qualification Record.

ND-4335.2 Impact Tests of Heat Affected Zone.

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials require

impact testing in accordance with the rules of ND-2310. Exemption of base materials by ND-2311(a)(8) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag, electro-gas, or thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(3) that portion of the heat affected zone associated with GTAW root deposits with a maximum of two layers of $\frac{3}{16}$ in. (5 mm) thickness, whichever is less.

(b) Charpy V-notch testing shall be performed as specified in (1) through (6).

(1) Charpy V-notch test specimens representing both the heat affected zone and the unaffected base material shall be tested. The unaffected base material specimens shall be tested at a temperature equal to or below the lowest service temperature.

(2) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable, or additional testing shall be performed at higher temperatures until either of the above requirements are met.

(3) The heat affected zone specimens shall be tested at the test temperature determined in (2). The applicable average toughness values of the heat affected zone specimens shall equal or exceed the applicable average toughness values of the unaffected base material specimens, or the adjustment given in (4) through (6) shall be made. Alternatively, another test coupon may be welded and tested.

(4) Additional Charpy V-notch tests shall be performed on either the heat affected zone or the unaffected base material, or both, at temperatures where the applicable toughness values of all three specimens tested are not less than that specified in (2). The applicable average toughness values for each test meeting this requirement shall be plotted on an applicable toughness value versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} , where the heat affected zone and the unaffected base material applicable average toughness values are the same and not less than that specified in (2), shall be used to determine the adjustment temperature T_{ADJ} where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(5) As an alternative to (4), if the toughness values of the heat affected zone are no less than the values specified in Table ND-2331(a)-1 or Table ND-2332(a)-2, as applicable, and the average of the heat affected zone specimens is not less than 7 ft-lb (10 N-m) or 5 mils (0.13 mm) below the average toughness values of the unaffected base material, T_{ADJ} may be taken as 15°F (8°C).

(6) As a second alternative to (4), if the applicable toughness values of the heat affected zone are no less than the values specified in Table ND-2331(a)-1 or Table ND-2332(a)-2, as applicable, the difference between the average applicable toughness values of the heat affected zone and the unaffected base material shall be calculated and used as described in (c)(3) below.

(c) At least one of the following methods shall be used to compensate for the heat affected zone toughness decrease due to the welding procedure.

(1) The lowest service temperature specified in the Design Specification for all material to be welded in production WPSs supported by this PQR shall be increased by the adjustment temperature T_{ADJ} .

(2) The specified testing temperature for the production material may be reduced by T_{ADJ} .

(3) The materials to be welded may be welded using the WPS provided that they exhibit toughness values that are no less than the minimum required toughness value specified in ND-2300 plus the difference in applicable average toughness values established in (b)(6) above.

(d) The Charpy V-notch testing results shall be recorded on the PQR and any offsetting T_{ADJ} or increased toughness requirements shall be noted on the PQR and on the WPS. More than one compensation method may be used on a par basis.

(e) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

ND-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of ND-4331 to ND-4335, inclusive.

ND-4350 SPECIAL QUALIFICATION REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

The welding procedure for tube-to-tubesheet welds shall be qualified in accordance with the ASME Section IX, QW-202.6 using a demonstration mockup in accordance with QW-193. The weld throat (minimum leakage path) shall be not less than two-thirds of the specified tube wall thickness. Welders and welding operators shall be qualified by demonstration mockup in accordance with QW-303.5.

ND-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

ND-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

ND-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials that are used in the fabrication and installation of components (ND-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

ND-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

ND-4420 RULES FOR MAKING WELDED JOINTS

ND-4421 Backing Rings

Backup plates and backing rings that remain in place, and compression rings or stiffeners of storage tanks such as angles, bars, and ring girders may be used. Their materials shall be compatible with the base metal, but spacer pins shall not be incorporated into the welds.

ND-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer root of the weld metal or on the final layer unless the weld is postweld heat treated.

ND-4423 Double Welded Joints, Single Welded Joints, and Plug Welds

ND-4423.1 Double Welded Joints. Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetrations are otherwise obtained and demonstrated to be satisfactory by welding procedure qualifications.

ND-4423.2 Single Welded Joints. Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

ND-4423.3 Plug Welds. In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

ND-4424 Surfaces of Welds

As-welded surfaces are permitted, except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress intensification factors given in Table ND-3672 (b)-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examination of the weld. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with ND-4426.1 for vessels, pumps, and valves, and with ND-4426.2 for piping.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of ND-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

(f) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within $\pm 10\%$.

ND-4425 Welding Components of Different Diameters

When components of different diameters are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld in accordance with ND-3361.

ND-4426 Reinforcement of Welds

ND-4426.1 Thickness of Weld Reinforcement for Vessels, Pumps, and Valves. The surface of the reinforcement of all butt welded joints in vessels, pumps, and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25), incl.	$\frac{3}{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$\frac{1}{8}$ (3)
Over 2 to 3 (50 to 75), incl.	$\frac{5}{32}$ (4)
Over 3 to 4 (75 to 100), incl.	$\frac{7}{32}$ (5.5)

Table continued

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Over 4 to 5 (100 to 125), incl.	$\frac{1}{4}$ (6)
Over 5 (125)	$\frac{5}{16}$ (8)

ND-4426.2 Thickness of Weld Reinforcement for Piping. For double welded butt joints, the limitation on the reinforcement given in Column 1 of the following tabulation shall apply separately to both inside and outside surfaces of the joint. For single welded butt joints, the reinforcement given in Column 2 shall apply to the inside surface and the reinforcement given in Column 1 shall apply to the outside surface. The reinforcement shall be determined from the higher of the abutting surfaces involved.

Maximum Reinforcement Thickness, in. (mm)	Material Nominal Thickness, in. (mm)	
	Column 1	Column 2
Up to $\frac{1}{8}$ (3), incl.	$\frac{3}{32}$ (2.5)	$\frac{3}{32}$ (2.5)
Over $\frac{1}{8}$ to $\frac{3}{16}$ (3 to 5), incl.	$\frac{1}{8}$ (3)	$\frac{3}{32}$ (2.5)
Over $\frac{3}{16}$ to $\frac{1}{2}$ (5 to 13), incl.	$\frac{5}{32}$ (4)	$\frac{1}{8}$ (3)
Over $\frac{1}{2}$ to 1 (13 to 25), incl.	$\frac{3}{16}$ (5)	$\frac{5}{32}$ (4)
Over 1 to 2 (25 to 50), incl.	$\frac{1}{4}$ (6)	$\frac{5}{32}$ (4)
Over 2 (50)	The greater of $\frac{1}{4}$ in. (6 mm) or $\frac{1}{8}$ times the width of the weld, in in. (mm)	

ND-4427 Shape and Size of Fillet Welds

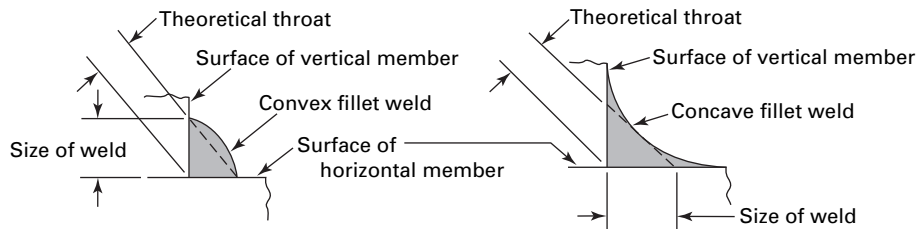
(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Figure ND-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. In making socket welds, a gap as shown in Figure ND-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between the butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in Figure ND-4427-1 may be used provided the requirements of ND-3000 are met.

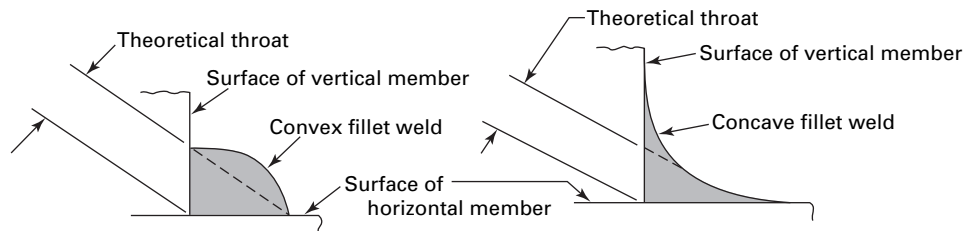
ND-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

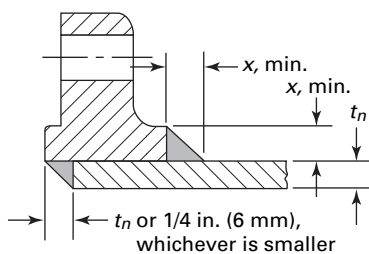
Figure ND-4427-1
Fillet and Socket Weld Details and Dimensions



(a) Equal Leg Fillet Weld [Note (1)]

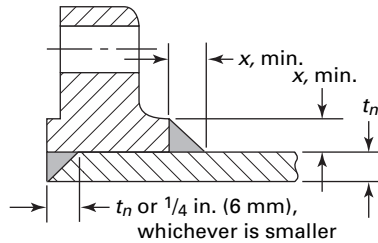


(b) Unequal Leg Fillet Weld [Note (2)]

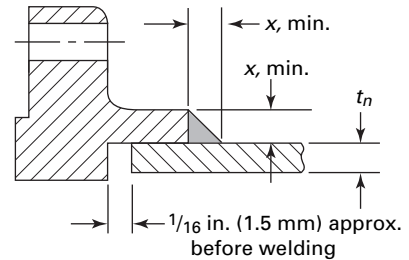


Front and back weld

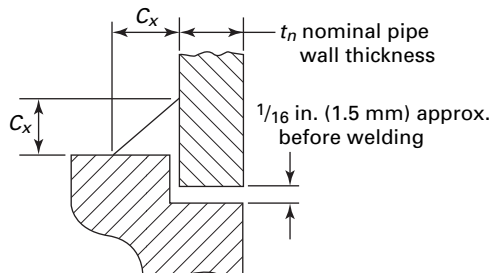
(c-1) Slip On Flange [Note (3)]



Face and back weld



(c-2) Socket Welding Flange [Note (3)]



(c-3) Socket Welding Fittings [Note (4)]

NOTES:

- (1) The size of an equal leg fillet is the leg length of the largest inscribed right isosceles triangle. Theoretical throat = $0.7 \times \text{size of weld}$.
- (2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.
- (3) $x \text{ min.} = 1.4 t_n$ or the thickness of the hub, whichever is smaller, but not less than $1/8 \text{ in. (3 mm)}$, where t_n = nominal pipe wall thickness
- (4) $C_x \text{ min.} = 1.09 t_n$ where t_n = nominal pipe wall thickness

ND-4430 WELDING OF ATTACHMENTS**ND-4431 Materials for Attachments**

Nonpressure-retaining attachments (ND-1132.1) welded to pressure retaining components shall be of materials that meet the requirements of ND-2190. Materials for pressure retaining attachments shall meet the requirements of ND-2120.

ND-4432 Welding of Structural Attachments

The rules of ND-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure retaining material.

ND-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous or intermittent welds. Figure ND-4433-1 illustrates some of the typical details for attaching structural attachments to a component. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds, provided the valve seat is shouldered against the pressure boundary part.

ND-4434 Types of Permanent Structural Attachments

Internal structural supports on cladding surfaces shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

ND-4435 Welding of Nonstructural Attachments and Their Removal

(a) Nonstructural attachments (ND-1132.1) welded to the pressure retaining portion of the component need not comply with ND-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

(1) The welding procedure and the welders have been qualified in accordance with ND-4321.

(2) The material is identified and is compatible with the material to which it is attached.

(3) The welding material is identified and is compatible with the materials joined.

(4) The welds are postweld heat treated when required by ND-4620.

(b) Removal of nonstructural temporary attachments shall be accomplished as follows:

(1) The temporary attachment is completely removed in accordance with the procedures of ND-4211.

(2) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

ND-4436 Installation of Attachments to Piping Systems After Testing

Attachments may be welded to the piping system after performance of the pressure test provided that

(a) the welds do not require PWHT as provided in ND-4622.7;

(b) welds shall be restricted to fillet welds not exceeding $\frac{3}{8}$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $\frac{1}{2}$ in. (13 mm) in thickness;

(c) welds shall not exceed a total length of 24 in. (600 mm) for fillet welds or 12 in. (300 mm) for full penetration welds;

(d) welds shall be examined as required by ND-5000.

ND-4437 Attachments of Stiffener Rings

ND-4437.1 General Requirements. All permanent and temporary attachments of stiffener rings to shells, including tack welds, shall be made by qualified welders using qualified welding procedures.

ND-4437.2 Attachment of Stiffening Rings to Shell.

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel and shall be attached to the shell by welding or bolting. The ring shall be in contact with the shell.

(b) Stiffening rings may be attached to the shell by either continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be

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

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

Acceptable arrangements and spacings of intermittent welds are shown in Figure ND-4437.2(b)-1. Welds on opposite sides of the stiffener may be either staggered or inline as indicated.

(c) All welding of stiffening rings shall comply with the requirements of this Subsection. In areas where a corrosion allowance is specified in the Design Specification, stiffening rings shall be attached to the shell with a continuous fillet weld, seal weld, or full penetration weld.

ND-4450 REPAIR OF WELD METAL DEFECTS**ND-4451 General Requirements**

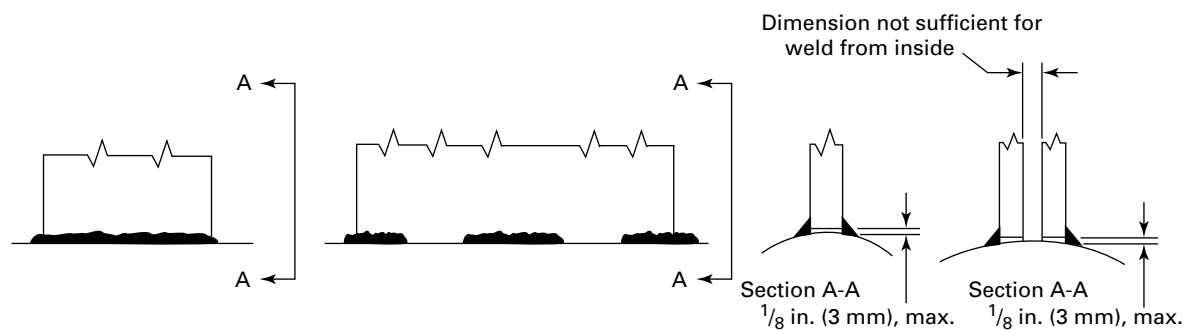
Defects in weld metal detected by the examinations required by ND-5000, or by the tests of ND-6000, shall be eliminated and repaired when necessary.

ND-4452 Elimination of Surface Defects

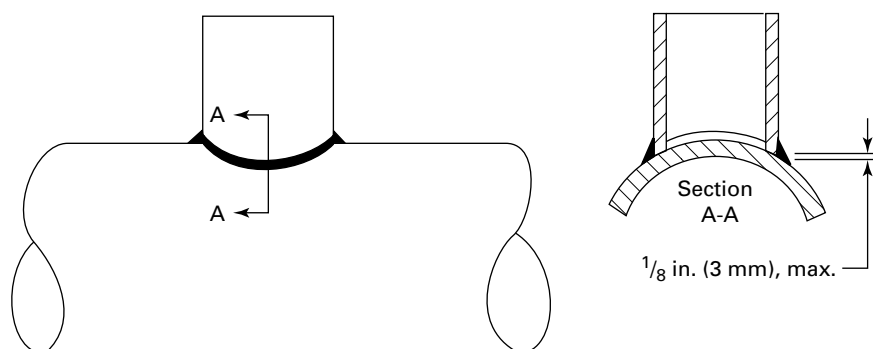
Weld metal surface defects may be removed by grinding or machining and not repaired by welding, provided that the requirements of (a), (b), and (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by ND-3000.

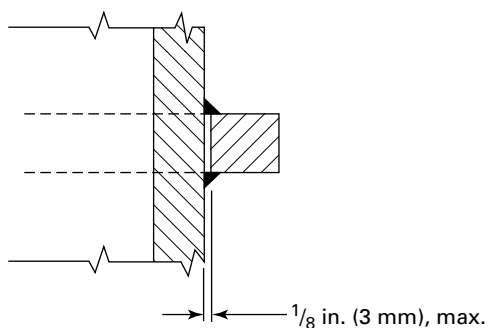
Figure ND-4433-1
Types of Attachment Welds



(a) Attachment of Lugs, Shoes, Pipe Saddles, and Brackets



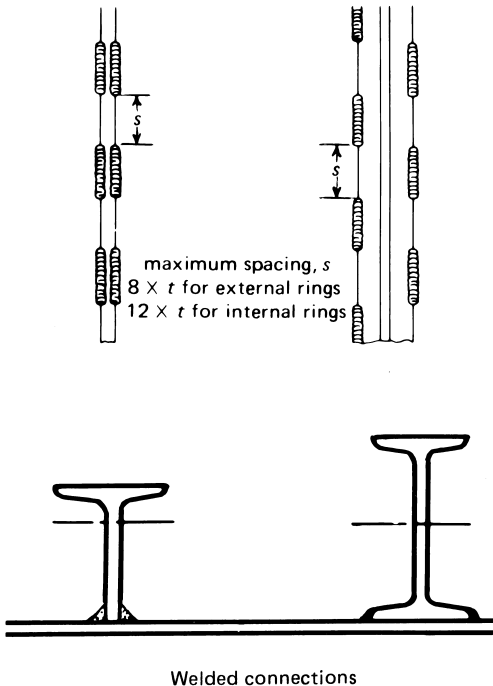
(b) Attachment of Trunnions



(c) Attachment of Rings

GENERAL NOTE: The welds may be full penetration, partial penetration, or fillet welds.

Figure ND-4437.2(b)-1
Some Acceptable Methods of Attaching
Stiffening Rings to Shells of Cylindrical Vessels
Subjected to External Pressure



(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with ND-5110 after blending and meets the acceptance standards of ND-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method that initially detected the defect when the interior surface is inaccessible for surface examination.

ND-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

ND-4453.1 Defect Removal. Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with ND-5110 and meet the acceptance standards of ND-5340 or ND-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

ND-4453.2 Requirements for Welding Material, Procedures, and Welders. The weld repair shall be made using welding materials, welders, and welding procedures qualified in accordance with ND-4125 and ND-4300.

ND-4453.3 Blending of Repaired Areas. After repair the surface shall be blended uniformly into the surrounding surface.

ND-4453.4 Examination of Repair Welds.

(a) The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

- (1) $\frac{1}{3}t$ for $t \leq \frac{3}{4}$ in. (19 mm)
- (2) $\frac{1}{4}$ in. (6 mm) for $\frac{3}{4}$ in. (19 mm) $\leq t \leq 2\frac{1}{2}$ in. (64 mm)
- (3) the lesser of $\frac{3}{8}$ in. (10 mm) or $10\%t$ for $t > 2\frac{1}{2}$ in. (64 mm)

where t equals the thickness of the weld.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted, provided

- (1) the weld had been previously radiographed and met the applicable acceptance standards;
- (2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 5 to the acceptance standards of ND-5330;
- (3) the substitution is limited to Category A and B welds in vessels and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

ND-4453.5 Heat Treatment of Repaired Areas. The area shall be heat treated in accordance with ND-4620.

ND-4460 WELDED TEST PLATES

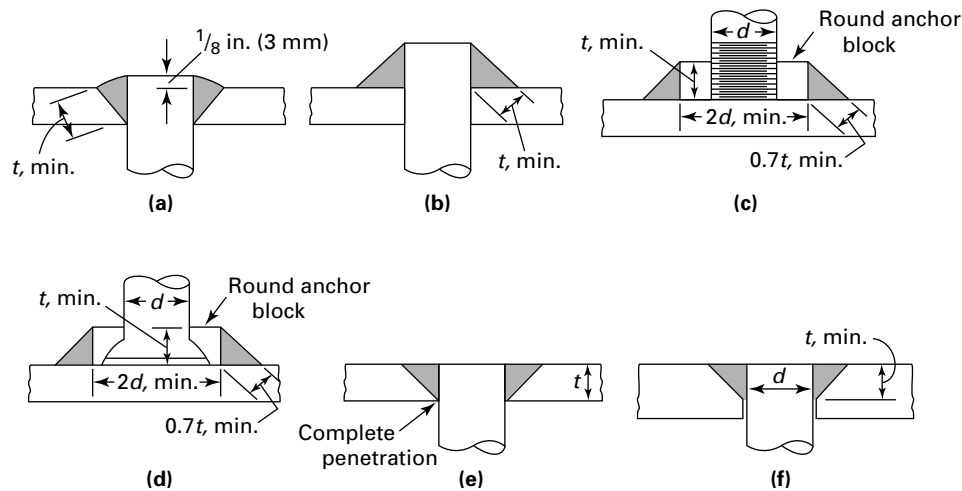
(a) For welded vessels constructed of Type 405 material which are not postweld heat treated, welded test plates shall be made to include material from each melt of plate steel used in the vessel. Plates from two different melts may be welded together and be represented by a single test plate.

(b) From each welded test plate there shall be taken two face bend test specimens as prescribed in Section IX, QW-161.2 and shall meet the requirements of Section IX, QW-162 and QW-163.

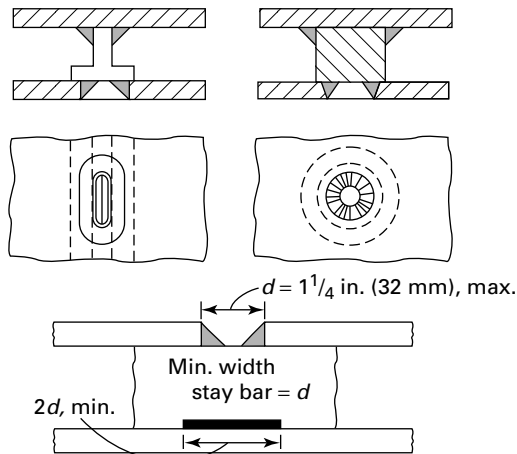
ND-4470 WELDED STAYED CONSTRUCTION

Welded staybolts must be attached using details similar to those shown in Figure ND-4470-1, where t equals the nominal thickness of the inner stayed plate.

**Figure ND-4470-1
Welded Stayed Construction**



(a) Typical Forms of Welded Staybolts



(b) Use of Plug and Slot Welds for Staying Plates

ND-4500 BRAZING

ND-4510 RULES FOR BRAZING

ND-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of tubes to tubesheets and as specified in ND-3671.6. Appurtenances and piping with outside diameter equal to that of NPS 4 (DN 100) and less may be fabricated using brazed joints in accordance with Figure ND-4511-1.

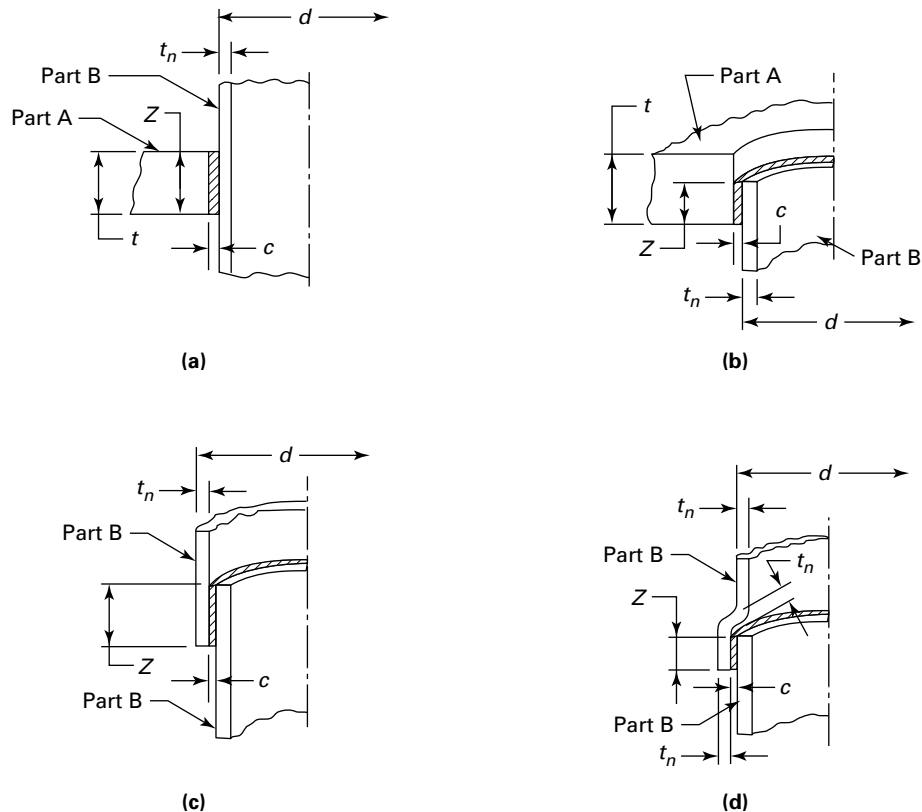
(b) Valves with inlet piping connections of NPS 4 (DN 100) and less may have seats brazed to the valve body or bonnet, provided the seat is shouldered against the pressure boundary part.

ND-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in ND-2150 and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (425°C) and at least 500°F (275°C) above the highest temperature of the joint in service.

Figure ND-4511-1
Brazed Connections for Appurtenances and Piping, NPS 4
(DN 100) and Less



t = thickness of part penetrated
 t_n = nominal thickness of connecting part
 d = outside diameter of part B
 c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
 z = depth of engagement and shall be the lesser of $3t_n$ or d , but in no case less than $1/4$ in. (6 mm)

GENERAL NOTES:

- (a) Part A shall be attached to a component in accordance with the requirements for the component proper.
- (b) Part B shall be attached either to part A or to another part B by the joints shown above, or in accordance with the requirements of the component proper.
- (c) Grooves for preplaced filler metal are permitted, provided the reduction in cross section due to the grooves is considered in the design.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

ND-4520 BRAZING QUALIFICATION REQUIREMENTS

ND-4521 Brazing Procedure and Performance Qualifications

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except as noted below.

ND-4522 Valve Seat Rings

Validation of the procedure qualification in accordance with QB-451.5 Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of NPS 4 (DN 100) and less.

ND-4523 Reheated Joints

In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (165°C) of the solidus temperature of the filler metal.

ND-4524 Maximum Temperature Limits

The design temperature shall not exceed the upper temperature shown in the third column of [Table ND-4524-1](#). For design temperatures below the temperature shown in the second column of [Table ND-4524-1](#), no further testing beyond that required by Section IX is required. For design temperatures in the range shown in the third column of [Table ND-4524-1](#), tests in addition to those required by Section IX are required. These tests shall be considered a part of the procedure qualification. For such design temperatures, two tension tests on production-type joints are required, one at the design temperature and one at $1.05T$ where T is the design temperature in °F ($1.03T$ where T is the design temperature in °C). Neither of these production-type joints shall fail in the braze metal.

ND-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

Parts to be joined by brazing shall be fitted, aligned, and retained in position during the brazing operation within the tolerances specified in the brazing procedure

specification. Brazed joints shall be assembled in a sequence that will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

ND-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with [ND-5360](#).

ND-4600 HEAT TREATMENT

ND-4610 WELDING PREHEAT REQUIREMENTS

ND-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

ND-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method that does not harm the base material or any weld metal already applied or that does not introduce deleterious material into the welding area.

ND-4613 Interpass Temperatures

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

ND-4620 POSTWELD HEAT TREATMENT

ND-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

ND-4622 PWHT Time and Temperature Requirements

ND-4622.1 General Requirements.² Except as otherwise permitted in [ND-4622.7](#), all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained

Table ND-4524-1
Maximum Design Temperatures for Brazing Filler Metal, °F (°C)

Filler Metal Classifica- tion	Temperature Below	Temperature Range Requiring
	Which Only Section IX Tests Are Required, °F (°C)	Section IX Tests and Additional Tests
BCuP	300 (150)	300 – 350 (150 – 175)
BAg	400 (205)	400 – 500 (205 – 260)
BCuZn	400 (205)	400 – 500 (205 – 260)
BCu	400 (205)	400 – 650 (205 – 345)
BAISi	300 (150)	300 – 350 (150 – 175)
BNi	800 (425)	...

GENERAL NOTE: Temperatures are based on AWS recommendations.

within the temperature range and for the minimum holding time specified in [Table ND-4622.1-1](#), except as otherwise permitted in ND-4622.4(d). For P-No. 11A, Group 1 material, the complete component shall be postweld heat treated within the temperature range specified in [Table ND-4622.1-1](#) and the provisions of [ND-4624.2](#) and [ND-4624.3](#) shall not be applied. P-Number groups in [Table ND-4622.1-1](#) are in accordance with Section IX, QW-420. Except as provided in [ND-4624.3](#), PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

ND-4622.2 Time-Temperature Recordings. Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld, item, part, or component. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

ND-4622.3 Definition of Nominal Thickness Governing PWHT. Nominal thickness in [Table ND-4622.7\(b\)-1](#) is the thickness of the weld, the pressure retaining material for structural attachment welds or the thinner of the pressure retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed 1/8 in. (3 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

ND-4622.4 Holding Times at Temperature.

(a) The holding time at temperature as specified in [Table ND-4622.1-1](#) shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of [Table ND-4622.1-1](#) may be used, provided that specimens so heat treated are tested in accordance with [ND-2200](#), [ND-2400](#), and [ND-4300](#).

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in [Table ND-4622.1-1](#), it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with [Table ND-4622.4\(c\)-1](#) and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in [Table ND-4622.4\(c\)-1](#) are to be postweld heat treated at these lower minimum temperatures, the impact test specimens for the welding procedure qualification required by [ND-4300](#) shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in [Table ND-4622.1-1](#) and at the lower minimum temperature and increased minimum holding time permitted by [Table ND-4622.4\(c\)-1](#), are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from [Table ND-4622.1-1](#) and the alternative requirements of [Table ND-4622.4\(c\)-1](#).

(2) Except for P-No. 1 materials, when welds in the materials listed in [Table ND-4622.4\(c\)-1](#) are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by [ND-2400](#) shall be made using the same minimum temperature and increased minimum holding times. Welding material certified at the temperature range and minimum holding time specified in [Table ND-4622.1-1](#) and at the lower minimum temperatures and increased minimum holding times permitted by [Table ND-4622.4\(c\)-1](#) are also certified for any temperature in between.

(3) Base material certified in accordance with [ND-2200](#) may be postweld heat treated at the lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum

Table ND-4622.1-1
Mandatory Requirements for Postweld Heat Treatment of Welds

P-No. (Section IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$\frac{1}{2}$ in. (13 mm) or less	Over $\frac{1}{2}$ in. to 2 in. (13 mm to 50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
1, 3	1,100 – 1,250 (595 – 675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
4	1,100 – 1,250 (595 – 675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1,250 – 1,400 (675 – 760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
6 Gr. 4	1,050 – 1,150 (565 – 620)				
7	1,300 – 1,400 (705 – 760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9A Gr. 1	1,100 – 1,250 (595 – 675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9B Gr. 1	1,100 – 1,175 (595 – 635)				
10C Gr. 1 10F Gr. 1	1,100 – 1,250 (595 – 675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
10I Gr. 1	1,300 – 1,400 (705 – 760)				
11A Gr. 4	1,000 – 1,050 (540 – 565)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min./mm)
15E Gr. 1	1,350 – 1,425 (730 – 775)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min. each additional inch (5 h plus 0.5 min/mm) over 125 mm
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45, and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%, and all nonferrous materials	...	PWHT neither required nor prohibited			

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in [ND-4622.7](#).

NOTE:

(1) All temperatures are metal temperatures.

Table ND-4622.4(c)-1
Alternative Holding Temperatures and Times

Material P-Nos.	Alternative Minimum Holding Temperatures, °F (°C)	Alternative Minimum Holding Times
1, 3, 9A Gr.1, 9B Gr.1	1,050 (565)	2 hr/in. thick (4 min/mm)
1, 3, 9A Gr.1, 9B Gr.1	1,000 (540)	4 hr/in. thick (8 min/mm)

GENERAL NOTE: All other requirements of ND-4622 shall apply.

holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

ND-4622.5 PWHT Requirements When Different P-Number Materials Are Joined. When pressure retaining materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table ND-4622.1-1 for the material requiring the higher PWHT temperature range.

ND-4622.6 PWHT Requirements for Nonpressure-Retaining Parts. When nonpressure-retaining material is welded to pressure retaining material, the postweld heat treatment temperature range of the pressure retaining material shall control.

ND-4622.7 Exemptions to Mandatory Requirements. Postweld heat treatment in accordance with this Subarticle is not required for (a) through (d) below:

- (a) nonferrous material;⁵⁶
- (b) welds exempted in Table ND-4622.7(b)-1;
- (c) welds subjected to temperatures above the PWHT temperature range specified in Table ND-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperatures;
- (d) welds connecting nozzles to components or branch to run piping, provided the requirements in ND-4622.8 are met;
- (e) weld repairs to P-No. 3 material in vessels, provided the requirements of ND-4622.9 are met.

ND-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch-to-Run Piping Welds. Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table ND-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) below are met for partial penetration and (b) below are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after

(1) the ferritic materials to be joined are buttered or built up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm), and

(2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with ND-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal, provided that

(1) the component or run pipe is built up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with ND-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the component or run pipe thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed $1\frac{1}{2}$ in. (38 mm), and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;

(6) a 200°F (95°C) minimum heat is maintained during welding whenever the nominal thickness of the weld exceeds:

(-a) $1\frac{1}{4}$ in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less; or

(-b) $\frac{3}{4}$ in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

ND-4622.9 Weld Repair to Vessels. Limited weld repairs to vessels of P-No. 3 material and A-No. 1, 2, 10, or 11 weld filler metal (Section IX, QW-442) may be made without PWHT or after the final PWHT, provided the following requirements are met.

(a) *Examination of Area to Be Repaired.* Before a repair is made, the area shall be examined by magnetic particle or liquid penetrant method in accordance with ND-5110 and this Subsection and shall meet the acceptance standards of ND-5340 or ND-5350, as appropriate.

(b) *Maximum Extent of Repairs.* A repair shall not exceed 10 in.² (6 500 mm²) in surface area and shall not be greater in depth than 50% of the base metal or weld thickness or $\frac{1}{2}$ in. (13 mm), whichever is less.

(c) *Repair Welding Procedure*

(1) The repairs shall be made using one or more procedures and welders qualified in accordance with Section IX using the shielded metal arc process and low hydrogen covered electrodes.

**Table ND-4622.7(b)-1
Exemptions to Mandatory PWHT**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (ND-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Req'd., °F (°C)
1	All welds, where the materials being joined are 1½ in. (38 mm) and less	1¼ in. (32 mm) and less	0.30 and less	...
		Over 1¼ in. (32 mm) to 1½ in. (38 mm)	0.30 and less	200 (95)
		¾ in. (19 mm) or less	Over 0.30	...
		Over ¾ in. (19 mm) to 1½ in. (38 mm)	Over 0.30	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ in. (19 mm) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. (38 mm) or less	...	0.30	100 (38)
	Over 1½ in. (38 mm) to 3 in. (75 mm)	...	0.30	200 (95) [Note (4)]
	Over 3 in. (75 mm)	...	0.30	250 (120) [Note (5)]
3	For vessel repair without required PWHT, see NC-4622.9	...	...	350 (175)
3 Except Gr. 3	All welds, except repair welds in vessels, provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	5/8 in. (16 mm) or less	0.25 or less	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure retaining material	1/2 in. (13 mm) or less	0.25 or less	200 (95)
	Circumferential butt welds in pipe and tubes	1/2 in. (13 mm) or less	0.25 or less	200 (95)
4	All welds in pipe NPS 4 (DN 100) and less, and tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	1/2 in. (13 mm) or less	0.15 or less	250 (120)
5A, 5B, 5C	All welds in pipe NPS 4 (DN 100) and less, and tubes with maximum, reported chromium 3.00% or less and nominal O.D. 4.5 in. (114 mm) or less and attachment welds	1/2 in. (13 mm) or less	0.15 or less	300 (150)
6 (for type 410S) or 7 Gr. 1 (for type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	3/8 in. (10 mm) or less	0.08 or less	...
9A Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	5/8 in. (16 mm) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	...	200 (95)
	Circumferential butt welds or socket welds in pipe NPS 4 (DN 100) and less, and tubes with nominal O.D. 4.5 in. (114 mm) or less, and attachment welds	1/2 in. (13 mm) or less	0.15 or less	250 (120)
9B Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	5/8 in. (16 mm) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	...	200 (95)

**Table ND-4622.7(b)-1
Exemptions to Mandatory PWHT (Cont'd)**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (ND-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Req'd., °F (°C)
10C Gr. 1	All welds, including repair welds, in material 1½ in. (38 mm) and less	1¼ in. (32 mm) and less	0.30 and less	...
		Over 1¼ in. (32 mm) to 1½ in. (38 mm)	0.30 and less	200 (95)
		¾ in. (19 mm) or less	Over 0.30	...
		Over ¾ in. (19 mm) to 1½ in. (38 mm)	Over 0.30	200 (95)
	Fillet, partial penetration, and repair welds in material over 1½ in. (38 mm)	¾ in. (19 mm) or less	...	200 (95)
10I Gr. 1	All welds in material ½ in. (13 mm) and less	½ in. (13 mm) or less	...	...
11A Gr. 1	All welds in material ½ in. (13 mm) and less	½ in. (13 mm) or less	...	...
11A Gr. 4	All welds in material ½ in. (13 mm) and less	½ in. (13 mm) or less	...	250 (120)

GENERAL NOTE: The exemptions noted in this Table do not apply to the following:

- (a) electron beam welds in ferritic materials of ⅛ in. (3 mm) in thickness;
- (b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410 S), P-No. 10, and P-No. 11 materials.

NOTES:

- (1) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
- (2) Carbon level of the pressure retaining materials being joined.
- (3) The maximum resulting hardness of the heat affected zone in the procedure qualification test plate shall not exceed 35 Rc.
- (4) Intermediate postweld soak at not less than 200°F (95°C) for 2 hr minimum.
- (5) Intermediate postweld soak at not less than 300°F (150°C) for 2 hr minimum.
- (6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

(2) The largest electrode diameter shall be 5/32 in. (4 mm), and the bead width shall not exceed four times the electrode diameter.

(3) The repair weld shall be made with a minimum of two layers of weld metal. The last layer shall be limited or ground off so that the weld surface does not extend above the base metal a greater distance than that allowed for reinforcement of butt welds.

(4) A preheat and interpass temperature of 300°F (150°C) minimum shall be used.

(d) *Examination of Repair Welds.* Following the repair and when the area has reached ambient temperature, the area shall again be examined by magnetic particle methods and accepted in accordance with (a).

ND-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (425°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.6 m) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 material may be cooled in air from the PWHT holding temperature specified in Table ND-4622.1-1.

(b) For P-No. 7 material the cooling rate at temperatures above 1,200°F (650°C) shall not exceed 100°F/hr (56°C/hr), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

ND-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

ND-4624.1 Furnace Heating — One Heat. Heating the component or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the component or item is prohibited.

ND-4624.2 Furnace Heating — More Than One Heat. The component or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of ND-4624.1 apply and overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful.

The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

ND-4624.3 Local Heating. Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperatures within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

ND-4624.4 Heating Components Internally. The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the component or item. Previous to this operation, the component or item shall be fully enclosed with insulating material.

ND-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

ND-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPE, PUMPS, AND VALVES

ND-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with ND-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $\frac{3}{4}$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with ND-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (100 mm) and a wall thickness greater than $\frac{1}{2}$ in. (13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold bent or formed shall require a heat treatment in accordance with ND-4620.

ND-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) below are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature of 1,650°F (900°C) or higher shall require no subsequent heat treatment, provided the requirements of ND-4213 have been met.

(b) Austenitic stainless steel pipe or portions of pumps or valves that have been heated for bending or other forming operations may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe or portions of pumps or valves that have been cold bent or formed may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy steel pipe or portions of pumps or valves with sizes and wall thicknesses less than specified in ND-4651(b) and ND-4651(c) may be cold bent or formed without a heat treatment following bending.

ND-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

ND-4700 MECHANICAL JOINTS

ND-4710 BOLTING AND THREADING

ND-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

ND-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

ND-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

ND-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

ND-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

(a) Electrical and mechanical penetration assemblies, except those portions performing an electrical conducting or insulating function, shall be constructed in accordance with the rules for components.

(b) Tubes or pipes of NPS 2 (DN 50) and less may be joined to a penetration assembly in accordance with the rules of [ND-4350](#).

(c) The closing seam for the penetration assembly may be made with a multipass single lap fillet weld as shown in [Figure ND-4730-1](#), provided the requirements of (1) through (5) below are met.

(1) One of the heads on the penetration assembly shall meet the requirements of [ND-3352.3](#).

(2) The penetration assembly shall not exceed 18 in. (450 mm) outside diameter.

(3) The Design Pressure of the penetration assembly shall not exceed 100 psi (700 kPa), and the Design Temperature shall not exceed 400°F (205°C).

(4) Examination of the fillet weld shall be by the liquid penetrant method in accordance with [ND-5350](#).

(5) The fillet weld and closure head shall meet the requirements of [ND-3720\(b\)](#).

ND-4800 EXPANSION JOINTS

ND-4810 FABRICATION AND INSTALLATION RULES FOR BELLOWS EXPANSION JOINTS

For bellows type expansion joints, the requirements of (a) through (f) below shall be met.

(a) All welded joints shall comply with the requirements of [ND-4000](#).

(b) The longitudinal seam weld in the bellows shall be a butt type full penetration weld.

(c) The bellows of the expansion joint shall be attached to the welding ends or flange by circumferential welds of a butt type having a full penetration through the thickness of the bellows portion, as shown in [Figure ND-4810\(c\)-1](#).

(d) Other than the attachment welds, no circumferential welds are permitted in the bellows elements.

(e) Prior to installation of the expansion joint in the system, weld repairs shall not be permitted on parent material of the bellows.

(f) See [ND-3649.2](#) for general requirements applicable to fabrication and installation.

**Figure ND-4730-1
Penetration Assembly**

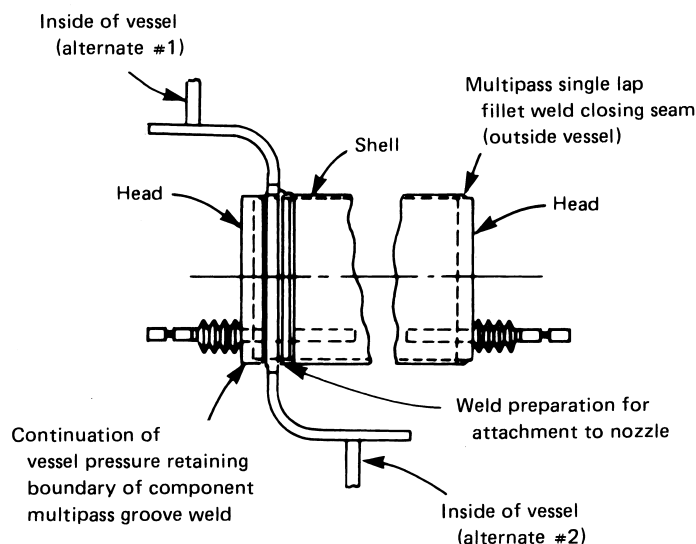
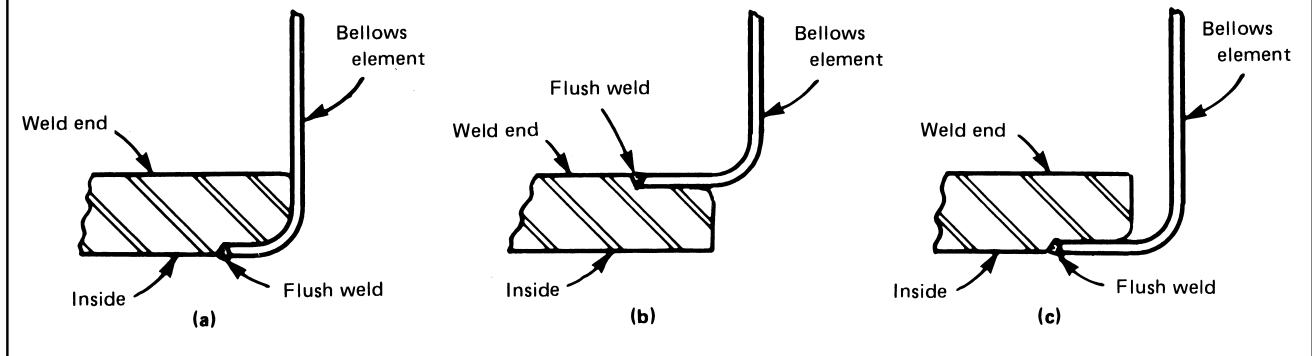


Figure ND-4810(c)-1
Permissible Attachment Welds for Bellows



ARTICLE ND-5000 EXAMINATION

ND-5100 GENERAL REQUIREMENTS FOR EXAMINATION

ND-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

ND-5111 General Requirements

(a) Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of T-274.2. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10.

(b) The extent of radiography shall meet the requirements of ND-3352 for the joint efficiency used in the design.

(c) The requirements for spot radiography are given in ND-5400.

(d) Nondestructive examination requirements for tanks are given in ND-5280.

(e) The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

ND-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures that have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

ND-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination material is applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

ND-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by ND-5200 shall be performed at the times stipulated in (a) through (d) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate⁵⁷ or final postweld heat treatment, when required, except as provided in (1) and (2) below.

(1) Radiographic examination of welds in items fabricated of P-No. 1 materials may be performed prior to any required postweld heat treatment.

(2) Radiographic examination of welds in P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment provided the welds are ultrasonically examined after an intermediate or the final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic materials that penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation that caused this inaccessibility. These examinations shall be performed before PWHT.

(e) Ultrasonic examination of electroslag welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

ND-5200 EXAMINATION OF WELDS**ND-5210 CATEGORY A VESSEL WELDED JOINTS IN VESSELS AND SIMILAR WELDED JOINTS IN PIPING, PUMPS, AND VALVES****ND-5211 Vessels****ND-5211.1 General Requirements.**

(a) Category A welded joints (ND-3351.1) shall be fully radiographed when

(1) the thickness exceeds the limits of ND-5211.2 or ND-5211.3;

(2) the welds are based on a joint efficiency permitted by ND-3352.1(a);

(3) the butt welds in nozzles or communicating chambers are attached to vessel sections or heads that are required to be fully radiographed by (1) or (2) above;

(4) the welds are made by the electroslag welding process.

(b) Welds not required to be fully radiographed by (a) above shall be examined by spot radiography in accordance with the requirements of ND-5111, except as permitted by (c) below. Spot radiography is required when a joint efficiency described in ND-3352.1(b) is used.

(c) No radiography is required when the vessel or part is designed for external pressure only or when the design complies with ND-3352.1(c).

ND-5211.2 Ferritic Materials. Complete radiography shall be performed at each butt welded joint at which the thinner of the plate or vessel wall thickness at the welded joint exceeds the thickness limit above which full radiography is required in Table ND-5211.2-1.

ND-5211.3 Nonferrous Materials.

(a) Vessels or parts of vessels constructed of nonferrous materials shall be radiographed in accordance with the requirements of ND-3352.

(b) Welded butt joints in vessels constructed of materials covered by specifications SB-163 (Alloy 800 only), SB-333, SB-334, SB-335, SB-336, SB-407, SB-408, SB-409, SB-443, SB-444, and SB-446 shall be examined radiographically for their full length when the thinner of the plate or vessel wall thicknesses at the welded joint exceeds $\frac{3}{8}$ in. (10 mm).

(c) Vessels constructed of unalloyed titanium shall have all welded joints of Categories A and B fully radiographed.

(d) All welds, both groove and fillet, in components constructed with materials SB-333, SB-334, SB-335, and SB-336 shall be examined for the detection of cracks by the liquid penetrant method.

(e) All welded joints in vessels constructed of unalloyed titanium shall be examined by the liquid penetrant method.

(f) All welded joints in components or parts constructed with materials SB-163 (Alloy 800 only), SB-407, SB-408, SB-409, SB-443, SB-444, and SB-446 not required to be radiographed shall be examined by the liquid penetrant method.

ND-5212 Piping, Pumps, and Valves

Longitudinal welded joints in piping greater than NPS 2 (DN 50) shall be examined by the requirements of ND-2500. Longitudinal welded joints in pressure retaining parts of pumps and valves greater than NPS 2 (DN 50) shall be examined in accordance with the requirements of ND-2500 for the applicable product form. Butt welds made by the electroslag welding process shall be radiographed for their entire length.

ND-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES**ND-5221 Vessels**

(a) Category B welded joints (ND-3351.2) shall be fully radiographed when

(1) the thickness exceeds the limits of ND-5211.2 or ND-5211.3, except as permitted in (b) below;

(2) the welds are based on a joint efficiency permitted by ND-3352.2(a), except as permitted in (b) below;

(3) they are butt welds in nozzles or communicating chambers attached to vessel sections or heads that are required to be fully radiographed and exceed NPS 10 (DN 250) or $1\frac{1}{8}$ in. (29 mm) wall thickness;

(4) the welds are made by the electroslag welding process.

(b) In accordance with (a)(2) above, any Category B and similar type welds not required to be fully radiographed by thickness or location as in (a) above shall as a minimum be partially radiographed. This shall consist of a radiographic examination at least 6 in. (150 mm) long of any section of the weld picked at random plus a similar examination of any intersection of the weld with all Category A

**Table ND-5211.2-1
Thickness Above Which Full Radiographic
Examination of Butt Welded Joint is
Mandatory**

P-Number Classification of Material	Nominal Thickness Above Which Butt Welded Joints Shall Be Fully Radiographed, in. (mm)
1	$1\frac{1}{4}$ (32)
3	$\frac{3}{4}$ (19)
4	$\frac{5}{8}$ (16)
5	0 0
7	$\frac{5}{8}$ (16)
8	$1\frac{1}{2}$ (38)
10	$\frac{5}{8}$ (16)
11	$\frac{5}{8}$ (16)

and similar welds in either of the sections being connected. Acceptance standards for partially examined welds shall be as set forth in [ND-5321](#).

(c) The welds not required to be radiographed by (a) or (b) above shall be examined by spot radiography except as permitted by (d) below. Spot radiography is required when a joint efficiency described in [ND-3352.2\(b\)](#) is used.

(d) No radiography is required when a vessel or part is designed for external pressure only or when a design complies with [ND-3352.1\(c\)](#).

(e) The requirements of [ND-5211.2](#) and [ND-5211.3](#) shall be met.

ND-5222 Piping, Pumps, and Valves

Circumferential welded joints in piping, pumps, and valves greater than NPS 2 (DN 50) shall be examined by either the magnetic particle, liquid penetrant, or radiographic methods. Acceptance standards shall be those stated in [ND-5300](#).

ND-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN PIPING, PUMPS, AND VALVES

ND-5231 Vessels

(a) Category C full penetration welds shall be fully radiographed when

(1) the thickness exceeds the requirements of [ND-5211.2](#) or [ND-5211.3](#);

(2) they are butt welds in nozzles or communicating chambers attached to vessel sections or heads that are required to be fully radiographed and exceed NPS 10 (DN 250) or $1\frac{1}{8}$ in. (29 mm) wall thickness;

(3) the welds are made by the electroslag process.

(b) Any Category C butt weld not required to be fully radiographed by thickness or location using the joint efficiency of [ND-3352.3\(a\)](#) shall meet the requirements of [ND-5221\(b\)](#).

(c) The welds not required to be fully radiographed by (a) above shall be examined by spot radiography, except as permitted by (d) below. Spot radiography is required when the butt welds are designed with a joint efficiency as described in [ND-3352.3\(b\)](#).

(d) No radiography is required when the vessel or part is designed for external pressure only, when the design complies with [ND-3352.1\(c\)](#), or when the joint is not a butt welded joint.

ND-5232 Piping, Pumps, and Valves

The requirements for welded joints similar to Category C shall be the same as given in [ND-5222](#).

ND-5240 CATEGORY D VESSEL WELDED JOINTS AND SIMILAR JOINTS IN PIPING, PUMPS, AND VALVES

ND-5241 Vessels

(a) Full penetration butt welds of Category D ([ND-3351.4](#)) shall be fully radiographed when located

(1) in a vessel or part that is designed with a joint efficiency as permitted by [ND-3352.1\(a\)](#);

(2) in nozzles or communicating chambers that are attached to vessel sections or heads required to be fully radiographed.

(b) Butt welds not required to be fully radiographed by (a) above shall be examined by spot radiography, except as permitted by (c) below.

(c) No radiography is required for butt welded joints when the vessel or part is designed for external pressure only or when the design complies with [ND-3352.1\(c\)](#). Radiography is not required for nonbutt-welded joints.

ND-5242 Piping, Pumps, and Valves

The requirements for welded joints similar to Category D welded joints shall be as given in [ND-5222](#).

ND-5260 WELDED STAYED CONSTRUCTION

Welded staybolts need not be radiographed. When welded stays are used to stay jacketed vessels, the inside weld shall be visually examined before closing plates are attached.

ND-5270 SPECIAL WELDS

ND-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

ND-5273 Hard Surfacing

Hard surfacing shall be examined by the liquid penetrant method in accordance with [ND-2546](#), and the acceptance standards applicable to material less than $\frac{5}{8}$ in. (16 mm) thick shall apply. Penetrant examination is not required for hard surfacing on valves with inlet connections NPS 4 (DN 100) or less.

ND-5274 Tube-to-Tubesheet Welds

Tube-to-tubesheet welds shall be examined by the liquid penetrant method.

ND-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints that cannot be directly examined.

ND-5276 Inertia and Continuous Drive Friction Welds

When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

ND-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

ND-5279 Special Exceptions

When the joint detail does not permit radiographic examination to be performed in accordance with this Article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure that has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examinations shall be in accordance with ND-5110 and meet the acceptance standards of ND-5300.

ND-5280 WELDED JOINTS IN STORAGE TANKS**ND-5282 Atmospheric Storage Tanks**

ND-5282.1 Sidewall Joints. Sidewall joints shall be examined in accordance with ND-5211 and ND-5221.

ND-5282.2 Roof Joints and Roof-to-Sidewall Joints. Roof joints and roof-to-sidewall joints shall be examined visually.

ND-5282.3 Bottom Joints. Bottom joints shall be examined from the inside of the tank by applying soapsuds to the joints and pulling a partial vacuum of at least 3 psi (20 kPa) by means of a vacuum box with transparent top.

ND-5282.4 Bottom-to-Sidewall Joints. Bottom-to-sidewall joints shall be examined by the vacuum box method as required by ND-5282.3. Alternatively, MT or PT examination may be substituted for the vacuum box tests, provided the outside of the joint is accessible for visual examination during the test required by ND-6000.

ND-5282.5 Nozzle-to-Tank Joints. Nozzle-to-sidewall or bottom joints shall be examined by either the magnetic particle or liquid penetrant method. Nozzle-to-roof joints shall be visually examined.

ND-5282.6 Joints in Nozzles. All joints in roof nozzles shall be visually examined. Joints in other nozzles shall be examined by the liquid penetrant or magnetic particle method.

ND-5282.7 Other Joints. Joints not specifically covered by ND-5282 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

ND-5283 Welds in 0 psi to 15 psi (0 kPa to 100 kPa) Storage Tanks

ND-5283.1 Sidewall Joints. Sidewall joints shall be examined in accordance with ND-5211 and ND-5221.

ND-5283.2 Roof Joints. Roof joints shall be examined in accordance with ND-5211.

ND-5283.3 Roof-to-Sidewall Joints. Roof-to-sidewall joints shall be radiographed in accordance with ND-5211 if the design permits. If not radiographed, this joint shall be examined by the magnetic particle or liquid penetrant method.

ND-5283.4 Bottom Joints. Joints in bottoms supported directly on grade shall be examined by the vacuum box method as detailed in ND-5282.3. Joints not supported directly on grade shall be fully radiographed.

ND-5283.5 Bottom-to-Sidewall Joints. Bottom-to-sidewall joints shall be examined by the vacuum box method as required by ND-5282.3. Alternatively, MT or PT examination may be substituted for the vacuum box test, provided the outside of the joint is accessible for visual examination during the test required by ND-6000.

ND-5283.6 Nozzle-to-Tank Joints. Nozzle-to-tank joints shall be examined by either the magnetic particle or the liquid penetrant method.

ND-5283.7 Joints in Nozzles. Joints in nozzles shall be examined by either the magnetic particle or the liquid penetrant method.

ND-5283.8 Other Joints. Joints not specifically covered by ND-5283 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

ND-5300 ACCEPTANCE STANDARDS**ND-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS****ND-5321 Evaluation of Indications**

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

- (a) any indication characterized as a crack or zone of incomplete fusion or penetration;
- (b) any other elongated indication that has a length greater than

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. (19 mm to 57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of that shown as acceptable in Appendix VI;

(f) when a Category B or C butt weld, partially radiographed as required in ND-5221(b) or ND-5231(b), is acceptable in accordance with (a) through (e) above, the entire weld length represented by this partial radiograph is acceptable;

(g) when a Category B or C butt weld, partially radiographed as required in ND-5221(b) or ND-5231(b), has been examined and any radiograph discloses welding that does not comply with the minimum quality requirements of (a) through (e) above, one additional section at least 6 in. long for each radiograph disclosing such defective welding, but a minimum total of two, shall be radiographically examined in the same weld unit at other locations. The location of these additional radiographs shall be acceptable to the Inspector.

(1) If the additional sections examined show welding which meets the minimum quality requirements of (a) through (e) above, the entire weld unit represented by the total number of radiographs is acceptable. The defective welding disclosed by the partial radiographs shall be removed and the area repaired by welding. The weld repaired areas shall be radiographically examined.

(2) If any of the additional sections examined shows welding that does not comply with the minimum quality requirements of (a) through (e) above, the entire unit of weld represented shall be rejected. The entire rejected weld represented shall be rewelded, or the entire unit of weld represented shall be completely radiographed and any part of the weld not meeting the requirements of (a) through (e) above shall be repaired and reexamined radiographically. The rewelded joint shall be partially radiographed as required in ND-5221(b) or ND-5231(b), or the weld repaired areas shall be radiographically reexamined.

ND-5322 Evaluation of Indications (Spot Radiography)

The acceptability of welds examined by spot radiography shall be determined by (a), (b), and (c) below.

(a) Welds in which the radiograph shows any type of crack or zone of incomplete fusion or penetration shall be unacceptable.

(b) Welds in which the radiographs show slag inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than $\frac{2}{3}T$ where T is the thickness of the thinner plate welded. If several imperfections within the above limitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such imperfections is not more than T in a length of $6T$ or proportionately for radiographs shorter than $6T$ and if the longest imperfections considered are separated by at least $3L$ of acceptable weld metal, where L is the length of the longest imperfection. The maximum length of acceptable imperfections shall be $\frac{3}{4}$ in. (19 mm). Any such imperfections shorter than $\frac{1}{4}$ in. (6 mm) shall be acceptable for any plate thickness.

(c) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

(d) Evaluation and Retests

(1) When an area which is spot radiographed is acceptable in accordance with (a) and (b) above, the entire weld length represented by this radiograph is acceptable.

(2) When a spot has been examined and the radiograph discloses welding that does not comply with the minimum quality requirements of (a) and (b) above, two additional spots shall be radiographically examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in ND-5420(c).

(-a) If the two additional spots examined show welding that meets the minimum quality requirements of (a) and (b) above, the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding, or it may be allowed to remain in the weld joint, at the discretion of the Inspector.

(-b) If either of the two additional spots examined shows welding that does not comply with the minimum quality requirements of (a) and (b) above, the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire unit of weld represented shall be completely radiographed and defective welding only need be corrected.

(-c) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be spot radiographically examined at one location in accordance with the foregoing requirements of ND-5420.

ND-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections that produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards as follows.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable, regardless of length.

ND-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS**ND-5341 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications that are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

ND-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (5 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.² (4 000 mm²) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

ND-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS**ND-5351 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding may produce similar indications that are nonrelevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

ND-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (5 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.² (4 000 mm²) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

ND-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Brazing metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow, visible line of brazing alloy at the joint.

ND-5380 GAS AND BUBBLE FORMATION TESTING

For gas and bubble formation testing, the test procedure shall be in accordance with Section V, Article 10, T-1030. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the

formation of bubbles or the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

ND-5400 SPOT EXAMINATION OF WELDED JOINTS⁵⁸

ND-5410 GENERAL REQUIREMENTS

Vessels and tanks that have butt welded joints that are not radiographed for their full length and that are required to be spot examined by the rules of this Subsection shall be examined locally by spot radiography in accordance with this Subarticle, except for those vessels or tanks designed for external pressure only.

ND-5420 MINIMUM EXTENT OF SPOT RADIOGRAPHIC EXAMINATION

(a) One spot shall be examined in the first 50 ft (15.2 m) of welding in each vessel and one spot shall be examined for each additional 50 ft (15.2 m) of welding or fraction thereof, except that when identical vessels or tanks individually of less than 50 ft (15.2 m) seam length are being fabricated under the rules of this Subsection, 50 ft (15.2 m) increments of welding may be represented by one spot examination.

(b) Such additional spots as may be required shall be selected so that an examination is made of the welding of each welding operator or welder. Under conditions where two or more welders or welding operators make weld layers in a joint or on the two sides of a double welded butt joint, one spot examination may represent the work of both welders or welding operators.

(c) Each spot examination shall be made as soon as practicable after the completion of the increment of weld that is to be examined. The location of the spot shall be chosen by the Inspector, except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the Certificate Holder may exercise his own judgment in selecting the spots.

ND-5430 STANDARDS FOR SPOT RADIOGRAPHIC EXAMINATION

Spot examination by radiography shall be made in accordance with the technique prescribed in Section V, Article 2. The minimum length of spot radiograph shall be 6 in. (150 mm).

ND-5440 EVALUATION AND RETESTS

(a) When an area that is spot radiographed is acceptable in accordance with ND-5322(a) and ND-5322(b), the entire weld length represented by this radiograph is acceptable.

(b) When an area that is spot radiographed has been examined and the radiograph discloses welding that does not comply with the minimum quality requirements of ND-5322(a) and ND-5322(b), two additional spots shall

be radiographically examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or Certificate Holder as provided for the original spot examination in ND-5420(c).

(1) If the two additional spots examined show welding which meets the minimum quality requirements of ND-5322(a) and ND-5322(b), the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding, or it may be allowed to remain in the weld joint, at the discretion of the Inspector.

(2) If either of the two additional spots examined shows welding that does not comply with the minimum quality requirements of ND-5322(a) and ND-5322(b), the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded, or, at the Certificate Holder's option, the entire unit of weld represented shall be completely radiographed and defective welding only need be corrected.

(3) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be spot radiographically examined at one location in accordance with the foregoing requirements of ND-5400.

ND-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

ND-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by ND-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of ND-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

ND-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

ND-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.^{59, 60} The ACCP qualified and certified NDE Personnel option shall not be used for Section III. The Employer's⁶¹ written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A and Table 6.3.1 B of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times identified in Table 6.3.1 A and Table 6.3.1 B of SNT-TC-1A for Level II certification may be reduced from 8 hr and 16 hr to 4 hr and 8 hr, respectively, for visual examination personnel.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

ND-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [ND-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

ND-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

ND-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

ND-5700 EXAMINATION REQUIREMENTS FOR EXPANSION JOINTS

ND-5720 BELLOWS EXPANSION JOINTS

The examinations stipulated in (a) through (f) below are required to verify the integrity of bellows expansion joints for installation in piping systems.

(a) The formed bellows shall be determined by visual examination to be free of defects such as notches, crevices, material buildup or upsetting, or weld spatter, which may serve as points of local stress concentration. Suspect surface areas shall be further examined by liquid penetrant method.

(b) The longitudinal seam weld in the bellows shall be examined by the liquid penetrant method. When the individual ply thickness exceeds $\frac{1}{8}$ in. (3 mm), the weld shall also be radiographed. These examinations may be performed either before or after the bellows is formed.

(c) The circumferential attachment weld between the bellows and pipe or flange shall be examined by the liquid penetrant method when the total bellows thickness is

$\frac{1}{4}$ in. (6 mm) or less. When the total thickness exceeds this limit, the weld shall be radiographed, except where radiography is not meaningful; for example, when the weld thickness constitutes less than 20% of the total thickness being radiographed, liquid penetrant examination may be substituted.

(d) In the case of liquid penetrant examination of bellows welds, imperfections producing the following indications are unacceptable:

(1) cracks or linear indications;

(2) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.5 mm) or less edge to edge;

(3) five or more randomly distributed rounded indications in a weld length of 6 in. (150 mm);

(4) any rounded indication exceeding the lesser of one-half the bellows thickness or $\frac{1}{16}$ in. (1.5 mm) in diameter.

(e) The examination of all other welds in the expansion joint shall comply with this Article.

(f) The variation of the cylindrical end thickness of the formed bellows from the nominal or specified thickness shall not exceed the values given in Table 2 of SA-480. Thinning of the bellows material during forming shall be considered in the design and selection of material thickness but need not be limited to the values specified in Table 2 of SA-480.

ARTICLE ND-6000 TESTING

ND-6100 GENERAL REQUIREMENTS

ND-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

ND-6111 Scope of Pressure Testing

All pressure retaining components, appurtenances, and completed systems shall be pressure tested, except as specified in (a) through (d) below. Portions of piping systems that are exempt shall be identified in the Design Specification and N-5 Data Report Form. The design specification shall be available to the Authorized Nuclear Inspector when the balance of the system is hydrostatically tested.

(a) Bolts, studs, nuts, washers, and gaskets are exempt.

(b) The following portions of piping systems whose only function is to transport fluids to and from spray ponds, lakes, reservoirs, or tanks that are open to the atmosphere are exempt:

(1) piping downstream of the last isolation valve preceding the pipe discharge to the spray pond, lake, reservoir or tank; and

(2) piping upstream of the intake pump inlet isolation valve.

(c) Where systems discharge into Class 3 vessels or the gaseous regions of MC containment vessels through spargers or spray nozzles, only that portion of the system external to the vessel is required to be pressure tested.

(d) The portion of a Class 3 safety and safety relief valve discharge piping that is submerged below the minimum Design Level in a containment pressure suppression pool of a MC or CC containment vessel is exempt. The minimum Design Level shall be specifically designated in the Design Specification.

ND-6112 Pneumatic Testing

A pneumatic test in accordance with ND-6300 may be substituted for the hydrostatic test when permitted by ND-6112.1(a).

ND-6112.1 Pneumatic Test Limitations.

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exist:

(1) when components, appurtenances, or systems are so designed or supported that they cannot safely be filled with liquid;⁶²

(2) when components, appurtenances, or systems which are not readily dried, are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

ND-6112.2 Precautions to Be Employed in Pneumatic Testing. Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

ND-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of NPS 4 (DN 100) and less need not be witnessed by the Inspector. For line valves and pumps NPS 4 (DN 100) and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form, and takes precedence over NCA-5280.

ND-6114 Time of Pressure Testing

ND-6114.1 System Pressure Test. The installed system shall be pressure tested prior to initial operation.

The pressure test may be performed progressively on erected portions of the system.

ND-6114.2 Component and Appurtenance Pressure Test.

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided

(1) the component can be repaired by welding in accordance with the rules of ND-4130 and ND-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with ND-4620, if required, and non-destructively examined in accordance with rules of ND-4130 and ND-4450, as applicable; and

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by ND-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with ND-3500.

(d) Items that, when assembled, form a completed pump or valve may be tested in the form of subassemblies, provided

(1) the test pressure is in accordance with the requirements of [ND-6221](#);

(2) the pressure test is performed in a manner that, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;

(3) the component Certificate Holder approves any pressure test of component subassemblies;

(4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;

(5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Nuclear Inspector;

(6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the Certification Mark with NPT Designator except as provided in NCA-8330; the test pressure shall be identified on the Partial Data Report Form;

(7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;

(8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;

(9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

ND-6114.3 Material Pressure Test. The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided

(a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;

(b) the material can be repaired by welding in accordance with rules of [ND-4130](#) if required as a result of the pressure test; and

(c) postweld heat treatment, when required after repairs, can be performed in accordance with [ND-4620](#).

ND-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing, where machining to critical dimensions and tolerances is required.

ND-6120 PREPARATION FOR TESTING

ND-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

ND-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

ND-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

ND-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for proposed test pressure.

ND-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

ND-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

ND-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

ND-6200 HYDROSTATIC TESTS

The requirements of this paragraph apply to all components except tanks, for which [ND-6500](#) applies.

ND-6210 HYDROSTATIC TEST PROCEDURE

ND-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

ND-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture. The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing fluid are at approximately the same temperature.

ND-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

ND-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices that satisfy the requirements of ND-7000.

(b) Valves shall be hydrostatically tested in accordance with the rules of ND-3500.

(c) Other components shall be hydrostatically tested at not less than 1.25 times their Design Pressure.

(d) As an alternative to (a) above, piping between the discharge side of a centrifugal pump and the first shutoff valve may be hydrostatically tested at the shutoff head of the pump. The pressure shall be maintained for a sufficient time to permit examination of all joints, connections, and regions of high stress.

ND-6222 Maximum Permissible Pressure

(a) If the minimum test pressure of ND-6221(a) or ND-6221(d) is to be exceeded by 6% at any location, the upper limit shall be established by analysis using all loadings that may exist during the test.

(b) When testing a system, the test pressure shall not exceed the maximum permissible test pressure of any component in the system.

ND-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by ND-6224.

ND-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (ND-6223), all joints, connections, and regions of high stress such as regions around openings and thickness transition sections shall be examined for leakage. Except in the case of pumps and valves, which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure, and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test that will later be replaced, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted

when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

ND-6230 BELLOWS EXPANSION JOINTS

The hydrostatic test requirements for bellows expansion joints shall be as required in (a) through (c) below.

(a) The completed expansion joint shall be subjected to a hydrostatic test in accordance with the applicable provisions of this Article as supplemented by the Design Specifications.

(b) This test may be performed with the bellows fixed in the straight position, at its neutral length, when the design has been shown to comply with ND-3649.4(e)(1) or ND-3649.4(e)(2). If the design is to comply with ND-3649(e)(3), this test shall be performed with the bellows fixed at the maximum design rotation angle or offset movement.

(c) In addition to inspecting the expansion joint for leaks and general structural integrity during the test, the Inspector shall also visually inspect the bellows for evidence of meridional yielding as defined in ND-3649.4(b) and for evidence of squirm as defined in ND-3649.4(c). If the design is to comply with ND-3649.4(e)(3), actual measurements shall be made before, during, and after the pressure test in accordance with ND-3649.4(b) and ND-3649.4(c).

ND-6240 PROVISION FOR EMBEDDED OR INACCESSIBLE WELDED JOINTS IN PIPING

When welded joints in piping subassemblies or piping systems will be embedded or otherwise inaccessible for inspection at the time of the system hydrostatic test, either of the following alternatives may be employed. Alternative (b) does not apply to brazed joints.

(a) The piping subassembly, or portion of the piping system that is to be embedded, or will otherwise be inaccessible, shall be hydrostatically tested at some point in the fabrication or installation prior to embedment or inaccessibility.

(b) Radiography shall be performed on all circumferential butt welds, and either magnetic particle or liquid penetrant examination shall be performed on all fillet or socket welds in accordance with the requirements of ND-5000. The longitudinal butt welds shall meet the requirements of ND-2000. The hydrostatic test may then be performed after embedment using maintenance of pressure as the acceptance criterion for those welds only. The system shall be pressurized to the hydrostatic test pressure and then isolated from the pressurizing source for a period of 1 hr/in. (2 min./mm) of wall thickness but not less than 1 hr. During the test period, there shall be no drop in pressure.⁶³

ND-6300 PNEUMATIC TESTS**ND-6310 PNEUMATIC TESTING PROCEDURES****ND-6311 General Requirements**

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of [ND-6100](#) and this Subarticle.

ND-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with [ND-6212\(b\)](#).

ND-6313 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

ND-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS**ND-6321 Minimum Required Pneumatic Test Pressure**

(a) The installed system shall be pneumatically tested at not less than 1.1 times the lowest Design Pressure of any component within the boundary protected by the over-pressure protection devices that satisfy the requirements of [ND-7000](#).

(b) Valves shall be pneumatically tested in accordance with the rules of [ND-3500](#).

(c) Components shall be pneumatically tested at not less than 1.1 times their Design Pressure.

ND-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in [ND-6222](#).

ND-6323 Test Pressure Holding Time

The test pressure of [ND-6321](#) shall be maintained for a minimum total time of 10 min.

ND-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in [ND-6323](#), the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure, and held for a sufficient time to permit examination as defined in [ND-6224](#).

ND-6330 BELLOWS EXPANSION JOINTS

When a pneumatic test is performed on a bellows expansion joint in lieu of a hydrostatic test, the requirements of [ND-6230](#) shall be met.

ND-6400 PRESSURE TEST GAGES**ND-6410 REQUIREMENTS FOR PRESSURE TEST GAGES****ND-6411 Types of Gages to Be Used and Their Location**

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gage.

ND-6412 Range of Indicating Pressure Gages

(a) Analog-type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital-type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

ND-6413 Calibration of Pressure Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding 2 weeks.

ND-6500 ATMOSPHERIC AND 0 psig TO 15 psig (0 kPa TO 100 kPa) STORAGE TANKS**ND-6510 TESTING OF ATMOSPHERIC STORAGE TANKS****ND-6511 Testing of Reinforcement Pads**

Following the examination specified in [ND-5282.5](#) and before filling the tank with test water, the reinforcement pads shall be tested by applying up to 15 psi (100 kPa) pneumatic pressure between the tank shell and the reinforcement plate on each opening, using the telltale hole; and while each such space is subject to such pressure, soapsuds, linseed oil, or other suitable material for detection of leaks shall be applied to all attachment welding around reinforcement, both inside and outside the tank.

ND-6512 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of [ND-6120](#) as applicable. Flat bottoms supported directly on grade need not comply with [ND-6121](#).

ND-6513 Hydrostatic Testing of Tank Shell

Upon completion of the tank, the shell shall be tested. For tanks with supported cone, self-supported cone, self-supported dome, and self-supported umbrella roofs, the tank shall be filled with water and inspected frequently during the filling operation. The filling height shall be 2 in. (50 mm) above the top leg of the angle. For tanks with flat roofs, the filling height shall be the liquid level for which the tank was designed or the bottom of any overflow that limits the filling height.

ND-6520 TESTING OF 0 psig TO 15 psig (0 kPa TO 100 kPa) STORAGE TANKS**ND-6521 Testing of Reinforcement Pads**

Following the examination specified in ND-5283.6 and before performing the preliminary pneumatic testing, the reinforcement pads shall be tested by using the same procedure as given in ND-6511.

ND-6522 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of ND-6120, as applicable. Flat bottoms supported directly on grade need not comply with ND-6121.

ND-6523 Preliminary Pneumatic Testing

Prior to the application of the hydrostatic or combination hydrostatic-pneumatic test, the tank shall be filled with air to a pressure of 2 psig (15 kPa) or one-half the pressure P_G for which the vapor space at the top of the tank is designed, whichever pressure is smaller. Soapsuds shall be applied to all joints in the tank wall above the high liquid design level. If any leaks appear, the defective condition shall be corrected and the applicable preliminary tightness test shall be repeated. In the case of a tank whose bottom rests directly on the tank grade without having anchor bolts provided near the boundary of contact to hold it down, if the bottom at this boundary rises slightly off the foundation during the tightness test with air pressure in the tank, sand shall be tamped firmly under the bottom, while the tank is under pressure, to fill the gap so formed.

ND-6524 Combination Hydrostatic-Pneumatic Tests

The following requirements apply to tanks that have not been designed to be filled with liquid to a test level higher than their specified capacity level.

ND-6524.1 Pressurizing. After the preliminary tests specified in ND-6523 have been completed, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid level. The vents at the top of the tank shall then be closed and air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-

half the pressure P_G for which this space is designed. Thereafter, the test pressure shall be increased in steps of approximately 2 psig (15 kPa) or one-fourth of the intended test pressure, whichever is the smaller, until the pressure in the vapor space is 1.25 times the pressure P_G for which this space is designed. Means shall be provided so that the required test pressure will not be exceeded.

ND-6524.2 Time at Pressure. The pressure in the tank shall be held stationary for a reasonable time after the application of each increment of pressure as specified so as to provide an opportunity to examine the tank carefully for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least 1 hr, after which the pressure shall be reduced slowly to the vapor space design pressure.

ND-6524.3 Soap Bubble Test. The vapor space design pressure shall be held for a sufficient time to permit a close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections. In this examination, soapsuds shall be applied to all weld joints located above the high liquid design level for which the tank is designed, including the roof-to-sidewall joint. This examination is not required for welds subject to radiography.

ND-6524.4 Precautions to Be Employed in Pneumatic Testing. An air test as specified in ND-6523 and in ND-6524 introduces some hazard. In view of the large amount of air that will be present during such a test, it is recommended that during this test no one be permitted to go near the tank while the pressure is being applied for the first time. While the pressure in the tank exceeds the pressure for which the vapor space is designed, the inspections should be made from a reasonable distance from the tank using optical aids, if necessary, for observations of particular areas.

ND-6525 Hydrostatic Test

The following requirements apply to tanks that have been designed and constructed to be filled with liquid to the top of the roof.

ND-6525.1 Filling. Following the preliminary tests specified in ND-6523 the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere, the tank shall be filled with water to the top of the roof, while allowing all air to escape in order to prevent accumulation of pressure. The vents on the tank shall be closed and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure P_G for which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid level.

ND-6525.2 Pressurizing. Test pressure may be developed either by (a) or (b) below:

(a) pumping water into the tank with all vents closed;

(b) superimposing a vertical pipe, not less than NPS 6 (DN 150), above the top of the tank with an overflow located at such a height as to give the desired test pressure by static head alone and then filling the pipe to the level of said overflow.

ND-6525.3 Time at Pressure. Test pressure shall be held for at least 1 hr. The hydrostatic pressure under the roof shall then be reduced to the Design Pressure and shall be held at this level for a sufficient time to permit close visual examination of all joints in the walls of the tank, and of all welding around manways, nozzles, and other connections.

ND-6526 Partial Vacuum Testing Procedure

Following the tests specified in [ND-6524](#) or in [ND-6525](#), the pressure in the tank shall be released and a manometer shall be connected to the vapor space. The ability of that part of the tank to withstand the partial vacuum for which it is designed shall then be checked by withdrawing water from the tank or by air evacuation, with all vents closed, until the design partial vacuum is developed. Careful observations shall be made under the above condition of loading to determine whether any appreciable changes occur in the shape of the tank.

ND-6530 TEST GAGES

ND-6531 Indicating Gage and Its Location

An indicating gage shall be connected directly to the topmost part of the roof on the tank under test, except that, in the case of a tank that is designed for storage of gases or vapors alone and is to be tested only with air, this gage may be connected to the tank at some lower level. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. Means shall be provided so that the required test pressure will not be exceeded.

ND-6532 Recording Gage and Its Location

A recording gage shall also be used on each tank and a record shall be kept of the pressures during all stages of the tests. This gage shall be connected either to the piping leading to the indicating gage or directly to the tank at a point near the indicating gage connection.

ND-6533 Accumulation of Static Head on Gages

In all cases in which a gage is mounted at a level lower than its connection to the tank or lower than some part of the piping leading to the gage, suitable precautions shall be taken to prevent accumulation of any static head of condensed moisture or water from other sources in the piping leads above the level of the gage.

ND-6534 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard deadweight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages, which are conducted in a period not exceeding 2 weeks.

ND-6600 SPECIAL TEST PRESSURE SITUATIONS

ND-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal or external test pressure at 1.25 times the design external pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

ND-6620 PRESSURE TESTING OF COMBINATION UNITS

ND-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be pressure tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

ND-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the Design Pressures of the adjacent chambers, the common elements shall be subjected to a pressure test of at least 1.25 times the maximum differential pressure.

(b) Following the test of the common elements as required by (a) and their inspection, the adjacent chambers shall be pressure tested ([ND-6221](#)). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

ND-6900 PROOF TESTS TO ESTABLISH DESIGN PRESSURE

ND-6910 GENERAL REQUIREMENTS

ND-6911 Establishment by Test of Design Pressure

The Design Pressure for components and piping or component parts for which the strength cannot be computed with a satisfactory assurance of accuracy, shall be

established in accordance with the requirements of this Subarticle, using one of the test procedures applicable to the type of loading and to the material used in construction.

ND-6911.1 Types of Proof Tests. Provision is made in these rules for two types of tests to determine the internal Design Pressure:

(a) tests based on yielding of the part to be tested (these tests are limited to materials with a ratio of specified minimum yield to specified minimum ultimate strength of 0.625 or less);

(b) tests based on bursting of the part.

ND-6911.2 Purpose for Which Proof Tests May Be Used. The tests in this Subarticle may be used only for the purpose of establishing the Design Pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Subsection. The Design Pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

ND-6911.3 Permissible Previous Pressurization of Component or Part. The component or component part for which the Design Pressure is to be established shall not previously have been subjected to a pressure greater than $1\frac{1}{2}$ times the desired or anticipated Design Pressure adjusted for Design Temperature as provided in ND-6911.9.

ND-6911.4 Test Requirements for Duplicate Components or Parts. When the Design Pressure of a component or component part has been established by a proof test, duplicate parts of the same materials, design, and construction need not be proof tested but shall be given a hydrostatic test in accordance with ND-6200 or a pneumatic test in accordance with ND-6300. The dimensions and minimum thickness of the structure to be tested shall not vary materially from those actually used. A geometrically similar part may be qualified by a series of tests covering the complete size range of the pressure part.

ND-6911.5 Application of Pressure. In the procedures given in ND-6921, ND-6923, and ND-6924, the hydrostatic pressure in the component or component part shall be increased gradually until approximately one-half the anticipated Design Pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated Design Pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

ND-6911.6 Check of Measurements. As a check that the measurements are being taken on the most critical areas, the Inspector may require a lime wash or other brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in ND-6923 and ND-6924. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

ND-6911.7 Determination of Design Pressure for Components or Parts Having Corrosion Allowance. The test procedures in this Subarticle give the Design Pressure for the thickness of material tested. When the thickness as tested includes extra thickness as provided in ND-3121, the Design Pressure at which the component shall be permitted to operate shall be determined by multiplying the Design Pressure obtained from the test by the ratio

$$(t - c) / t$$

where

c = allowance added for corrosion, erosion, and abrasion

t = nominal thickness of the material at the weakest point

ND-6911.8 Determination of Yield Strength and Tensile Strength.

(a) For proof tests based on yielding (ND-6921, ND-6923, or ND-6924), the yield strength (or yield point for those materials that exhibit that type of yield behavior indicated by a "sharp-knead" portion of the stress-strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E8. For proof tests based on bursting, ND-6922, the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(b) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in ND-6921, ND-6922, ND-6923, and ND-6924 for evaluation of proof test results to establish the Design Pressure.

(c) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimens shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

ND-6911.9 Design Pressure at Higher Temperatures.

The Design Pressure for components and component parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following equation:

$$P_o = P_t \left(\frac{S_o}{S_t} \right)$$

where

P_o = Design Pressure at the Design Temperature

P_t = Design Pressure at test temperature

S_o = maximum allowable stress value at the Design Temperature

S_t = maximum allowable stress value at test temperature

ND-6912 Retests

A retest shall be allowed on a duplicate component or component part if errors or irregularities are obvious in the test results.

ND-6913 Witnessing of Tests by Inspector

Tests to establish the Design Pressure of components or component parts shall be witnessed and approved by the Inspector.

ND-6914 Safety Precautions

Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in [ND-6922](#).

ND-6920 PROCEDURES**ND-6921 Brittle Coating Test Procedure**

(a) Subject to the limitations of [ND-6911.1\(a\)](#), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a lime wash or other brittle coating in accordance with [ND-6911.6](#). Pressure shall be applied in accordance with [ND-6911.5](#). The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding or, if desired, at some lower pressure.

(b) The Design Pressure P in psig at test temperature for components or component parts tested under [ND-6921](#) shall be computed as stipulated in (1) through (4) below.

(1) If the average yield strength is determined in accordance with [ND-6911.8](#)

$$P = 0.5H \frac{Y_s}{Y_a}$$

(2) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the Design Pressure.

(-a) For carbon steel meeting an acceptable specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi (485 MPa)

(U.S. Customary Units)

$$P = 0.5H \left(\frac{S}{S + 5,000} \right) \quad (1)$$

(SI Units)

$$P = 0.5H \left(\frac{S}{S + 34,500} \right)$$

(-b) For any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

$$P = 0.4H \quad (2)$$

where

H = hydrostatic test pressure at which the test was stopped

S = specified minimum tensile strength

Y_a = actual average yield strength from test specimens

Y_s = specified minimum yield strength

(3) When [eq. \(2\)\(-a\)\(1\)](#) or [eq. \(2\)\(-b\)\(2\)](#) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value.

(4) The Design Pressure at other temperatures shall be determined as provided in [ND-6911.9](#).

ND-6922 Bursting Test Procedure

(a) This procedure may be used for components or component parts under internal pressure when constructed of any material permitted to be used under the rules of this Subsection. The Design Pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined.

(b) The Design Pressure P in psig (MPa gage) at test temperature for parts tested under [ND-6922](#) shall be computed as stipulated in (1) through (3) below.

(1) Parts constructed of materials other than cast materials

$$P = \frac{B}{5} \times \frac{SE}{S_{ave}} \quad \text{or} \quad P = \frac{B}{5} \times \frac{SE}{S_{max}} \quad (3)$$

(2) Parts constructed of cast materials, except cast iron and cast nodular iron that are not permitted

$$P = \frac{Bf}{5} \times \frac{SE}{S_{ave}} \quad \text{or} \quad P = \frac{Bf}{5} \times \frac{SE}{S_{max}} \quad (4)$$

where

B = bursting test pressure
 E = efficiency of welded joint, if used (ND-3352-1)
 f = casting quality factor (ND-3115)
 S = specified minimum tensile strength
 S_{ave} = average actual tensile strength of test specimens
 S_{max} = maximum tensile strength of range of specification

(3) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

ND-6923 Strain Measurement Test Procedure

(a) Subject to limitations of ND-6911.1(a), this procedure may be used for components or component parts under internal pressure, constructed of any material permitted to be used under the rules of this Subsection. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts (see ND-6911.6) by means of strain gages of any type capable of indicating strains to 0.00005 in./in. (0.00125 mm/mm). Pressure shall be applied as provided in ND-6911.5.

(b) After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(c) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H that will, by the equation, justify the desired Design Pressure, but shall not exceed the pressure at which the plotted points for the most highly strained gage line reach the value given below for the material used

(1) 0.2% permanent strain for aluminum-base and nickel-base alloys

(2) 0.2% permanent strain for carbon low alloy and high alloy steels

(3) 0.5% strain under pressure for copper-base alloys

(d) The Design Pressure P in psig at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (3) below.

(1) If the average yield strength is determined in accordance with ND-6911.8

$$P = 0.5H \left(\frac{Y_s}{Y_a} \right) \quad (5)$$

(2) If the actual average yield strength is not determined by test specimens

$$P = 0.4H \quad (6)$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (c) above
 S = specified minimum tensile strength
 Y_a = actual average yield strength from test specimens
 Y_s = specified minimum yield strength, psi (kPa)

(3) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

ND-6924 Displacement Measurement Test Procedure

(a) Subject to the limitations of ND-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts (ND-6911.6) by means of measuring devices of any type capable of measuring to 0.001 in. (0.025 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure or between a reference point and a fixed base point. Pressure shall be applied as provided in ND-6911.5.

(b) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released, and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to assure that the readings represent only displacements of the parts on which measurements are being made, and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(c) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(d) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(e) The Design Pressure P in psig at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (4) below.

(1) If the average yield strength is determined in accordance with ND-6911.8

$$P = 0.5H \frac{Y_s}{Y_a} \quad (7)$$

(2) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, eq. (-a)(8) or eq. (-b)(9) may be used to determine the Design Pressure.

(-a) For carbon steel, meeting an acceptable specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi (485 MPa)

(U.S. Customary Units)

$$P = 0.5H \left(\frac{S}{S + 5,000} \right) \quad (8)$$

(SI Units)

$$P = 0.5H \left(\frac{S}{S + 34,500} \right)$$

(-b) For any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

$$P = 0.4H \quad (9)$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part test

S = specified minimum tensile strength

Y_a = actual average yield strength from test specimens

Y_s = specified minimum yield strength

(3) When eq. (2)(-a)(8) or eq. (2)(-b)(9) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value.

(4) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

ND-6930 PROCEDURE FOR COMPONENTS HAVING CHAMBERS OF SPECIAL SHAPE SUBJECT TO COLLAPSE

(a) Pressure chambers of components, portions of which 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, that are not fully staybolted as required by ND-3133 and ND-3329, shall withstand without excessive deformation a hydrostatic test of not less than 3 times the desired Design Pressure.

(b) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

ARTICLE ND-7000 OVERPRESSURE PROTECTION

ND-7100 GENERAL REQUIREMENTS

ND-7110 SCOPE

(a) A system⁶⁴ shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause either the Design Pressure or the Service Limits specified in the Design Specification to be exceeded.

(b) Pressure relief devices⁶⁵ are required when the operating conditions considered in the Overpressure Protection Report would cause the Service Limits specified in the Design Specification to be exceeded.

(c) Protection of components in the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article. These effects shall be included in the Design Specification.

ND-7111 Definitions

(a) Overpressure, as used in this Article, can consist of either one of the following pressure changes:

(1) an increase in system fluid pressure, resulting from thermal imbalances, excess pump flow, and other similar phenomena, capable of causing a system pressure increase of a sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article; or

(2) changes in differential pressure resulting from thermal imbalances, vapor condensation, and other similar phenomena, capable of causing an internal or external pressure increase of sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article.

(b) The basic definitions of pressure relief devices as specified in this Article are in accordance with ASME PTC 25-1994, Pressure Relief Devices.

(c) *Primary pressure* is the pressure of the fluid at the inlet of the pressure relief device.

(d) *Secondary pressure* is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

ND-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the system shall be provided by any of the following methods as an integrated overpressure protection:

(a) the use of pressure relief devices and associated pressure sensing elements;

(b) a design without pressure relief devices that does not exceed the Service Limits specified in the Design Specifications [ND-7110(b)].

ND-7130 VERIFICATION OF THE OPERATION OF RECLOSING PRESSURE RELIEF DEVICES

ND-7131 Construction

(a) Reclosing pressure relief devices shall be constructed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

(b) Reclosing pressure relief devices and their associated pressure-sensing elements shall be so constructed that their correct operation can be demonstrated under service or test conditions, as may be required by regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

ND-7140 INSTALLATION

ND-7141 Pressure Relief Devices

(a) Pressure relief devices shall be as close as practicable to the major source of overpressure anticipated to arise within the system under the conditions summarized in the Overpressure Protection Report (ND-7200).

(b) The connection between a system and its pressure relief device shall have a minimum inside diameter equal to or greater than the nominal inside diameter of the pressure relief device inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the system and the pressure relief device.

(c) The connection between a system and its safety valve shall be not longer than the face-to-face dimension of the corresponding tee fitting of the same dimension and pressure rating listed in ASME B16.5a, ASME B16.9, or ASME B16.11. Alternatively, the connection shall not result in accumulative line losses greater than 2% of the relieving pressure.

(d) The connection between a system and its safety relief valve or relief valve shall not result in accumulated line losses greater than 3% of the relieving pressure.

(e) Safety, safety relief, and relief valves shall be installed in an upright position.

(f) The flow area of the discharge piping connected to a pressure relief device shall not be less than the flow area of the device outlets. If two or more pressure relief valves

discharge into common piping, the area of the common piping shall not be less than the combined outlet area of the valves discharging into it. Back pressure that may exist or develop shall not reduce the relieving capacity of the relieving device(s) below that required to protect the system; potential for flashing shall be considered.

(g) Valve installation not in accordance with (c), (d), (e), and (f) above may be used provided

(1) the NV Certificate Holder confirms that the valve design is satisfactory for the intended installation and satisfies the requirements of the valve Design Specification;

(2) the valves are adjusted for acceptable performance and in conformance with the requirements of the valve Design Specification;

(3) technical justification for the adequacy of the installation is provided in the Overpressure Protection Report, including verification that the requirements of (1) and (2) have been met.

(h) When a rupture disk device is used as the sole pressure relief device, the nominal pipe size of the connections on either side of the rupture disk device shall not be less than the nominal size of the rupture disk device, unless the smaller size connecting pipe is taken into account in determining the capacity of the device.

(i) Rupture disk devices used as the sole pressure relieving device may be installed in any position provided the medium is such that any accumulation of material at the inlet of the rupture disk devices will not impair the proper burst and opening of the rupture disk.

ND-7142 Stop Valves

(a) No stop valve or other device shall be placed in such a location, relative to a pressure relief device, that it could reduce the overpressure protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements of ND-7300 are met under all conditions of operation of both the system and the stop valves.

(b) Simple administrative control of stop valve position is not acceptable.

(c) Stop valves shall have independent and diverse interlocks to prevent valves from being closed during all conditions of system operation when the pressure relief device is needed to meet the requirements of ND-7300.

(d) Stop valves shall have independent and diverse interlocks to assure that the valves will automatically open and remain open during all conditions of system operation when the pressure relief device is needed to meet the requirements of ND-7300.

(e) Means shall be provided to permit verification of the operation of controls and interlocks.

ND-7143 Draining of Pressure Relief Devices

(a) A pressure relief device installation shall be fitted with a drain at its lowest point where liquid or residue can collect if such liquid or residue could interfere with proper relieving operation.

(b) If the design of a pressure relief device permits liquid or residue to collect on the discharge side of the disk and could interfere with proper relieving operation, the device shall be fitted with a drain to minimize the collection of liquid or residue.

ND-7150 ACCEPTABLE PRESSURE RELIEF DEVICES

ND-7151 Pressure Relief Valves⁶⁶

Pressure relief valves may be used in accordance with ND-7170 and ND-7500.

ND-7152 Vacuum Relief Valves⁶⁷

Vacuum relief valves may be used in accordance with ND-7170 and ND-7500.

ND-7153 Nonreclosing Pressure Relief Devices⁶⁸

Nonreclosing pressure relief devices may be used in accordance with ND-7170 and ND-7600.

ND-7160 UNACCEPTABLE PRESSURE RELIEF DEVICES

ND-7161 Deadweight Pressure Relief Valves

Deadweight valves shall not be used.

ND-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

ND-7171 Safety Valves⁶⁹

Safety valves, meeting the requirements of ND-7510, may be used for

- (a) steam service;
- (b) air and gas service.

ND-7172 Safety Relief Valves⁷⁰

Safety relief valves, meeting the requirements of ND-7510, may be used for

- (a) steam service;
- (b) air and gas service;
- (c) liquid service.

ND-7173 Relief Valves⁷¹

Relief valves, meeting the requirements of ND-7510, may be used for liquid service.

ND-7174 Pilot Operated Pressure Relief Valves⁷²

Pilot operated pressure relief valves, meeting the requirements of ND-7520, may be used for

- (a) steam service;

(b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot should fail;

(c) liquid service.

ND-7175 Power Actuated Pressure Relief Valves⁷³

Power actuated pressure relief valves, meeting the requirements of [ND-7530](#), may be used for

(a) steam service;

(b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the actuator should fail;

(c) liquid service.

ND-7176 Safety Valves With Auxiliary Actuating Devices

Safety valves with auxiliary actuating devices, meeting the requirements of [ND-7540](#), may be used for steam service.

ND-7177 Vacuum Relief Valves⁶⁷

Vacuum relief valves, meeting the requirements of [ND-7550](#), may be used for air and gas service.

ND-7178 Nonreclosing Devices

(a) Rupture disk devices⁷⁴ may be used on liquid, air, gas, or steam service, except for main steam service, in accordance with [ND-7600](#).

(b) Application on liquid service shall be evaluated to ensure that the design of the rupture disk device and that the fluid energy of the system on which it is installed will provide adequate opening to meet the requirements of [ND-7300](#).

ND-7200 OVERPRESSURE PROTECTION REPORT

ND-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection Report prepared by the Owner or his Designee.

ND-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the Report shall include the following:

(a) identification of specific ASME Section III, [Article ND-7000](#), Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;

(b) drawings showing arrangement of the protected systems, including the pressure relief devices;

(c) the analysis of the effect of the range of operating conditions, including the effect of discharge piping back pressure;

(d) an analysis of the conditions that give rise to the maximum pressure or vacuum relieving requirements, except when the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal input to the system is at a maximum;

(e) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device;

(f) the relief capacity required to prevent a pressure or vacuum rise in any component from exceeding the limitations of [ND-7300](#);

(g) the redundancy and independence of the pressure relief devices and their associated pressure or vacuum sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing element, associated control, or external power sources.

ND-7230 CERTIFICATION OF REPORT

The Report, after it has been reconciled with the requirements of this Article, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII.

ND-7240 REVIEW OF REPORT AFTER INSTALLATION

(a) Any modification of the installation from that used for the preparation of the Overpressure Protection Report shall be reconciled with the Overpressure Protection Report.

(b) Modifications shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either

(1) a statement that the as-built system meets the requirements of the Overpressure Protection Report; or

(2) a revision to the Overpressure Protection Report to make it agree with the as-built system; or

(3) a description of the changes made to the as-built system to make it comply with the Overpressure Protection Report.

(c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII.

ND-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the Inspector signing the Owner's Data Report. The report shall be made

available to the Authorized Inspector and the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

ND-7300 RELIEVING CAPACITY REQUIREMENTS

ND-7310 EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS⁷⁵

ND-7311 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with [ND-7700](#), intended for overpressure protection within the scope of this Subsection, and credited in conformance with [ND-7500](#) or [ND-7600](#)) shall take into account any losses due to fluid flow through piping and other components.

(b) The total rated relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi, whichever is greater, above the Design Pressure of any component within the pressure retaining boundary of the protected system under any expected system pressure transient conditions as summarized in the Overpressure Protection Report ([ND-7200](#)).

(c) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the valve Design Specification and in the Overpressure Protection Report.

ND-7312 Relieving Capacity of Pressure Relief Devices Used With Pressure Reducing Devices

When using pressure reducing devices, the combined relieving capacity of the pressure relief devices shall be sufficient to meet the requirements of [ND-7311](#), when

(a) pressure reducing devices and their bypass valves are fully open; and

(b) all discharge paths are blocked on the low pressure side of the pressure reducing device.

ND-7313 Required Number and Capacity of Pressure Relief Devices

(a) Systems or components requiring individual protection may be served by one or more devices.

(b) When more than one device is used, no device shall have a capacity less than 50% of the device with the largest capacity.

ND-7314 Required Number and Capacity of Pressure Relief Devices for Isolatable Components Requiring Overpressure Protection

The required relieving capacity for overpressure protection of an isolatable component shall be secured by the use of at least one pressure relief device meeting the requirements of [ND-7500](#) or [ND-7600](#).

ND-7315 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

ND-7320 UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS⁷⁶

ND-7321 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with [ND-7700](#), intended for overpressure protection within the scope of this Subsection, and credited in conformance with [ND-7500](#) or [ND-7600](#)) shall take into account any losses due to fluid flow through piping and other components.

(b) The total rated relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi, whichever is greater, above the Design Pressure of any component within the pressure retaining boundary of the protected system under each of the unexpected system excess pressure transient conditions specified in the Overpressure Protection Report.

ND-7322 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification of the system being protected.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

ND-7330 SYSTEM FAULTED CONDITIONS

This Article does not provide rules for overpressure protection of system faulted conditions.

ND-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES**ND-7410 SET PRESSURE LIMITATIONS FOR EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS**

The stamped set pressure of at least one of the pressure relief devices connected to the system shall not be greater than the Design Pressure of any component within the pressure retaining boundary of the protected system. Additional pressure relief devices may have higher stamped set pressures, but in no case shall these set pressures be such that the total system pressure exceeds the system limitations specified in [ND-7310](#).

ND-7420 SET PRESSURE LIMITATIONS FOR UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS

The establishment of the stamped set pressure shall take into account the requirements of [ND-7320](#).

ND-7500 OPERATING AND DESIGN REQUIREMENTS FOR PRESSURE AND VACUUM RELIEF VALVES**ND-7510 SAFETY, SAFETY RELIEF, AND RELIEF VALVES****ND-7511 General Requirements**

ND-7511.1 Spring-Loaded Valves. Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

ND-7511.2 Balanced Valves. Balanced valves, whose operation is independent of back pressure, may be used if means are provided to verify the integrity of the balancing devices.

ND-7511.3 Restricted Lift Valves. The capacity of a Certification Mark with NV Designator-stamped valve may be reduced by the valve manufacturer provided the following limitations have been met:

- (a) The valve size shall be NPS $\frac{3}{4}$ (DN 20) or larger.
- (b) The valve design shall be tested and the capacity certified in accordance with the rules specified in [ND-7731](#) and [ND-7734](#).
- (c) No changes shall be made in the design of the valve except to change the valve lift by use of the lift restraining device.
- (d) The restriction of valve capacity is permitted only by the use of a lift restraining device, which shall limit valve lift and shall not otherwise interfere with flow through the valve.
- (e) The lift restraining device is designed so that, if adjustable, the adjustable feature shall be sealed. Seals shall be installed in accordance with [ND-7515](#).

(f) For air and gas service and for Classes 2 and 3 steam service other than main steam service, if a valve design has been tested in combination with a rupture disk in accordance with the requirements of [ND-7000](#), restricted lift valves of this design may be used in combination with rupture disks without further testing. Valves shall not have their lift restricted to a value less than 30% of the full rated lift, nor less than 0.080 in.

(g) During production testing, the manufacturer shall assure that the set pressure, blowdown, and valve performance meet the applicable requirements of this Article and the valve design specification.

Valves beyond the capability of the production test facility, because of size or flow rate, may be adjusted for blowdown and performance based on test or experience data, or other adequate technical justification, to meet the requirements of this Article and the valve design specification. The basis for the manufacturer's adjusting ring settings shall be documented in the Overpressure Protection Report ([ND-7200](#)).

(h) When sizing and selecting valves, the restricted lift capacity shall be determined by multiplying the capacity at full rated lift, as defined in [ND-7734](#), by the ratio of the restricted lift to the full rated lift.

(i) Valves shall be marked in accordance with the relevant nameplate stamping provisions of [ND-7800](#) modified as follows:

- (1) Replace "capacity" with "restricted lift capacity."
- (2) Add "restricted lift _____ in. (mm)."

ND-7512 Safety Valve Operating Requirements

ND-7512.1 Antichattering and Lift Requirements. Safety valves shall be constructed to operate without chattering and to attain rated lift at a pressure that does not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater.

ND-7512.2 Set Pressure Tolerance.

(a) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (15 kPa) for pressures up to and including 70 psi (480 kPa); 3% for pressures over 70 psi (480 kPa) up to and including 300 psi (2 100 kPa); 10 psi (70 kPa) for pressures over 300 psi (2 100 kPa) up to and including 1,000 psi (7 MPa); and 1% for pressures over 1,000 psi (7 MPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report ([ND-7200](#)) and in the safety valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam. Alternative fluids may be used as the test media if the requirements of [ND-7560](#) have been met.

ND-7512.3 Blowdown. Safety valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification

(NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (ND-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data. Alternative fluids may be used as the test media if the requirements of ND-7560 have been met.

ND-7513 Safety Relief and Relief Valve Operating Requirements

Safety relief and relief valves shall be constructed to attain rated lift at a pressure that does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

ND-7513.1 Set Pressure Tolerance.

(a) The set pressure tolerance plus or minus from the set pressure of safety relief and relief valves shall not exceed 2 psi (15 kPa) for pressures up to and including 70 psi (480 kPa) and 3% for pressures above 70 psi (480 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (ND-7200) and in the valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid. Alternative fluids may be used as the test media if the requirements of ND-7560 have been met.

ND-7513.2 Blowdown. Safety relief and relief valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting shall be covered in the Overpressure Protection Report (ND-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data. Alternative fluids may be used as the test media if the requirements of ND-7560 have been met.

ND-7514 Credited Relieving Capacity

The credited relieving capacity of safety, safety relief, and relief valves shall be based on the certified relieving capacity. In addition, the capacity can be prorated as permitted by ND-7700.

ND-7515 Sealing of Adjustments

Means shall be provided in the design of all valves for sealing all adjustments or access to adjustments that can be made without disassembly of the valve. For a pilot operated pressure relief valve, an additional seal shall be provided to seal the pilot and main valve together. Seals shall be installed by the Certificate Holder at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment or disassembly of the valve without breaking the seal. The seal shall serve as a means of identifying the Certificate Holder making the initial adjustment.

ND-7520 PILOT OPERATED PRESSURE RELIEF VALVES

ND-7521 General Requirements

Pilot operated pressure relief valves shall operate independently of any external energy source.

ND-7522 Operating Requirements

ND-7522.1 Actuation. The pilot control device shall be actuated directly by the fluid pressure of the protected system.

ND-7522.2 Response Time. The Overpressure Protection Report (ND-7200) shall include the effects of divergence between opening (set) and closing (blowdown) pressures of the pilot valve and the pressures at which the main valve attains rated lift and closes. These divergences are caused by the inherent time delay (i.e., response time) between the operation of the pilot and the main valve, and the rate of the system pressure change. The limits for response time shall be specified in the valve Design Specification (NCA-3250).

ND-7522.3 Main Valve Operation. The main valve shall operate in direct response to the pilot control device. The valve shall be constructed to attain rated lift under stable conditions at pressures that do not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater, for steam, and 10% or 3 psi (20 kPa), whichever is greater, for air, gas, or liquid service.

ND-7522.4 Sensing Mechanism Integrity. For other than spring loaded direct acting pilot control devices, means shall be provided to detect failure of the pressure sensing element, such as bellows, when operation of the pilot control device is dependent upon the integrity of a pressure sensing element.

ND-7522.5 Set Pressure Tolerance.

(a) The set pressure tolerance shall apply only to the pilot valve.

(b) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (15 kPa) for pressures up to and including 70 psi (480 kPa); 3% for pressures over 70 psi (480 kPa) for liquid valves and 3% for pressures over 70 psi (480 kPa) up to and including 300 psi (2 100 kPa); 10 psi (70 kPa) for pressures over 300 psi (2 100 kPa) up to and including 1,000 psi (7 000 kPa); and 1% for pressures over 1,000 psi (7 000 kPa) for steam, air, and gas valves. The set pressure tolerance as stated shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (ND-7200) and in the valve Design Specification (NCA-3250).

(c) Conformance with the requirements of (b) above shall be established for each production valve by test. Steam valves shall be tested on steam, air, or gas valves on air or gas, and liquid valves on liquid.

ND-7522.6 Blowdown.

(a) The blowdown requirements shall only apply to the pilot valve.

(b) Pilot operated valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (ND-7200).

(c) The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

ND-7523 Credited Relieving Capacity

The credited relieving capacity of pilot operated pressure relief valves shall be based on the certified relieving capacity. In addition, the capacity may be prorated as permitted in ND-7700.

ND-7524 Sealing of Adjustments

The sealing requirements of ND-7515 shall apply.

ND-7530 POWER ACTUATED PRESSURE RELIEF VALVES**ND-7531 General Requirements**

Power actuated pressure relief valves, which depend upon an external energy source such as electrical, pneumatic, or hydraulic systems and that respond to signals from pressure or temperature sensing devices, may be used, provided the requirements of this Sub-subarticle are met.

ND-7532 Operating Requirements

ND-7532.1 Response Time. In systems protected by power operated pressure relief valves, consideration shall be given to the time lapse between the signal to open and achieving the fully opened position and to the time lapse between the signal to close and achieving the fully closed position.

ND-7532.2 Sensors, Controls, and External Energy Sources.

(a) The sensors, controls, and external energy sources for valve operation shall have redundancy and independence at least equal to that required for the control and safety protection systems associated with the system.

(b) The relief valve and its auxiliary devices treated as a combination shall comply with the following requirements:

(1) The valve opening pressure shall be controlled within a tolerance as specified in ND-7512.2 of the set pressure when the automatic control is in use.

(2) The valve blowdown shall be controlled to a pressure not lower than that specified in the valve Design Specification (NCA-3250).

ND-7533 Certified Relieving Capacity

The power actuated pressure relief valve certified relieving capacity and the proration of capacity shall be as determined by ND-7700.

ND-7534 Credited Relieving Capacity

ND-7534.1 Expected System Pressure Transient Conditions. For expected system pressure transient conditions, the relieving capacity with which these valves are credited shall be not more than

(a) the certified relieving capacity of the smaller one when two valves are installed;

(b) one-half of the total certified relieving capacity when three or more valves are installed.

ND-7534.2 Unexpected System Excess Pressure Transient Conditions. For unexpected system excess pressure transient conditions, the relieving capacity with which these valves are credited shall not be more than

(a) the relieving capacity of the valve with the smaller stamped capacity where two valves are installed;

(b) the relieving capacity of all except the valve with the largest certified capacity for valves where three through ten valves are installed;

(c) the relieving capacity of all except two valves of the largest certified capacity where more than ten valves are installed.

ND-7540 SAFETY AND SAFETY RELIEF VALVES WITH AUXILIARY ACTUATING DEVICES**ND-7541 General Requirements**

Safety and safety relief valves with auxiliary actuating devices that operate independently of the spring loading of the valve may be used, provided the requirements of ND-7510 are met except as modified by this Subsubarticle.

ND-7542 Construction

(a) The construction shall be such that the valve opens automatically by direct action of the fluid at a pressure not higher than the safety valve set pressure and relieves at the certified relieving capacity in the event of failure of any essential part of the valve's auxiliary devices.

(b) The construction of the auxiliary actuating device shall be such that the safety valve will not be prevented from operating as defined in ND-7510 when the auxiliary actuating device is deenergized.

ND-7550 VACUUM RELIEF VALVES**ND-7551 General Requirements**

Vacuum relief valves shall meet the construction requirements applicable to Class 3 valves and the additional requirements of this Article.

ND-7552 Types Permitted

(a) Balanced self-actuating horizontally installed swing-disk valves.

(b) Vertically installed vacuum disk or pallet-type valves.

(c) All vacuum relief valves shall have provisions for adjustment of the differential pressure.

ND-7553 Operating Requirements

Vacuum relief valves, which are operated by indirect means depending on an external energy source, such as electrical, pneumatic, or hydraulic systems, are not acceptable unless at least two independent external power operated valves and control systems are employed so that the required relieving capacity is obtained if any one of the valves or systems should fail to operate.

ND-7560 ALTERNATIVE TEST MEDIA

ND-7561 General Requirements

Pressure relief devices may be subjected to set-pressure tests using a test medium (fluid or temperature) other than that for which they are designed, provided the testing complies with ND-7562 through ND-7564.

Valves designed for steam service shall be tested with steam. Valves designed for compressible fluids shall be tested with a compressible fluid and valves designed for noncompressible fluids shall be tested with a noncompressible fluid.

ND-7562 Correlation

Correlation of pressure relief device operation, with respect to the parameters under test, shall be established for the specified alternative media, as compared with the operating media conditions.

ND-7563 Certification of Correlation Procedure

The Certificate Holder shall ensure that the correlation established in accordance with the procedure will be of sufficient accuracy such that the pressure relief device tested or adjusted, or both, using the alternative media, will comply with the tolerance criteria. Results of the tests performed to verify the adequacy of the alternative test media correlation shall be documented.

ND-7564 Procedure

A written procedure shall be prepared by the Certificate Holder and certified in accordance with the requirements of ND-7563. The procedure shall specify all the test parameters that affect correlation and shall include, but not be limited to, the following:

- (a) specific description of test setup;
- (b) specific requirements for instrumentation;
- (c) specific requirements for assist equipment (if any); and
- (d) specific requirements for testing conditions, i.e., device temperature, ambient temperature, ambient pressure, etc.

Test parameters shall be listed, i.e., time between openings, number of tests, etc.

ND-7600 NONRECLOSING PRESSURE RELIEF DEVICES

ND-7610 RUPTURE DISK DEVICES

ND-7611 General Requirements

Rupture disk devices certified in accordance with ND-7720 and ND-7750 are subject to the following:

(a) Rupture disk devices may be used as the sole pressure relief device for services where release of the contents of the protected system is acceptable to the enforcement authority having jurisdiction at the nuclear power plant site;

(b) Rupture disk devices may be used on the inlet side of pressure relief valves only when such valves are of the full bore⁷⁷ type (ND-7623);

(c) Rupture disk devices may be used in conjunction with pressure relief valves on the outlet side (ND-7624).

ND-7612 Burst Pressure Tolerance

The burst pressure tolerance at the specified disk temperature⁷⁸ shall not exceed ± 2 psi (± 15 kPa) for stamped burst pressure up to and including 40 psi (300 kPa) and $\pm 5\%$ for stamped burst pressure above 40 psi (300 kPa) as established by the rules of ND-7613, unless other values have been established in the Design Specification and are covered in the Overpressure Protection Report.

ND-7613 Tests to Establish Stamped Burst Pressure

(a) Every rupture disk shall have a stamped burst pressure established by rules of ND-7612 within a manufacturing design range,⁷⁹ at a specified disk temperature, and shall be stamped with a lot number.

(b) Each lot of rupture disks shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service.

(1) At least two sample rupture disks from each lot of rupture disks⁸⁰ shall be burst at the specified disk temperature. The stamped burst pressure shall be determined so that the sample rupture disk burst pressures are within the tolerance specified by ND-7612.

(2) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in ND-7612.

The value for the stamped burst pressure shall be established from the curve for a specified disk temperature.

(3) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of material. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in [ND-7612](#).

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room rating of the lot of disks. The curve shall be used to establish the stamped rating at the specified disk temperature for the lot of disks.

ND-7614 Burst Pressure in Relation to Pressure Relief Valve Set Pressure

The burst pressure of a rupture disk may be either lower or higher than the set pressure of the associated pressure relief valve, but in no case shall the rupture disk burst pressure and valve set pressure be such that the total accumulated pressure during full capacity relief exceeds the permitted limit ([ND-7400](#)).

ND-7620 INSTALLATION REQUIREMENTS

ND-7621 Provisions for Venting or Draining

When a rupture disk is used in conjunction with a pressure relief valve, the space between the rupture disk and the associated pressure relief valve shall be vented and/or drained. This space shall be provided with means to monitor its internal pressure during service periods.

ND-7622 System Obstructions

When the release of rupture disk material may occur, piping and other components downstream of the rupture disk shall be constructed such that no obstruction can be caused nor the function of a pressure relief valve impaired.

ND-7623 Rupture Disk Devices at the Inlet Side of Pressure Relief Valves

A rupture disk device may be installed at the inlet side of a pressure relief valve if the following provisions are met:

(a) the combination of the pressure relief valve and the rupture disk device capacity meets the requirements of [ND-7300](#);

(b) the stamped burst pressure at the specified disk temperature of the rupture disk does not exceed the limits of [ND-7400](#);

(c) the opening provided through the rupture disk after burst is sufficient to permit a flow equal to the capacity of the valve, and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the

capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with [ND-7700](#).

ND-7624 Rupture Disk Devices at the Outlet Side of Pressure Relief Valves

A rupture disk device may be installed at the outlet side of pressure relief valves if the following provisions are met:

(a) the set pressure of the valve is independent of back pressure; or for unbalanced valves the set pressure of the valve plus the stamped bursting pressure of the rupture disk plus any pressure in the outlet piping does not exceed the limits of [ND-7400](#);

(b) the relieving capacity meets the requirements of [ND-7300](#);

(c) the stamped burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping from the rupture disk device shall not exceed the secondary Design Pressure of the Design Pressure of the pressure relief valve and any pipe or fittings between the valve and the rupture disk device. However, in no case shall the stamped bursting pressure of the rupture disk at the operating temperature plus any pressure in the outlet piping from the rupture disk device exceed the limits of [ND-7400](#);

(d) the opening provided through the rupture disk device after burst is sufficient for the pressure relief valve to flow its certified capacity.

ND-7700 CERTIFICATION

ND-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE AND VACUUM RELIEF VALVES

(a) The Certificate Holder shall be responsible for having the relieving capacity of valves certified as prescribed in this Subarticle.

(b) Capacity certification that is obtained in compliance with other Subsections and that complies with this Subsection may be considered as qualified for capacity certification under the rules of this Subsection, and the valve may be stamped with the appropriate Certification Mark of this Subsection.

ND-7720 RESPONSIBILITY FOR CERTIFICATION OF NONRECLOSING PRESSURE RELIEF DEVICES

(a) When rupture disk devices are used as the sole pressure relief device, the rupture disk device manufacturer shall be responsible for having the relieving capacity of the rupture disk device determined ([ND-7760](#)).

(b) When rupture disk devices are used at the inlet of pressure relief valves, the manufacturer of the rupture disk devices or the pressure relief valves shall be responsible for having the relieving capacity of the combination determined (ND-7760).

ND-7730 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES — COMPRESSIBLE FLUIDS

ND-7731 General Requirements

ND-7731.1 Capacity Certification.

(a) Capacity certification procedures shall be as required in ND-7732 through ND-7736.

(b) For steam at pressures over 1,500 psig (10 MPa gage) and up to 3,200 psig (22.1 MPa gage), the value of K used to determine the certified relieving capacity shall be multiplied by

(U.S. Customary Units)

$$\frac{0.1906P - 1,000}{0.2292P - 1,061}$$

(SI Units)

$$\frac{27.6P - 1000}{33.2P - 1061}$$

where

P = set pressure, psig (MPa)

This correction is also applicable to the certified relieving capacity as determined by the curve method. The correction shall be used only if it is 1.0 or greater.

ND-7731.2 Test Media.

(a) Capacity certification tests of pressure relief valves for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (10°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity certification tests for pressure relief valves for air and gas service shall be conducted with air, gas, or dry saturated steam.

ND-7731.3 Test Pressure.

(a) Capacity certification tests of pressure relief valves for main steam service shall be conducted at a pressure that does not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater.

(b) Capacity certification tests of pressure relief valves with set pressures of 15 psig (100 kPa gage) and higher for air, gas, or steam service other than main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

(c) Capacity certification tests for air or gas service with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage) shall be conducted in accordance with the requirements of ND-7731 through ND-7734. When tests are performed in accordance with ND-7734, the capacity shall be determined at no more than 2 psi (15 kPa) above the actual set pressure.

ND-7731.4 Blowdown.

(a) Valves set at or above 15 psig (100 kPa gage), having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure.

(b) Valves set below 15 psig (100 kPa gage), having adjustable blowdown construction, shall be adjusted prior to capacity certification testing so that blowdown does not exceed 3 psi (20 kPa) and shall not be less than 0.5 psi (4 kPa).

ND-7731.5 Drawings. Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designated organization for review and acceptance.

ND-7731.6 Design Changes. When changes are made in the design of a pressure relief valve that affect the flow path, lift, or performance characteristics, new tests shall be performed in accordance with this Subarticle.

ND-7731.7 Restricted Lift Valves.

(a) The design of the lift restraining device shall be subject to review by an ASME designated organization.

(b) For air or gas services and for steam service other than in (a) above, all valves shall be capacity tested at each pressure and lift at a flow rating pressure not exceeding 110% of the set pressure as required in the applicable Code paragraph.

(c) For each valve tested, it shall be verified that actual measured capacity at restricted lift will equal or exceed the ASME rated capacity at full rated lift multiplied by the ratio of measured restricted lift to full rated lift.

ND-7732 Flow Model Test Method — Pilot or Power Operated Valves

ND-7732.1 Flow Capacity. When test facility limitations make it impossible to perform capacity tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the accepted test laboratory where the tests will be conducted and shall accurately model those features, such as orifice size, valve lift, and internal flow configuration, which affect flow capacity. The test models need not be functional pressure relief valves, provided that other tests are conducted to demonstrate proper function of the valve design are conducted as prescribed in ND-7732.2. The relieving capacity of valve designs

certified by use of flow models shall be established by the coefficient of discharge method similar to that outlined in ND-7734. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of ND-7734, shall not exceed the value calculated by the appropriate equation in ND-7734.2 multiplied by the coefficient K .

ND-7732.2 Demonstration of Function. The function of three valves of the design to be certified shall be demonstrated by tests. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves. The purpose of these tests is to demonstrate to the satisfaction of a representative from an ASME designated organization that the valve will open at set pressure within the required opening pressure tolerance, will achieve full lift, and will re-close within required blowdown. If required by test facility limitations, these tests may be conducted at reduced flow capabilities. Measurement of valve blowdown may not be possible.

ND-7733 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at pressures that will cover the appropriate range of pressures for which the valves are to be used or within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as follows:

(1) For valves with set pressures of 15 psig (100 kPa gage) and greater, slope is defined as the measured capacity divided by the absolute inlet pressure.

(2) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage), slope is defined as the measured capacity divided by the quantity.

$$F[(P)(P - P_o)]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right)\left(r^{2/k}\right)\left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

k = ratio of specific heats, C_p/C_v

P = inlet pressure, psi (kPa)

P_o = discharge pressure, psi (kPa)

r = pressure ratio, P_o / P

(c) If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these

valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

(d) For valves with set pressures of 15 psig (100 kPa gage) and greater, the certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

(e) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage), the certified capacity shall be 90% of the average slope multiplied by the quantity.

$$F[(P)(P - P_o)]^{1/2}$$

(f) In addition, demonstration of function tests shall be conducted as prescribed in ND-7732.2.

ND-7734 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in the following subparagraphs.

ND-7734.1 Number of Valves to Be Tested. For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure. For restricted lift valves, each size valve shall be tested for capacity at its full rated lift, at the minimum lift for which certification is required, and at an intermediate lift point approximately halfway between the full rated lift and minimum lift certification points. Each of the three test valves shall be set at a different pressure.

ND-7734.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each pressure relief valve to determine its lift, opening, and blowdown pressures, and capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and the Theoretical Flow is calculated by the following equation:

(1) For valves with set pressures of 15 psig (10 MPa gage) and greater. For test with dry saturated steam

Pressures up to 1,500 psig (10.9 MPa gage)

$$W_T = 51.5AP$$

Pressures over 1,500 psig (10.9 MPa gage) and up to 3,200 psig (22.1 MPa gage) the value of W_T , calculated by the above equation, shall be corrected by being multiplied by the following factor which shall be used only if it is 1.0 or greater:

(U.S. Customary Units)

$$\frac{(0.1906P - 1,000)}{(0.2292P - 1,061)}$$

(SI Units)

$$\frac{(27.6P - 1000)}{(33.2P - 1061)}$$

For test with air

$$W_T = 356AP \sqrt{\frac{M}{T}}$$

For test with gas

$$W_T = CAP \sqrt{\frac{M}{ZT}}$$

where

A = actual discharge area through the valve at developed lift, in.² (mm²)

C = constant for gas or vapor which is a function of the ratio of specific heats, k

$k = c_p/c_v$ ratio of specific heats (see Figure XVIII-1110-1)

M = molecular weight

P = (set pressure \times 1.03) plus atmospheric pressure, psia, or set pressure plus 2 psi (15 kPa) plus atmospheric pressure, whichever is greater, for test pressures determined by ND-7731.3(a)

= (set pressure \times 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi (20 kPa) plus atmospheric pressure, whichever is greater, for test pressures determined by ND-7731.3(b)

T = absolute temperature at inlet, °F + 460 (°C + 273)

W_T = Theoretical Flow, lb/hr

Z = compressibility factor corresponding to P and T

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(2) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage). The following equation may be used for other than saturated steam flow

(U.S. Customary Units)

$$W = CFA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

(SI Units)

$$W = CFA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

where

C = 735 for U.S. Customary

C = 55.86 for SI Units

(U.S. Customary Units)

$$Q = CFA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

(SI Units)

$$Q = CFA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

where

C = 279,000 for U.S. Customary

C = 1 324 for SI Units

where

$$F = \sqrt{\left(\frac{k}{k-1} \right) \left(r^{2/k} \right) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r} \right]}$$

or is obtained from Figure ND-7734.2(a)-1.

A = flow area, in.² (mm²)

k = ratio of specific heats, c_v/c_p

M = molecular weight

P = inlet pressure, psi (MPa)

P_o = discharge pressure, psi (MPa)

Q = ft³/hr at 14.7 psi and 60°F (m³/hr at 101 kPa and 20°C)

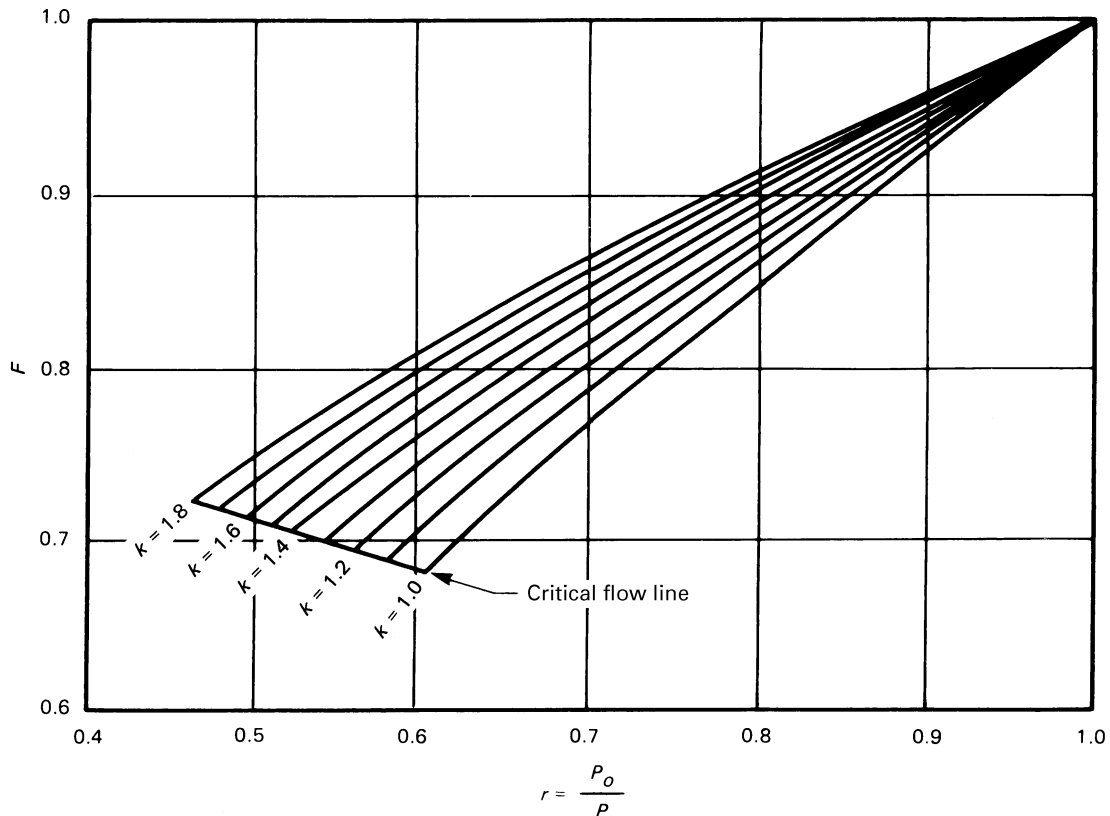
r = pressure ratio, P_o/P

T = temperature, deg Rankin (R)

W = lb/hr (kg/hr)

The average of the coefficients of discharge K_d of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.878 (the product of 0.90×0.975).

Figure ND-7734.2(a)-1
Values of F for Nonchoking Flow



(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

ND-7734.3 Calculation of Certified Capacity.

(a) The certified capacity of all sizes and pressures of a given design, for which the value of K has been established under the provisions of ND-7734.2 and that are manufactured subsequently, shall not exceed the value calculated by the appropriate equation multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within

$\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7734.4 Demonstration of Function. Tests shall be conducted as prescribed in ND-7732.2.

ND-7735 Single Valve Method

ND-7735.1 Valve Capacity Within Test Facility Limits.

(a) When a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

ND-7735.2 Valve Capacity in Excess of Test Facility Limits. For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (ND-7734.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in ND-7734.3.

ND-7735.3 Valve Demonstration of Function. The proper operation of the valve shall be demonstrated as prescribed in ND-7732.2.

ND-7736 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification

(1) the prorated capacity shall be 90% of the average slope determined in ND-7733 multiplied by the prorated relieving pressure, or;

(2) the prorated capacity shall be calculated using the appropriate equation from ND-7734.2 (where P is the prorated relieving pressure multiplied by the coefficient K).

ND-7737 Capacity Conversions

The relieving capacity of pressure relief valves for fluids other than the fluid used for certification shall be determined by the method of conversion given in Section III Appendices, Mandatory Appendix XVIII, Article XVIII-1000, except that valves for steam service shall be tested on steam.

ND-7738 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-2001, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.⁸¹

ND-7739 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing capacity and range of fluid properties so that the testing requirements of ND-7732.2 are met.

ND-7740 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES — INCOMPRESSIBLE FLUIDS

ND-7741 General Requirements

ND-7741.1 Capacity Certification. Capacity certification procedures shall be as required in ND-7742 through ND-7744.

ND-7741.2 Test Medium. The test medium to be used for capacity certification shall be water at a temperature between 40°F and 125°F (5°C and 50°C).

ND-7741.3 Test Pressure. Tests shall be conducted at pressures which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

ND-7741.4 Blowdown. Blowdown shall be recorded at the time of the test.

ND-7741.5 Drawings. Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designated organization for review and acceptance.

ND-7741.6 Design Changes. When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Subarticle shall be performed.

ND-7742 Valve Designs in Excess of Test Facility Limits

(a) For a valve design where test pressures will exceed test facility limits, the certified capacity may be based on a flow coefficient K (ND-7744.2) determined from blocked open flow tests at four pressures covering the range of the test facility.

(1) For a valve design to be certified at a single size and set pressure, a demonstration of function test shall be conducted as prescribed in ND-7732.2 on one valve at the specified pressure.

(2) For a valve design of a single size to be certified over a range of set pressures, demonstration of function tests shall be conducted as prescribed in ND-7732.2 on two valves covering the minimum set pressure for the design and the maximum set pressure that can be accommodated at the demonstration facility selected for the test.

(b) For a valve design that will be used over a range of set pressures and sizes, where test facility limitations make it impossible to perform tests of full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. The flow model test method in ND-7732.1 shall be used along with the coefficient of discharge method in ND-7744.

(1) A demonstration of function tests for three valves shall be performed as prescribed in ND-7732.2.

ND-7743 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures that cover the appropriate range of pressures for which the valves are to be used or within the range of the test facility. The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the square root of the difference between the flow rating pressure and the valve discharge pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

ND-7744 Coefficient of Discharge Method

Instead of individual capacity tests or the capacity curve method, a coefficient K may be established for a specific pressure relief valve design in accordance with the following subparagraphs.

ND-7744.1 Number of Valves to Be Tested. For each design, three valves for each of three different sizes shall be tested, for a total of nine valves. Each valve of a given size shall be set at a different pressure.

ND-7744.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity in terms of pounds of water per hour. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated by the following equation:

For tests with water

(U.S. Customary Units)

$$W_t = 2,407A\sqrt{(P - P_d)w}$$

(SI Units)

$$W_t = 5,092A\sqrt{(P - P_d)w}$$

where

A = actual minimum discharge area through the valve at developed lift, in.² (mm²)

P = (set pressure $\times 1.10$) plus atmospheric pressure, psia (kPa abs), or set pressure plus 3 psi (20 kPa) plus atmospheric pressure, whichever is greater

P_d = pressure at discharge from valve, psia (kPa abs)

W_t = Theoretical Flow, lb/hr (kg/hr)

w = density of water at valve inlet conditions, lb/ft³ (kg/m³)

The average of the coefficients of discharge K_D of the tests shall be multiplied by 0.90 and the product shall be taken as the coefficient K of the design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

ND-7744.3 Calculation of Certified Capacity.

(a) The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of ND-7744.2 shall not exceed the value calculated by the theoretical equation above and multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7745 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate tests of the single valve at the specified set pressure.

(b) The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the tests repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

ND-7746 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-2001, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.⁸¹

ND-7747 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification

(1) the prorated capacity shall be 90% of the average slope determined in ND-7743 multiplied by the prorated relieving pressure (psia), or

(2) the prorated capacity shall be calculated using the appropriate equation from ND-7744.2 [where P is the prorated relieving pressure (psia) multiplied by the coefficient K].

ND-7748 Capacity Conversion

The rated pressure relieving capacity of pressure relief valves for liquids other than the liquids used for certification shall be determined by the method of conversion given in Section III Appendices, Mandatory Appendix XVIII, Article XVIII-1000. This conversion is not valid for liquid flashing valve operating conditions.

ND-7750 CAPACITY CERTIFICATION OF VACUUM RELIEF VALVES**ND-7751 General Requirements**

ND-7751.1 Capacity Certification. Capacity certification procedures shall be as required in ND-7752 through ND-7755.

ND-7751.2 Test Media. Capacity certification tests for vacuum relief valves for air and gas service shall be conducted with dry steam, air, or gas. For steam test purposes, the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to dry saturated condition from these limits.

ND-7751.3 Test Method and Pressure. Capacity tests may be conducted by pressurizing the valve instead of using a vacuum, provided the inlet conditions of the valve (not the vessel) are known and the inlet pressure is not greater than 5 psi (35 kPa), and the direction of flow through the valve is the same on pressure as is experienced on vacuum. Tests shall be conducted at twice the set pressure or 1 psi (7 kPa), whichever is greater.

ND-7751.4 Blowdown. Blowdown shall be recorded at the time of the test.

ND-7751.5 Drawings. Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designated organization for review and acceptance.

ND-7751.6 Design Change. When changes are made in the design of a vacuum relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

ND-7752 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate and distinct tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(b) Should additional valves of the same design be constructed at a later date, the results of the test on the original valve may be included as applicable to the particular test method selected.

ND-7753 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures that cover the appropriate range of pressures for which the valves are to be used or set within the range

of the test facility. The slope of each test shall be calculated and averaged, where slope is defined as the measured capacity divided by the quantity, $F[(P)(P - P_o)]^{1/2}$.

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) \left(r^{2/k}\right) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

where

k = ratio of specific heats, c_v/c_p

P = inlet pressure

P_o = discharge pressure

r = pressure ratio, P_o/P

If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the quantity, $F[(P)(P - P_o)]^{1/2}$.

ND-7754 Coefficient of Discharge Method

A coefficient K may be established for a specific vacuum relief valve design in accordance with ND-7754.1 and ND-7754.2.

ND-7754.1 Number of Valves to Be Tested. For each design, three valves of three different sizes, a total of nine valves, shall be tested. Each valve of a given size shall be set at a different pressure.

ND-7754.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity. A coefficient of discharge K_D shall be established for each run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated from the appropriate equation for the test fluid. The following equation may be used for other than saturated steam flow:

(U.S. Customary Units)

$$W = 735FA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

(SI Units)

$$W = 55.8FA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

(U.S. Customary Units)

$$Q = 279,000FA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

(SI Units)

$$Q = 1320FA \left[\frac{MP(P - P_o)}{MT} \right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) \left(r^{2/k}\right) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

or is obtained from Figure ND-7754.2(a)-1.

A = flow area

k = ratio of specific heats, C_v / C_p

M = molecular weight

P = inlet pressure, MPa

P_o = discharge pressure, MPa

Q = ft³/hr at 14.7 psi and 60°F (m³/hr at 101 MPa and 20°C)

r = pressure ratio, P_o/P

T = temperature, deg Rankin (deg K)

W = lb/hr (kg/hr)

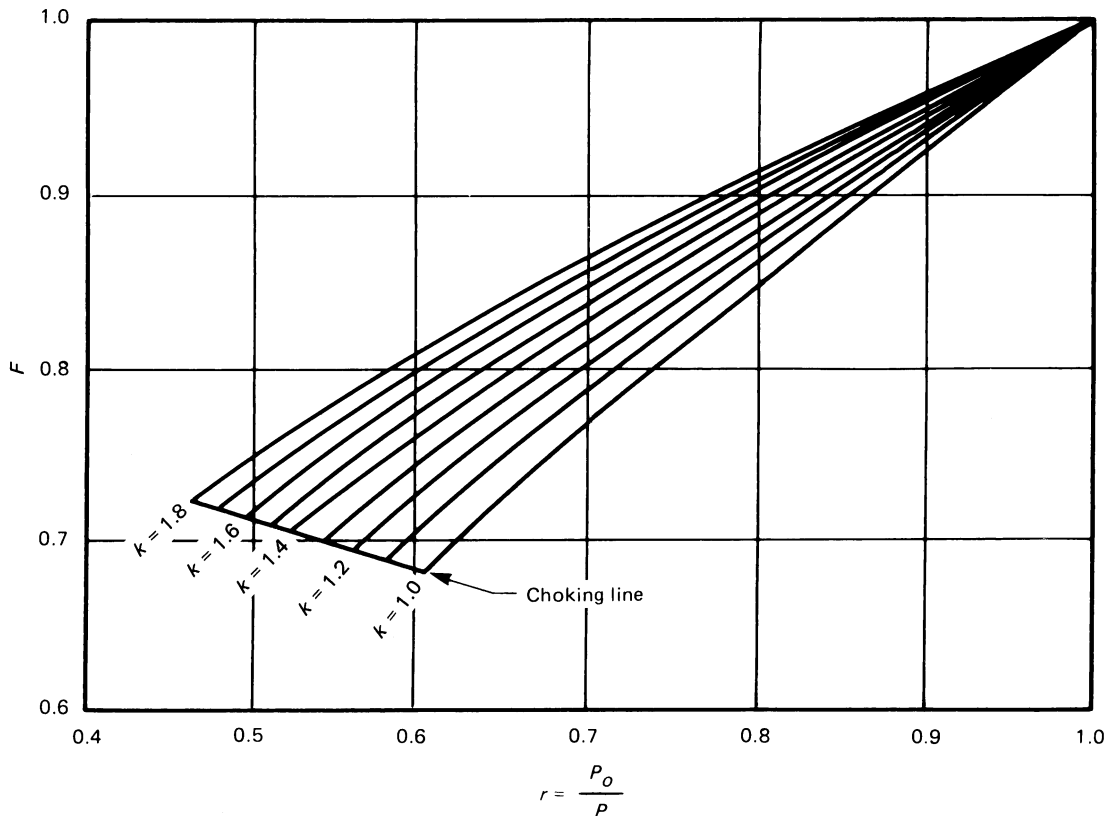
The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

ND-7754.3 Calculation of Relieving Capacity.

(a) The certified relieving capacity of all sizes and pressures of a given design, for which the value of K has been established, shall be calculated by the appropriate

Figure ND-7754.2(a)-1
Values of F for Nonchoking Flow



equation given above multiplied by the coefficient K . Values obtained from pressurized tests may be converted to equivalent vacuum from the above equation.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7755 Laboratory Acceptance of Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25-2001. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of

the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.

ND-7760 CAPACITY DETERMINATION OF RUPTURE DISK DEVICES

ND-7761 General Requirements

ND-7761.1 Capacity Determination Procedures.

(a) Capacity determination procedures without flow tests shall be as given in [ND-7762.1](#) and [ND-7763.1](#).

(b) Capacity determination procedures with flow tests shall be as required in [ND-7762.2](#).

ND-7761.2 Test Media

(a) Capacity tests of rupture disk devices for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity tests for rupture disk devices for air and gas service shall be conducted with air, gas, or dry saturated steam.

ND-7761.3 Test Pressure. Capacity tests of rupture disk devices shall be conducted at a pressure not exceeding 110% of the burst pressure.

ND-7761.4 Drawings. Prior to tests, the Certificate Holder shall submit drawings showing the rupture disk device construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designated organization for review and acceptance.

ND-7761.5 Design Changes.

(a) When, in a type of rupture disk device, changes occur that may affect the flow area of the rupture disk device, each such change shall be treated as a different series of disks and must be tested.

(b) When changes are made in the design of a type of rupture disk device in such a manner as to affect area or performance characteristics of the rupture disk device, new tests must be made.

ND-7762 Capacity Determination of Rupture Disk Devices in Combination With Pressure Relief Valves

ND-7762.1 Capacity Determination Without Flow Test.

(a) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the inlet side of the valve shall not exceed 80% of the certified capacity of the valve. Alternatively, the capacity of such a combination shall be established in accordance with ND-7762.2.

(b) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the outlet of the valve shall be the certified capacity of the valve.

ND-7762.2 Capacity of Pressure Relief Valves in Combination With a Rupture Disk Device at the Inlet. For each combination of pressure relief valve design and rupture disk device design, the Certificate Holder or the rupture disk device manufacturer shall have the capacity of the combination determined as prescribed in (a) and (b) below.

(a) The Certificate Holder or the rupture disk device manufacturer shall submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.

(b) Tests shall be performed in accordance with the requirements of (1) through (5) below. The rupture disk device and pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(1) The test shall be made using the minimum burst pressure of the rupture disk device design that is to be used in combination with the pressure relief valve design. The stamped bursting pressure shall be between 90% and 100% of the stamped set pressure of the valve.

(2) The test procedure to be used shall be as follows:

(-a) The pressure relief valve by itself shall be tested for capacity without the rupture disk device at a pressure 10% above the valve set pressure.

(-b) The rupture disk device shall then be installed in front of the pressure relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the test of (a) above.

(3) The tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(4) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity that is determined by the combination tests to the capacity which is determined by the test of (a) above. The Combination Capacity Factor shall be used as a multiplier to the certified capacity of the pressure relief valve in all sizes of the design except when a different factor has been established for larger sizes and other pressures in accordance with ND-7762.3. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design and manufacture of the pressure relief valve and the same design and manufacture of the rupture disk device as those tested.

(5) The test laboratory shall submit the test results to the ASME designated organization for acceptance of the Combination Capacity Factor.

ND-7762.3 Optional Testing of Rupture Disk Devices and Pressure Relief Valves.

(a) If desired, a Certificate Holder or a rupture disk manufacturer may conduct tests in the same manner as given in ND-7762.2 using the next two larger sizes of the same design of rupture disk device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be approved, it may be used for all larger sizes of the combination, but the Factor shall not be greater than one.

(b) If desired, additional tests may be conducted at higher pressures in accordance with ND-7762.2 to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but the Factor shall not be greater than one.

ND-7763 Capacity of Rupture Disk Devices**ND-7763.1 Calculated Capacity.**

(a) The calculated capacity of a rupture disk device shall not exceed a value based on the applicable theoretical equation multiplied by a value for K of 0.62. For compressible fluids, see Appendix XVIII. The theoretical equation for liquids shall be as follows:

(U.S. Customary Units)

$$W_t = 2407A\sqrt{(P - P_d)w}$$

(SI Units)

$$W_t = 5092A\sqrt{(P - P_d)w}$$

where

A = minimum net flow area existing after rupture disk burst, in.² (mm²)

P = (stamped rupture pressure \times 1.10) plus atmospheric pressure, flow rating pressure, psia (MPa abs)

P_d = pressure at discharge from rupture disk device, psi (MPa)

w = specific weight of liquid at rupture disk device inlet conditions, lb/ft³ (kg/m³)

W_t = Theoretical Flow, lb/hr (kg/hr)

(b) The minimum net flow area is the calculated net area after a complete burst of the rupture disk with appropriate allowance for any structural members that may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

ND-7763.2 Tested Capacity. A manufacturer may have the capacity of a given rupture disk device design approved for K_D in general accordance with the procedures of NC-7730, as applicable.

ND-7764 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-2001, Pressure Relief Devices. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.⁸¹

ND-7800 MARKING, STAMPING WITH CERTIFICATION MARK, AND DATA REPORTS**ND-7810 PRESSURE AND VACUUM RELIEF VALVES****ND-7811 Marking and Stamping With Certification Mark**

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $\frac{3}{32}$ in. (2.5 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Certification Mark with NV Designator shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

(a) name, or an acceptable abbreviation, of the Certificate Holder

(b) Certificate Holder's design or type number

(c) size _____ [NPS (DN), the nominal pipe size] of the valve inlet

(d) set pressure _____ psi (kPa)

(e) certified capacity and overpressure in percent or psi (kPa) in accordance with [ND-7700](#)

Pressure Relief Valves:

- lb/hr (kg/hr) of saturated steam for valves certified on steam, or
- scfm [standard cubic feet per minute (m³ per hour)] at 60°F (15°C) and 14.7 psia (101 kPa) of air for valves certified on air or gas, or
- gal/min (l/min) of water at 70°F (20°C) for valves certified on water

Vacuum Relief Valves

- scfh (standard cubic feet per hour) at 60°F (15°C) and 14.7 psi (101 kPa)

(f) applicable official Certification Mark, as shown in Table NCA-8100-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and [ND-3593.2](#).

ND-7812 Report Form for Pressure and Vacuum Relief Valves

A Data Report Form NV-1 shall be filled out and signed by the Certificate Holder and signed by the Inspector for each pressure and vacuum relief valve stamped with the Certification Mark with NV Designator.

ND-7820 RUPTURE DISK DEVICES**ND-7821 Rupture Disks**

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking shall be placed on the flange of the rupture disk or on a metal tab permanently attached thereto.⁸² The marking shall include the following:

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) lot number
- (d) size ____ in. (DN)
- (e) stamped bursting pressure ____ psi (kPa)
- (f) specified disk temperature ____ °F (°C)
- (g) capacity ____ lb/hr (kg/hr) of saturated steam or standard cu ft/min of air [60°F (20°C) and 14.7 psia (101 kPa)]
- (h) year built

ND-7822 Disk Holders (If Used)

Rupture disk holders shall be marked with the following:

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) size ____ in. (DN)
- (d) year built
- (e) serial number

ND-7830 PRESSURE RELIEF VALVE IN COMBINATION WITH RUPTURE DISK DEVICES**ND-7831 Marking When Capacity Is Approved in Accordance With ND-7762.1**

The marking shall be placed either on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include a Combination Capacity Factor of 0.8.

ND-7832 Marking When Capacity Is Approved in Accordance With ND-7762.2

The following marking shall be in addition to the marking required by ND-7811 and ND-7822. The marking shall be placed on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include the following:

- (a) name of the Certificate Holder
- (b) design or type or serial number of valve
- (c) name of manufacturer of rupture disk device
- (d) design or type designation of rupture disk device
- (e) approved Combination Capacity Factor

ND-7840 CERTIFICATE OF AUTHORIZATION TO USE CERTIFICATION MARK

Each pressure and vacuum relief valve within the scope of this Article shall be constructed by a Certificate Holder possessing a Certification Mark with NV Designator and a valid Certificate of Authorization. Pressure and vacuum relief valves shall have the Certification Mark with NV Designator applied in accordance with the rules of ND-8100.

ARTICLE ND-8000 NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS

ND-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping with Certification Mark, and reports shall be as given in NCA-8000.

ENDNOTES

- 1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties inservice under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.
- 2 Any postweld heat treatment time that is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.
- 3 *Lowest Service Temperature* (LST) is the minimum temperature of the fluid retained by the component, or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.
- 4 The requirements for impact testing of the heat affected zone (ND-4335.2) may result in reduced test temperatures or increased toughness requirements for the base material.
- 5 The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.
- 6 It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.
- 7 *Stress* means the maximum normal stress.
- 8 The minimum thickness for all pipe materials is the nominal wall thickness listed in Table 2 of ASME B36.10M less 12½%. For diameters other than those listed in the table, this shall be based on the next larger pipe size.
- 9 Special consideration shall be given to the design of shells, nozzle necks, or flanges to which noncircular heads or covers are attached.
- 10 The equations provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.
- 11 Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.
- 12 The minimum cross section is usually at the root of the thread.
- 13 The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups that extend a distance greater than the inside diameter of the shell as covered in ND-3329.6(c). When this occurs, the efficiencies computed by the rules under ND-3329.6(b) shall govern.
- 14 The rules governing openings as given in this Subsection are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. They are based on experience with vessels designed with design factors of 4 and 5 applied to the ultimate strength of the shell material. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.
- 15 The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.
- 16 An *obround opening* is one that is formed by two parallel sides and semicircular ends.

- 17 *Communicating chambers* are defined as appurtenances to the vessel that intersect the shell or heads of a vessel and form an integral part of the pressure retaining closure, e.g., sumps.
- 18 *Side plates* of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.
- 19 Written for fittings with internal threads but also applicable to externally threaded and socket or butt welded fittings.
- 20 t_D is defined in Section III Appendices, Mandatory Appendix XI, XI-3130.
- 21 All dimensions given, for size of vessel on which inspection openings are required, are nominal.
- 22 It is recognized that other acceptable procedures may exist that also constitute adequate design methods, and it is not the intention to rule out these alternative methods provided they can be shown to have been satisfactory by actual service experience.
- 23 The minimum thicknesses of straight pipe shown in [Table ND-3642.1\(c\)-1](#) should be sufficient to allow the pipe to meet the minimum wall thickness requirements of [ND-3641](#) after having been bent on the radii shown.
- 24 Expansion Joint Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591.
- 25 See Section III Appendices, Mandatory Appendix II, II-1520(g).
- 26 The pressure term in [eqs. ND-3652\(8\)](#), [ND-3653.1\(a\)\(9a\)](#), [ND-3653.1\(b\)\(9b\)](#) and [ND-3653.2\(c\)\(11\)](#) may not apply for bellows and expansion joints.
- 27 Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.
- 28 Socket welded joints should not be used where the existence of crevices could result in accelerated corrosion.
- 29 Fillet and partial penetration welds should not be used where severe vibration is expected.
- 30 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.
- 31 The limitation of the Design Pressure to *atmospheric* is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressures or vacuums exceed $\frac{1}{2}$ oz/in.², especially in combination with large diameter tanks, the forces involved may require special consideration in the design.
- 32 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.
- 33 The *nominal thickness* of shell plates refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.
- 34 API Standard 2000, 1968 Edition, Venting Atmospheric and Low Pressure Storage Tanks, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070.
- 35 The decrease in yield stress at Design Temperature shall be taken into account.
- 36 The equations applying to self-supporting roofs provide for a uniform live load of 25 lb/ft² (1.2 kPa).
- 37 Whenever a tank is to be operated with liquid levels that at no time reach the top of the roof, but is to be filled to the very top of the roof during the hydrostatic test, it shall be designed for both of these maximum liquid level conditions, using in each case the density of the liquid employed. If a tank is not designed to be filled to the very top of the roof, overfill protection is required.
- 38 A suitable margin shall be allowed between the pressure normally existing in the gas or vapor space and the pressure at which the relief valves are set, so as to allow for the increases in pressure caused by variations in the temperature or gravity of the liquid contents of the tank and other factors affecting the pressure in the gas or vapor space.
- 39 The partial vacuum shall be greater than that at which the vacuum relief valves are set to open.
- 40 Recommended Rules for Design and Construction of Large, Welded Low-Pressure Storage Tanks, published by American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070.

- 41 These rules do not apply when the circumferential stress on a cylindrical shell is compressive as in a cylinder acted upon by external pressure.
- 42 In these expressions if the unit force is latitudinal, R shall be considered to be R_1 and, if meridional, R shall be considered as equal to R_2 .
- 43 (a) Equation ND-3932.2(a)(2) has been derived from a summation of the components, normal to the surface, of the T_1 and T_2 forces acting on a unit area of the tank wall subjected only to a pressure P . To be technically correct, the normal to the surface components of other loads, such as metal, snow, or insulation, should be added to or subtracted from the term P . For the usual internal Design Pressure, these added loads are small compared to the pressure P and can be omitted without significant error. When the pressure P is relatively small including the case of a partial vacuum loading, the other load components can have a substantial effect on the calculated T_2 force and the resultant thickness.
- (b) Example F.3.01 in Appendix F of API 620 Feb. 1970 Edition calculates the required roof thicknesses under a small vacuum by considering the metal, insulation, and snow loads in ND-3932.2(a)(1), ND-3932.2(a)(2), ND-3932.2(d)(3), ND-3932.2(d)(4), ND-3932.2(e)(1)(5), and ND-3932.2(e)(1)(6). The designer should note that if these loads had been omitted the calculated thicknesses would have been much less than the correct values.
- (c) In eqs. ND-3932.2(a)(1), ND-3932.2(e)(1)(5), ND-3932.2(e)(1)(7), and ND-3932.2(e)(3)(10), the term W is intended to include loads, such as metal weight, of significant value. At points away from the vertical center line of the roof, the value of T_2 is required for the thickness calculations of eqs. ND-3932.3(d), Step 1(18), ND-3932.3(d), Step 3(20), and ND-3932.3(d), Step 5(22) and the value of P in eqs. ND-3932.2(a)(2), ND-3932.2(e)(1)(6), and ND-3932.2(e)(2)(9) must be modified by the normal components of the added loads for the correct determination of T_2 .
- 44 These rules do not contain provisions in respect to the design of cylindrical sidewalls subject to partial internal vacuum in tanks constructed for storage of gases or vapors alone.
- 45 The vacuum relief valve or valves shall be set to open at a smaller partial vacuum so that the 1 oz (0.28 N) partial vacuum will not be exceeded when the inflow of air or gas through the valves is at its maximum specified rate.
- 46 If external anchor bolts are used for resisting such uplift, it is recommended that their nominal diameter be not less than 1 in. (25 mm) plus a corrosion allowance of at least $\frac{1}{4}$ in. (6 mm) on the diameter.
- 47 These forces are computed by the applicable equations in ND-3932.
- 48 Use of a knuckle radius as small as 6% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for such region will be found more reasonable if a larger knuckle radius is used.
- 49 Because of the discontinuities and other conditions found in a compression ring region, biaxial stress design criteria are not considered applicable for a compressive force determined as in eq. ND-3933.4(b)(26). Experience has shown that a compressive stress of the order of 15,000 psi (100 MPa), as indicated in eq. ND-3933.4(b)(27), is permissible in this case, provided the requirements of ND-3933.5 are satisfied.
- 50 Note that, unless the effect of the unit forces T_2 and T_{2s} on the resulting increments in width of participating plate may safely be neglected, the use of thicker plates involves recomputing not only w_h and w_c but also Q and A_c for the increased plate thicknesses; hence, the design of the compression ring region in this case resolves into a trial and error procedure.
- 51 See Figure ND-3933.5(d)-1 for some acceptable details of construction of compression rings.
- 52 Note that the value required for I_1 as calculated from eq. ND-3933.5(h)(28) is not applicable for materials other than steel.
- 53 See ND-4246 and ND-4247 for special weld joint requirements in storage tanks.
- 54 One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat of material, the same heat treatment lot, and forged in the same manner.
- 55 Written and illustrated with internal threads, but also applicable to externally threaded and socket or butt welded fittings.
- 56 PWHT shall be performed only by agreement between the Owner and the Certificate Holder, except for casting SB-148 alloy CD954. Agreement shall cover time, temperature, and method of PWHT.

- 57 An *intermediate postweld heat treatment* for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld shall be subjected during the final postweld heat treatment.
- 58 (a) Spot radiographing of a welded joint is recognized as an effective inspection tool. The spot radiography rules are also considered to be an aid to quality control. Spot radiographs made directly after a welder or an operator has completed a unit of weld proves that the work is or is not being done in accordance with a satisfactory procedure. If the work is unsatisfactory, corrective steps can then be taken to improve the welding in the subsequent units, which unquestionably will improve the weld quality.
(b) Spot radiography in accordance with these rules will not insure a fabrication product of predetermined quality level throughout. It must be realized that an accepted vessel or tank under these spot radiography rules may still contain defects that might be disclosed on further examination. If all radiographically disclosed unacceptable weld defects are required to be eliminated from a vessel or tank, then 100% radiography shall be employed.
- 59 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlington Lane, P.O. Box 28518, Columbus, OH 43228-0518.
- 60 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the edition referenced in Table NCA-7100-2 when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the edition referenced in Table NCA-7100-2.
- 61 *Employer*, as used in this Article, shall include: N Certificate Holders; Quality System Certificate Holders; and Material Organizations that are qualified in accordance with NCA-3842; and organizations that provide subcontracted nondestructive examination services to organizations described above.
- 62 These tests may be made with the item being tested partially filled with liquid, if desired.
- 63 Temperature fluctuations within the piping system may affect the pressure. Precautions must be taken to ensure that the test is not biased by temperature effects.
- 64 Wherever the word *system* appears in this Article, it refers to the component or group of components for which overpressure protection is provided as described in the Overpressure Protection Report.
- 65 A *pressure relief device* is designed to open to prevent a rise of internal fluid pressure greater than a specified value, resulting from exposure to pressure transient conditions. It may also be designed to prevent excessive internal vacuum. It may be a pressure relief valve, a nonreclosing pressure relief device, or a vacuum relief valve.
- 66 A *pressure relief valve* is a pressure relief device that is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.
- 67 A *vacuum relief valve* is a pressure relief device designed to admit fluid to prevent an excessive internal vacuum; it is designed to reclose and prevent further flow of fluid after normal conditions have been restored.
- 68 A *nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.
- 69 A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.
- 70 A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening generally proportional to the increase in pressure over the opening pressure.
- 71 A *relief valve* is a pressure relief valve actuated by inlet static pressure and having a gradual lift generally proportional to the increase in pressure over the opening pressure.
- 72 A *pilot operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and controlled by a self-actuated auxiliary pressure relief valve.
- 73 A *power actuated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and controlled by a device requiring an external source of energy.
- 74 A *rupture disk device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk.
- 75 *Expected system pressure transient conditions* are those associated with normal system transient operation.

- 76 *Unexpected system pressure transient conditions* are those associated with unusual or abnormal system transients, but still considered to be within the design basis.
- 77 A pressure relief valve that has no protrusions in the bore and wherein the valve disk lifts to an extent sufficient for the minimum area, at any section at or below the body seat, to become the controlling orifice.
- 78 The specified disk temperature supplied to the rupture disk manufacturer shall be the temperature of the disk when the disk is expected to burst.
- 79 The *manufacturing design range* is a range of pressure within which the stamped burst pressure must fall. This range is included in the Design Specification and the Overpressure Protection Report.
- 80 *A lot of rupture disks* is those disks manufactured of material at one time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.
- 81 Valve capacities published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.
- 82 In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of a manufacturer's coding number sufficient to identify each rupture disk with a certificate or tab that includes the required information and is supplied with each lot of rupture disks.

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