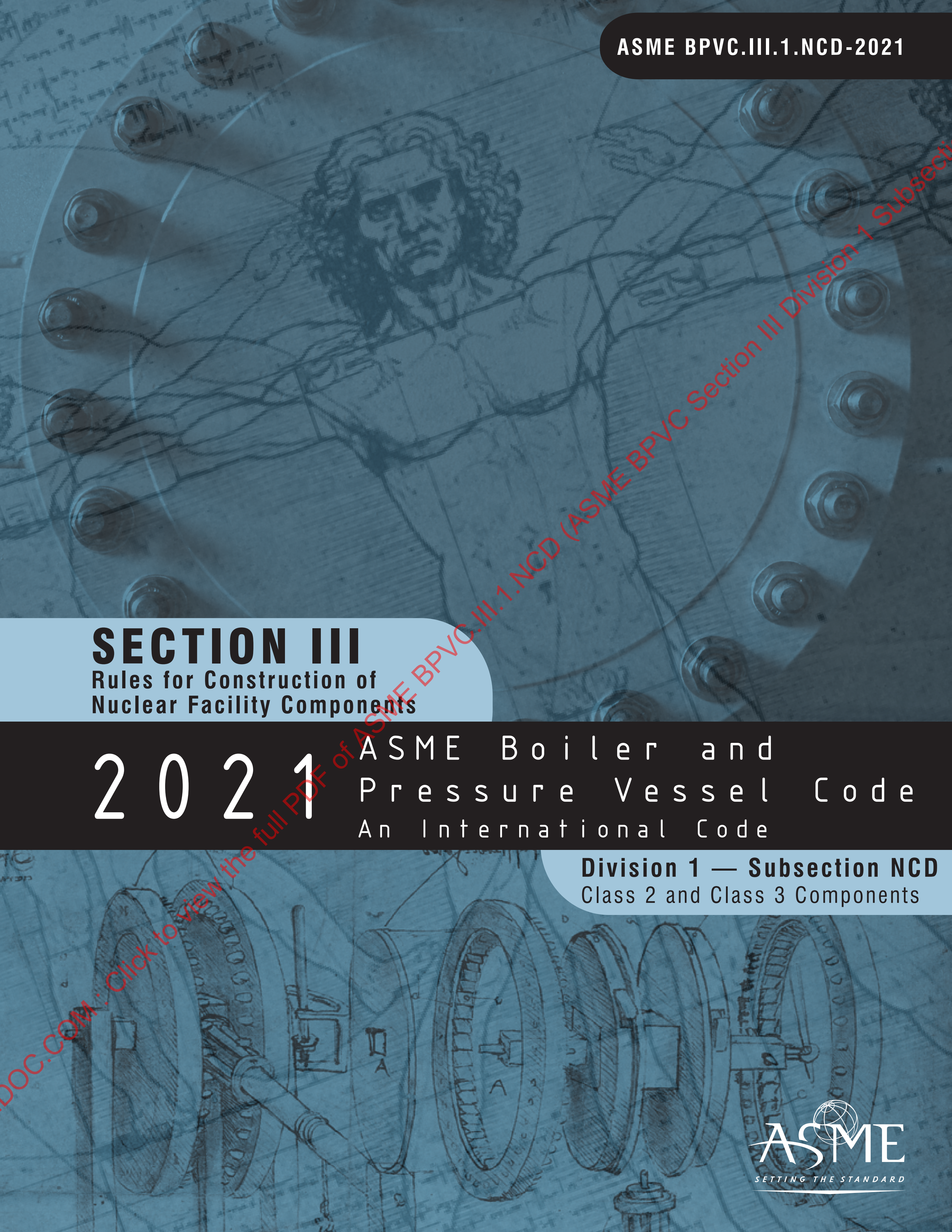

ASME BPVC.III.1.NCD-2021

SECTION III

Rules for Construction of Nuclear Facility Components

2021 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NCD

Class 2 and Class 3 Components

ASME
SETTING THE STANDARD

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME,” ASME logos, or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code or Standard. Use of of the ASME Single Certification Mark requires formal ASME certification; if no certification program is available, such ASME markings may not be used. (For Certification and Accreditation Programs, see https://www.asme.org/certification-accreditation.)

Items produced by parties not formally possessing an ASME Certificate may not be described, either explicitly or implicitly, as ASME certified or approved in any code forms or other document.

AN INTERNATIONAL CODE

2021 ASME Boiler & Pressure Vessel Code

2021 Edition July 1, 2021

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NCD

Class 2 and Class 3 Components

ASME Boiler and Pressure Vessel Committee
on Construction of Nuclear Facility Components

The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2021

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

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Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

The endnotes and preamble in this document (if any) are part of this American National Standard.

ASME Collective Membership Mark

ASME Single Certification Mark

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INTERPRETATIONS

Interpretations are issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

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 2021 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2023 Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. Code Case users can check the current status of any Code Case at http://go.asme.org/BPVCCDatabase. Code Case users can also view an index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases at http://go.asme.org/BPVCC.

FOREWORD*

(21)

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

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

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

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

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 judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

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

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

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

responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

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

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of 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://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

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

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

When required by context in 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.

The words "shall," "should," and "may" are used in this Standard as follows:

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

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

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

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

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

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

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

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

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

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

(21) # 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 applicable Boiler and Pressure Vessel (BPV) Standards Committee (hereinafter referred to as the Committee). See the guidelines on approval of new materials under the ASME Boiler and Pressure Vessel Code in Section II, Part D for requirements for requests that involve adding new materials to the Code. See the guidelines on approval of new welding and brazing materials in Section II, Part C for requirements for requests that involve adding new welding and brazing materials ("consumables") to the Code.

Technical inquiries can include requests for revisions or additions to the Code requirements, requests for Code Cases, or requests for Code Interpretations, as described below:

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

(2) Code Cases. Code Cases represent alternatives or additions to existing Code requirements. 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 regulators, jurisdictions, or Owners automatically accept Code Cases. The most common applications for Code Cases are as follows:

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

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

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

(3) Code Interpretations

(-a) Code Interpretations provide clarification of the meaning of existing requirements in the Code and are presented in Inquiry and Reply format. Interpretations do not introduce new requirements.

(-b) Interpretations will be issued only if existing Code text is ambiguous or conveys conflicting requirements. If a revision of the requirements is required to support the Interpretation, an Intent Interpretation will be issued in parallel with a revision to the Code.

(b) Code requirements, Code Cases, and Code Interpretations established by the Committee 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 requirements.

(c) Inquiries that do not comply with the following guidance or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the Inquirer with no action.

2 INQUIRY FORMAT

Submittals to the Committee should include the following information:

(a) Purpose. Specify one of the following:

(1) request for revision of present Code requirements

(2) request for new or additional Code requirements

(3) request for Code Case

(4) request for Code Interpretation

(b) Background. The Inquirer should 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. This information should include a statement indicating why the included paragraphs, figures, or tables are ambiguous or convey conflicting requirements. Preferably, the Inquirer should provide a copy of, or relevant extracts from, the specific referenced portions of the Code.

(c) *Presentations.* The Inquirer may desire to attend 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 BPV Standards Committee meeting shall be at the expense of the Inquirer. The Inquirer's attendance or lack of attendance at a meeting will not be used by the Committee as a basis for acceptance or rejection of the Inquiry by the Committee. However, if the Inquirer's request is unclear, attendance by the Inquirer or a representative may be necessary for the Committee to understand the request sufficiently to be able to provide an Interpretation. If the Inquirer desires to make a presentation at a Committee meeting, the Inquirer should provide advance notice to the Committee Secretary, to ensure time will be allotted for the presentation in the meeting agenda. The Inquirer should consider the need for additional audiovisual equipment that might not otherwise be provided by the Committee. With sufficient advance notice to the Committee Secretary, such equipment may be made available.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions should include the following information:

(a) *Requested Revisions or Additions.* For requested revisions, the Inquirer should identify those requirements of the Code that they believe should be revised, and should submit a copy of, or relevant extracts from, the appropriate requirements as they appear in the Code, marked up with the requested revision. For requested additions to the Code, the Inquirer should provide the recommended wording and should clearly indicate where they believe the additions should be located in the Code requirements.

(b) *Statement of Need.* The Inquirer should provide a brief explanation of the need for the revision or addition.

(c) *Background Information.* The Inquirer should 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 requested revision or addition. Sketches, tables, figures, and graphs should be submitted, as appropriate. The Inquirer should identify any pertinent portions of the Code that would be affected by the revision or addition and any portions of the Code that reference the requested revised or added paragraphs.

4 CODE CASES

Requests for Code Cases should be accompanied by a statement of need and background information similar to that described 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) should be described. In addition, it is important that the request is in connection with equipment that will bear the ASME Single Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and should 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 requested Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations should be accompanied by the following information:

(1) *Inquiry.* The Inquirer should propose a condensed and precise Inquiry, omitting superfluous background information and, when possible, composing the Inquiry in such a way that a "yes" or a "no" Reply, with brief limitations or conditions, if needed, can be provided by the Committee. The proposed question should be technically and editorially correct.

(2) *Reply.* The Inquirer should propose a Reply that clearly and concisely answers the proposed Inquiry question. Preferably, the Reply should be "yes" or "no," with brief limitations or conditions, if needed.

(3) *Background Information.* The Inquirer should include a statement indicating why the included paragraphs, figures, or tables are ambiguous or convey conflicting requirements. The Inquirer should provide any need or background information, such as described in 3(b) and 3(c), respectively, for Code revisions or additions, that will assist the Committee in understanding the proposed Inquiry and Reply.

If the Inquirer believes a revision of the Code requirements would be helpful to support the Interpretation, the Inquirer may propose such a revision for consideration by the Committee. In most cases, such a proposal is not necessary.

(b) Requests for Code Interpretations should be limited to an Interpretation of a particular requirement in the Code or in a Code Case. Except with regard to interpreting a specific Code requirement, the Committee is not permitted to 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

(a) Submittal. Requests for Code Interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt. If the Inquirer is unable to use the online form, the Inquirer may mail the request to the following address:

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

All other Inquiries should be mailed to the Secretary of the BPV Committee at the address above. Inquiries are unlikely to receive a response if they are not written in clear, legible English. They must also include the name of the Inquirer and the company they represent or are employed by, if applicable, and the Inquirer's address, telephone number, fax number, and e-mail address, if available.

(b) Response. The Secretary of the appropriate Committee will provide a written response, via letter or e-mail, as appropriate, to the Inquirer, upon completion of the requested action by the Committee. Inquirers may track the status of their Interpretation Request at http://go.asme.org/Interpretations.

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January 1, 2021

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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 NCD — Class 2 and Class 3 Components*
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
  - Subsection WD — Class ISS Internal Support Structures
- 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 SM Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class SN Nonmetallic Core Components
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

* In the 2021 Edition, Subsections NC and ND have been incorporated into one publication, Subsection NCD (BPVC.III.1.NCD), Class 2 and Class 3 Components.

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 Article NB-3000 includes all material in Article NB-3000; reference to NB-3100 includes all material in subarticle NB-3100; reference to NB-3110 includes all paragraphs, NB-3111 through NB-3113.

(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 (https://www.asme.org/).

(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-58-2009.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, 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-1210. 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.

[**] 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.

(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.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

SUMMARY OF CHANGES

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 by ASME at http://go.asme.org/BPVCerrata.

In the 2021 Edition, Subsections NC and ND have been incorporated into this publication, Subsection NCD. All paragraph, figure, and table designators and related cross-references have been reviewed and revised to reflect the consolidation. For the user's convenience, a table listing the former and current designations of the paragraphs, figures, and tables that have been renumbered follows this Summary of Changes.

This Edition includes the following additional changes, identified by a margin note, **(21)**, placed next to the affected area.

Page	*Location*	*Change*
xi	List of Sections	(1) Listing for Section III updated (2) Section XIII added (3) Code Case information updated
xiii	Foreword	(1) Subparagraph (k) added and subsequent subparagraph redesignated (2) Second footnote revised (3) Last paragraph added
xvi	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	Paragraphs 1(a)(3)(-b), 2(b), and 5(a)(3) revised
xix	Personnel	Updated
xl	Organization of Section III	(1) In para. 1, Division 1 listing updated (2) In para. 9(c)(3), "MSS SP-89-2003" corrected by errata to "MSS SP-58-2009"
6	NCD-2121	In subpara. (c), table cross-references revised
9	NCD-2160	Cross-reference to Section III, Subsection NCA revised
40	NCD-3131.1	In subpara. (a), cross-reference to Section III, Subsection NCA revised
46	NCD-3133.8	Revised
47	Figure NCD-3133.8-1	(1) x-axis label revised (2) General Note added
46	NCD-3211.1	In subpara. (e), cross-reference to Section III, Subsection NCA revised
60	Figure NCD-3224.13(c)(6)(-a)-1	General Note revised
61	Figure NCD-3224.13(c)(6)(-b)-1	General Note revised
70	Figure NCD-3239.1(b)-1	In equations following the figure, "r^3" inserted by errata
72	Figure NCD-3239.4-1	In General Notes (a)(1) and (a)(2), "$(T/D)^2/_3$" corrected by errata to "$(T/D)^{2/3}$"
78	NCD-3264.4	In subpara. (d), cross-reference to Section III, Subsection NCA revised
79	NCD-3310	Cross-reference to Section III, Subsection NCA revised
82	NCD-3324.4	In subpara. (a), "$0.665S$" corrected by errata to "$0.665SE$"
100	NCD-3329.2.5	Formerly ND-3329.6; subpara. (a) revised
117	NCD-3413	Cross-reference to Section III, Subsection NCA revised
121	NCD-3441.1	In subparas. (f)(1) and (f)(2), cross-references to Section III, Subsection NCA revised
131	NCD-3441.9	Subparagraphs revised and restructured
136	NCD-3441.10	In subpara. (a)(1) eq. (2), "$PB/4F$" corrected by errata to "$4F/\pi G^2$"
143	NCD-3511	Cross-references to Section III, Subsection NCA revised
147	NCD-3531.1	Revised
147	NCD-3591	Revised in its entirety
151	NCD-3595.3	Last sentence added

Page	Location	Change
152	NCD-3595.5	Last sentence added
152	NCD-3596.1	Cross-reference to Section III, Subsection NCA revised
153	NCD-3612.4	In subpara. (f), first column of in-text table revised
180	NCD-3673.2	In subparas. (j) and (k), cross-references to Section III, Subsection NCA revised
189	NCD-3812	Cross-reference to Section III, Subsection NCA revised
192	NCD-3852.6	(1) In subpara. (b)(3), "*FS*" revised to "DF" (2) After third equation in subpara. (b)(3), U.S. Customary value of *C* corrected by errata to "149,000"
202	NCD-3912	Cross-reference to Section III, Subsection NCA revised
285	NCD-4335.2	In subpara. (b)(5), "(−9°C)" corrected by errata to "(8°C)"
300	Table NCD-4622.7(b)-1	Revised to reconcile former NC and ND tables
318	NCD-6111	Subparagraph (a) revised
334	NCD-7511.4	In subparas. (b) and (i), cross-references revised
334	NCD-7512	In NCD-7512.2(a), NCD-7512.3(a), and NCD-7512.3(b), cross-references to Section III, Subsection NCA revised
335	NCD-7513	In NCD-7513.1(a) and NCD-7513.2, cross-references to Section III, Subsection NCA revised
335	NCD-7514	Revised
335	NCD-7522	In NCD-7522.2, NCD-7522.5(b), and NCD-7522.6(b), cross-references to Section III, Subsection NCA revised
336	NCD-7532.2	In subpara. (b)(2), cross-reference to Section III, Subsection NCA revised
338	NCD-7611	Cross-reference to NCD-7750 revised to NCD-7760
340	NCD-7700	(1) NCD-7710(a) and NCD-7763.2 revised to reference Section XIII (2) NCD-7730 through NCD-7736 and NCD-7738 through NCD-7755 deleted (3) NCD-7737 revised and redesignated as NCD-7730

NC- AND ND- PARAGRAPHS, FIGURES, AND TABLES RENUMBERED FOR SUBSECTION NCD

The following table lists only renumbered designators. It does not include subparagraphs that have been restructured (i.e., relettered or renumbered) or designators in which only “NC-” or “ND-” has been revised to “NCD-.”

Subsection NC–2019	Subsection NCD–2021
NC-2130	NCD-2131
NC-2150	NCD-2151
NC-2223.1	NCD-2223.1.1
NC-2223.2	NCD-2223.1.2
NC-2223.3	NCD-2223.1.3
NC-2223.4	NCD-2223.1.4
NC-2223.5	NCD-2223.1.5
Table NC-2311(a)-1	Table NCD-2311-1
NC-2351	NCD-2351.1
NC-2551	NCD-2551.1
NC-2561	NCD-2561.1
NC-2571	NCD-2571.1
Table NC-2571-1	Table NCD-2571.1-1
NC-3361.2	NCD-3361.2.1
NC-3441.10	NCD-3441.11
Figure NC-3441.10-1	Figure NCD-3441.11-1
NC-3591.1	NCD-3591.1 and NCD-3591.2
Figure NC-3591.1-1	Figure NCD-3591.2-1
Figure NC-3591.1-2	Figure NCD-3591.2-2
NC-3591.2	NCD-3591.3
NC-3591.3	NCD-3591.4
NC-3591.4	NCD-3591.5
NC-4241	NCD-4241.1
NC-4242	NCD-4242.1
NC-4243	NCD-4243.1
Figure NC-4243-1	Figure NCD-4243.1-1
Figure NC-4243-2	Figure NCD-4243.1-2
NC-4243.1	NCD-4243.3
Figure NC-4243.1-1	Figure NC-4243.3-1
NC-4244	NCD-4244.1
Figure NC-4244(a)-1	Figure NCD-4244.1-1
Figure NC-4244(b)-1	Figure NCD-4244.1-2
Figure NC-4244(c)-1	Figure NCD-4244.1-3
Figure NC-4244(d)-1	Figure NCD-4244.1-4
Figure NC-4244(e)-1	Figure NCD-4244.1-5
Figure NC-4244(e)-2	Figure NCD-4244.1-6
NC-4245	NCD-4245.1
NC-5111	NCD-5111.1
Table NC-5111-1	Table NCD-5111.1-1

Subsection NC–2019	Subsection NCD–2021
NC-5211	NCD-5211.1
NC-5212	NCD-5212.1
NC-5221	NCD-5221.1
NC-5222	NCD-5222.1
NC-5230	NCD-5231.1
NC-5241	NCD-5241.1
NC-5242	NCD-5242.1
NC-5261	NCD-5261(a)
NC-5262	NCD-5261(b)
NC-5400	NCD-5600
NC-5410	NCD-5610
NCD-7737	NCD-7730

Subsection ND–2019	Subsection NCD–2021
ND-2130	NCD-2132
ND-2150	NCD-2152
ND-2223.1	NCD-2223.2.1
ND-2223.2	NCD-2223.2.2
ND-2223.3	NCD-2223.2.3
ND-2223.4	NCD-2223.2.4
ND-2223.5	NCD-2223.2.5
Table ND-2311-1	Table NCD-2311-2
ND-2331	NCD-2333.1
Table ND-2331(a)-1	Table NCD-2333.1-1
Table ND-2331(a)-2	Table NCD-2333.1-2
ND-2333	NCD-2333.2
Table ND-2333-1	Table NCD-2333.2-1
ND-2351	NCD-2351.2
ND-2551	NCD-2551.2
ND-2561	NCD-2561.2
ND-2571	NCD-2571.2
Table ND-2571-1	Table NCD-2571.2-1
Figure ND-3133.7-1	Figure NCD-3133.8-1
ND-3329.2	NCD-3329.2.1
Figure ND-3329.2(e)-1	Figure NCD-3329.2.1-1
ND-3329.3	NCD-3329.2.2
ND-3329.4	NCD-3329.2.3
ND-3329.5	NCD-3329.2.4
ND-3329.6	NCD-3329.2.5
ND-3358.5	NCD-3358.5.1
ND-3358.6	NCD-3358.5.2
ND-3361.2	NCD-3361.2.2
Table ND-3361.2(a)-1	Table ND-3361.2.2-1
ND-3591.1	NCD-3591.1 and NCD-3591.2
Figure ND-3591.1-1	Figure NCD-3591.2-1
Figure ND-3591.1-2	Figure NCD-3591.2-2
ND-3591.2	NCD-3591.3
ND-3591.3	NCD-3591.4
ND-3591.4	NCD-3591.5
ND-3661.2	[Note (1)]
ND-3661.3	NCD-3661.2
ND-3661.4	NCD-3661.3

Subsection ND–2019	Subsection NCD–2021
ND-4241	NCD-4241.2
ND-4242	NCD-4242.2
ND-4243	NCD-4243.2
Figure ND-4243-1	Figure NCD-4243.2-1
ND-4243.1	NCD-4243.3
Figure ND-4243.1-1	Figure NCD-4243.3-1
ND-4244	NCD-4244.2
Figure ND-4244(a)-1	Figure NCD-4244.1-1
Figure ND-4244(b)-1	Figure NCD-4244.1-2
Figure ND-4244(c)-1	Figure NCD-4244.1-3
Figure ND-4244(d)-1	Figure NCD-4244.1-4
Figure ND-4244(e)-1	Figure NCD-4244.1-5
Figure ND-4244(e)-2	Figure NCD-4244.1-6
Figure ND-4244(f)-1	Figure NCD-4244.2-1
Figure ND-4244(g)-1	Figure NCD-4244.2-2
ND-4245	NCD-4245.2
Figure ND-4245-1	Figure NCD-4245.2-1
Table ND-4245-1	Table NCD-4245.2-1
ND-5111	NCD-5111.2
ND-5211	NCD-5211.2
ND-5211.1	NCD-5211.2(a)
ND-5211.2	NCD-5211.2(b)
ND-5211.3	NCD-5211.2(c)
ND-5212	NCD-5212.2
ND-5221	NCD-5221.2
ND-5222	NCD-5222.2
ND-5231	NCD-5231.2
ND-5232	NCD-5232.2
ND-5241	NCD-5241.2
ND-5242	NCD-5242.2
ND-5260	NCD-5262
ND-7737	NCD-7730

NOTE: (1) ND-3661.2 has been deleted.

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).

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ARTICLE NCD-1000
INTRODUCTION

NCD-1100 SCOPE

NCD-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NCD contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder for items that are intended to conform to the requirements for Class 2 or Class 3 construction.

(b) The rules of Subsection NCD 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 materials. NCA-1130 further limits the rules of this Subsection.

(c) Subsection NCD does not contain rules to cover all details of construction of Class 2 or Class 3 vessels and storage tanks. Where complete details are not provided in this Subsection, it is intended that the N 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.

(d) Class 2 vessels are to be designed using the standard design method in NCD-3300 or the alternative design rules of NCD-3200, which allow the use of analysis with the higher design stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

NCD-1120 TEMPERATURE LIMITS

The rules of Subsection NCD shall not be used for items that are to be subjected to metal temperatures that exceed the temperature limit in the applicability column shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 for design stress values or in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 for design stress intensity values for Class 2 vessels designed to the alternative design rules of NCD-3200. For vessels operating beyond the temperature limits referenced above, the creep and stress rupture characteristics of materials permitted to be used become significant factors that are not presently covered by the rules of this Subsection. Fatigue design curves and specified methods for fatigue analysis are not applicable above 700°F (370°C) for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.4 and above 800°F (425°C) for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.2 and I-9.3.

NCD-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NCD-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.

NCD-1132 Boundary Between Components and Attachments

NCD-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 may have either a pressure-retaining function or a non-pressure-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 non-pressure-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 may 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 (nonstructural attachments):

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

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

(-c) may be permanent or temporary.

Nonstructural attachments include items such as name-plates, insulation supports, and locating and lifting lugs.

NCD-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 NCD-1132.2-1 through NCD-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.

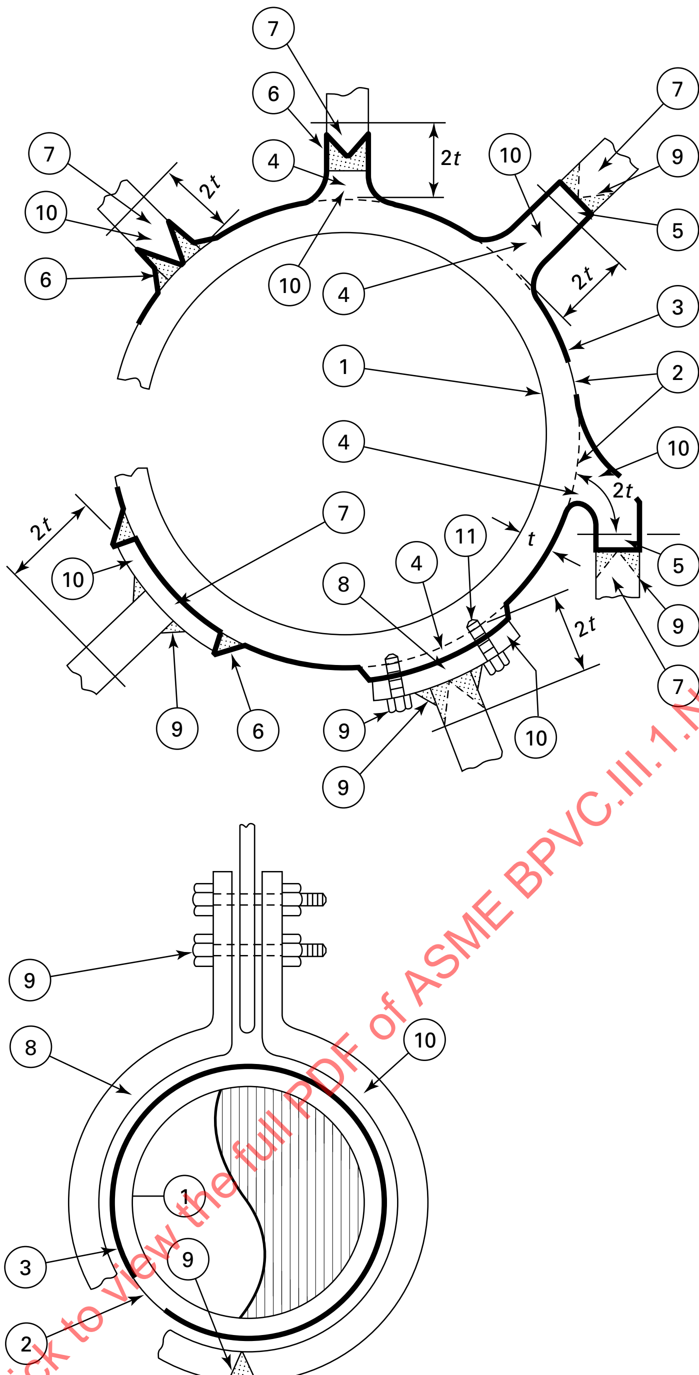
(d) The first connecting weld of a non-pressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material. Beyond $2t$ 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 NCD-4430.

(f) Mechanical fasteners used to connect a non-pressure-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 NCD-1132.2-1
Attachments in the Component Support Load Path That Do Not Perform a Pressure-Retaining Function



(1) Component shall conform to Subsection NCD.

(2) Pressure-retaining portion of the component.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NCD.

(5) Beyond $2t$ from the pressure-retaining portion of the component, the design rules of Article NF-3000 may be used as a substitute for the design rules of Article NCD-3000.

(6) At or within $2t$ from the pressure-retaining portion of the component, the first connecting weld shall conform to Subsection NCD.

(7) Beyond $2t$ from the pressure-retaining portion of the component or beyond the first connecting weld, the attachment shall conform to Subsection NF [see Note (1)].

(8) Bearing, clamped, or fastened attachment shall conform to Subsection NF [see Note (1)].

(9) Attachment connection shall conform to Subsection NF [see Note (1)].

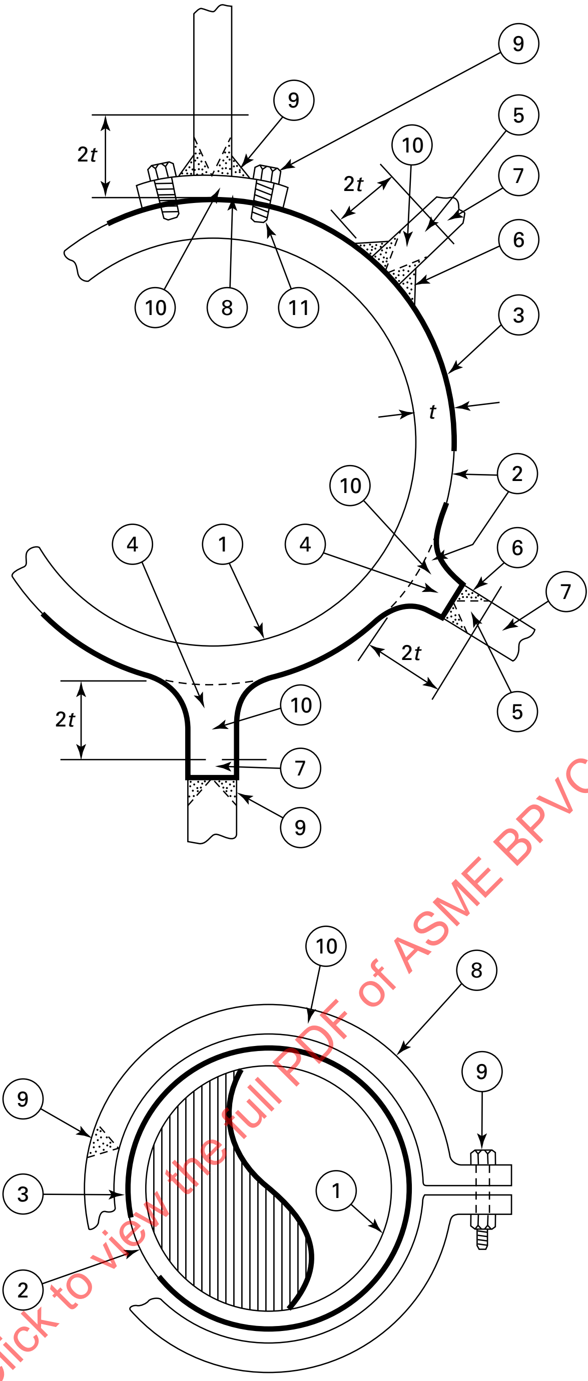
(10) At or within 2t from the pressure-retaining portion of the component, the interaction effects of the attachment shall be considered in accordance with NCD-3135.

(11) Drilled holes shall conform to Subsection NCD.

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 NCD-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 NCD.

(2) Pressure-retaining portion of the component.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NCD.

(5) At or within 2*t* from the pressure-retaining portion of the component, the material of the first welded nonstructural attachment shall conform to NCD-2190; design is outside Code jurisdiction.

(6) At or within 2*t* from the pressure-retaining portion of the component, the first connecting weld shall conform to NCD-4430.

(7) Beyond 2*t* 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.

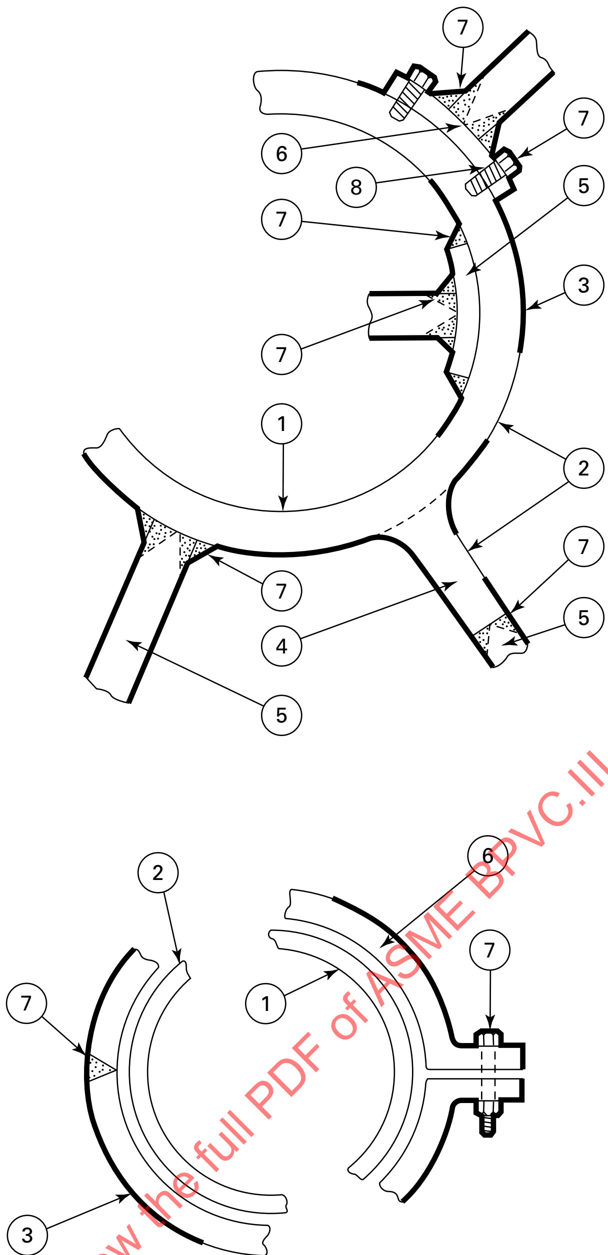
(9) Nonstructural attachment connection is outside Code jurisdiction.

(10) At or within 2*t* from the pressure-retaining portion of the component, the interaction effects of the nonstructural attachment shall be considered in accordance with NCD-3135.

(11) Drilled holes shall conform to Subsection NCD.

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

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



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

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

ARTICLE NCD-2000
MATERIAL

NCD-2100 GENERAL REQUIREMENTS FOR MATERIAL

NCD-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 Article NCA-9000.

(b) The term *pressure-retaining materials* as used in this Subsection applies to 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.

NCD-2120 PRESSURE-RETAINING MATERIAL

NCD-2121 Permitted Material Specifications (21)

(a) Pressure-retaining material shall conform to the requirements of one of the specifications for materials given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and to all of the requirements of this Article that apply to the product form in which the material is used. Attachments that perform a pressure-retaining function shall be pressure-retaining material. For vessels that are designed in accordance with NCD-3200, the materials shall be restricted to those materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, including all applicable notes in the tables, and to the following clad product specifications, provided they are composed of materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4:

(1) SA-263, Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet, and Strip

(2) SA-264, Specification for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip

(3) SA-265, Specification for Nickel and Nickel-Base Alloy Clad Steel Plate

(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, wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating materials and special alloys used as seal materials in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Section II, Part D, Subpart 1, Tables 1A and 1B 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 the 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, Subpart 1, provided that the fittings are in conformance with the requirements of NCD-3671.4, the valves meet the requirements of NCD-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 which is 10% or less of the thickness of the base material (NCD-3122).

NCD-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-4256). Where the special requirements include an examination, test, or treatment which 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 NCD-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 NCD-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 NCD-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 NCD-4243.3. The tension test specimen shall be located in accordance with NCD-4243.3 and Figure NCD-4243.3-1.

NCD-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-4256).

(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 lesser value of 0.01 in. (0.25 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 lesser of 0.01 in. (0.25 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, Subpart 1. After the minimum wall thickness is determined (NCD-3641.1), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

NCD-2125 Material in Combination[1]

A component may be constructed of any combination of materials permitted in Article NCD-2000, provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

NCD-2126 Finned Tubes

NCD-2126.1 Integrally Finned Tubes. Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Tables 1A and 1B 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 NCD-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 Section II, Part D, Subpart 1, Tables 1A and 1B 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. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to NCD-5100 or by personnel qualified in accordance with NCD-5500.

NCD-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 which 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 5× 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.

NCD-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 3. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 3. Refer to Section II, Part D, Subpart 1, Table 4 for bolting material for vessels designed to the requirements of NCD-3200.

(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.

NCD-2130 CERTIFICATION OF MATERIAL

NCD-2131 For Class 2 Components

All materials used in the construction of components shall be certified as required in NCA-3861 and NCA-3862. Certified Material Test Reports are required for pressure-retaining material except as provided by NCA-3861. 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.

NCD-2132 For Class 3 Components

All materials used in the construction of components shall be certified as required in NCA-3861 and NCA-3862. Certified Material Test Reports are required for pressure-retaining material except as provided by NCA-3861, and for small products as defined in NCD-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.

NCD-2140 WELDING MATERIALS

For the requirements governing the materials to be used for welding, see NCD-2400.

NCD-2150 MATERIAL IDENTIFICATION

NCD-2151 For Class 2 Items

The identification of pressure-retaining material shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture and installation of the item so that the material is identifiable as acceptable at all times. Welding and brazing materials shall be controlled during the repair of material and the manufacture and installation of the items so that they are identifiable as acceptable until the material is actually consumed in the process (NCD-4122).

NCD-2152 For Class 3 Items

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 item so that the material is identifiable as acceptable at all times. Welding and brazing materials shall be controlled during the repair of material and the manufacture and installation of the items so that they are identifiable as acceptable until the material is actually consumed in the process (NCD-4122).

(21) NCD-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-3211.19(b)] with specific attention being given to the effects of service conditions upon the properties of the material.

NCD-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.

NCD-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 temperature-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.

NCD-2190 NON-PRESSURE-RETAINING MATERIAL

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

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

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

NCD-2210 HEAT TREATMENT REQUIREMENTS

NCD-2211 Test Coupon Heat Treatment for Ferritic Material[2]

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.

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

NCD-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 rate at which the main body of the material was cooled, except in the case of certain forgings and castings (NCD-2223.1.3 for Class 2, NCD-2223.2.3 for Class 3, and NCD-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 NCD-2212.2 or one of the specific procedures described in NCD-2220 shall be used for each product form.

NCD-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 NCD-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 which 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 ($^1/_4t$) 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 NCD-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 (which 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.

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

NCD-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.

NCD-2222 Plates

NCD-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.

NCD-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 NCD-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NCD-2223 Forgings

NCD-2223.1 Location of Test Coupons for Class 2 Forgings.

NCD-2223.1.1 Forgings With 2 in. (50 mm) Maximum Thickness. For forgings with a maximum thickness of 2 in. (50 mm) the coupons shall be taken so that specimens shall have their longitudinal axes at the midplane of the thickness or the center of the cross section and with the midlength of the specimens at least 2 in. (50 mm) from any second surface.

NCD-2223.1.2 Forgings With Thickness Exceeding 2 in. (50 mm). For forgings exceeding a thickness of 2 in. (50 mm) the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ of the maximum heat-treated thickness from any surface and with the midlength of the specimens at least t from any second surface. This is normally referred to as $\frac{1}{4}t \times t$, where t is the maximum heat-treated thickness. A thermal buffer may be used to achieve the above conditions [NCD-2212.2(c)(3)] unless cooling rates applicable to the bulk forgings are simulated in accordance with NCD-2212.2.

NCD-2223.1.3 Very Thick and Complex Forgings. Test coupons for forgings which are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at 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 surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any heat-treated surface.

NCD-2223.1.4 Coupons From Separately Produced Test Forgings. Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness, except when the thickness–length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NCD-2223.1.3.

NCD-2223.1.5 Test Specimens for Forgings. When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamp on them, and witnessing the testing of these specimens.

NCD-2223.2 Location of Test Coupons for Class 3 Forgings.

NCD-2223.2.1 General Requirements. The longitudinal axis of the test specimens shall be located at least $^1/_4t$ 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 $^1/_2$ in. (13 mm) from the buffered surface of the forging and at least $^1/_4t$ 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 NCD-2223.2.1 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.

NCD-2223.2.2 Very Thick and Complex Forgings. For forgings that are very thick and complex (e.g., 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 NCD-2223.2.4. They shall be taken so that the longitudinal centerline 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 $^3/_4$ in. (19 mm) from the nearest surface and $1^1/_2$ in. (38 mm) from any second surface.

NCD-2223.2.3 Multiple Forgings.

(a) Multiple Forgings Separated Into Identical Individual Forgings Before Quench and Temper Treatment. At least one individual forging from each multiple forging in each heat treating lot shall be tested using the test specimen locations of NCD-2223.2.1 or NCD-2223.2.2 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 Brinell hardness number (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 NCD-2223.2.1 or NCD-2223.2.2 as specified on the purchase order.

NCD-2223.2.4 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 NCD-2223.2.1. Test specimen locations shall meet the requirements of NCD-2223.2.1 or NCD-2223.2.2 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.

NCD-2223.2.5 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 $^1/_4t$ 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 $1^1/_2$ in. (38 mm). For bars (other than those used for bolting materials) with diameters or thickness exceeding $1^1/_2$ in. (38 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ 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.

NCD-2224 Bars and Bolting Material

NCD-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.

NCD-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 $^1/_4t$ 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.

NCD-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.

NCD-2225 Tubular Products

NCD-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.

NCD-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 $^1/_4\, t$ from the outside surface and with the midlength of the specimens at least one wall thickness from a heat-treated end.

NCD-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 NCD-2223.1.4 for Class 2 and NCD-2223.2.4 for Class 3 shall be met.

NCD-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 $^1/_4\, t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $^1/_4\, t$ 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 (1). 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 (1) 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). 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.

NCD-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NCD-2310 MATERIAL TO BE IMPACT TESTED

NCD-2311 Material for Which Impact Testing Is Required

(a) Pressure-retaining material shall be impact tested in accordance with the requirements of NCD-2330, except that impact testing of materials 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 thicknesses shall be taken as defined in (-a) through (-e) 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;

(-e) for Class 2 integral fittings used to attach process piping to the containment vessel (Figure NE-1110-1), use the larger nominal thickness of the pipe connections.

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

(3) bar with a nominal cross-sectional area that does not exceed 1 in.^{2} (650 mm^2);

(4) all thicknesses of material for pipe, tube, fittings, pumps, and valves with a diameter of NPS 6 (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 steels, including precipitation hardened austenitic Grade 660 (UNS S66286);

(7) nonferrous materials;

(8) For Class 2 Only

(-a) materials listed in Table NCD-2311-1 for which the listed value of T_{NDT}[3] is lower than the Lowest Service Temperature[4] (LST) by an amount established by the rules in Section III Appendices, Nonmandatory Appendix R. This exemption does not exempt either the weld metal (NCD-2430) or the welding procedure qualification (NCD-4335) from impact testing.

(-b) materials for components for which the Lowest Service Temperature exceeds 150°F (65 °C).

(9) For Class 3 Only

(-a) materials listed in Table NCD-2311-2 in the thicknesses shown and for Lowest Service Temperatures[4] equal to or more than the tabulated temperatures.

Table NCD-2311-1
For Class 2 Only — Exemptions From Impact Testing Under NCD-2311(a)(8)

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT}, °F (°C) [Notes (3), (4)]
SA-537, Class 1	N	−30 (−35)
SA-516, Grade 70	Q&T	−10 (−25)
SA-516, Grade 70	N	0 (−20)
SA-508, Class 1	Q&T	+10 (−10)
SA-533, Grade B	Q&T	+10 (−10)
SA-299 Note (5)	N	+20 (−7)
SA-216, Grades WCB and WCC	Q&T	+30 (0)
SA-36 (Plate)	HR	+40 (+5)
SA-508, Class 2	Q&T	+40 (+5)

NOTES:
(1) These materials are exempt from toughness testing when LST − T_{NDT} is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R.
(2) Material Condition letters refer to
N = normalize
Q&T = quench and temper
HR = hot rolled
(3) These values for T_{NDT} were established from data on heavy section steel [thickness greater than $2\frac{1}{2}$ in. (64 mm)]. Values for sections less than $2\frac{1}{2}$ in. (64 mm) thick are held constant until additional data are obtained.
(4) T_{NDT} = temperature at or above nil-ductility transition temperature NDT (ASTM E208); T_{NDT} is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.
(5) Materials made to a fine-grain melting practice.

This exemption does not exempt either the weld metal (NCD-2430) or the welding procedure qualification (NCD-4335) from impact testing.

(-b) 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.

(c) For Class 2 Only. Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Table 1A. The other requirements of NCD-2331 and NCD-2332 apply for these steels. For nominal wall thicknesses greater than $2\frac{1}{2}$ in. (64 mm), the required C_v values shall be 40 mils (1.0 mm) lateral expansion.

NCD-2320 IMPACT TEST PROCEDURES

NCD-2321 Types of Tests

NCD-2321.1 For Class 2 Only — Drop Weight Tests. The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. When drop weight tests are performed to meet the requirements of NCD-2300, the test temperature and the results shall be reported on the Certified Material Test Report.

NCD-2321.2 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 NCD-2330 shall be reported in the Certified Material Test Report.

NCD-2322 Test Specimens

NCD-2322.1 Location of Test Specimens. Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that 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. 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.

NCD-2322.2 Orientation of Impact Test Specimens.

(a) Orientation of Specimens for C_v Impact Test. Specimens for C_v impact tests shall be oriented as required in NCD-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.

(b) For Class 2 Only — Orientation of Specimens for Drop Weight Tests. Specimens for drop weight tests may have their axes oriented in any direction.

NCD-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NCD-2331 For Class 2 Only — Pressure-Retaining Material Test Methods and Temperature

Pressure-retaining material shall be impact tested in accordance with one of the test methods indicated below:

(a) Charpy V-notch testing at or below the Lowest Service Metal Temperature[5, 6]

Table NCD-2311-2
For Class 3 Only — Exemptions From Impact Testing Under NCD-2311(a)(9)

Material	Material Condition [Note (1)]	Lowest Service Temperature for the Thickness Shown: Over 5/8 in. to 3/4 in. (16 mm to 19 mm), Incl.	Over 3/4 in. to 1 in. (19 mm to 25 mm), Incl.	Over 1 in. to 1½ in. (25 mm to 38 mm), Incl.	Over 1½ in. to 2½ 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 [Note (3)]	Q&T	[Note (2)]	[Note (2)]	[Note (2)]	10°F (−12°C)
SA-216 Grades WCB and 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 "Over 1½ in. to 2½ in. (38 mm to 64 mm)" column may be used for these thicknesses.
(3) Material made to a fine-grain melting practice.

Table NCD-2332.1-1
For Class 2 Only — Required C_v Lateral Expansion Values for Pressure-Retaining Material Other Than Bolting Material

Nominal Wall Thickness, in. (mm) [Note (1)]	Lateral Expansion, mils (mm): Average of 3 Specimens	Lowest 1 of 3 Specimens
5/8 (16) or less [Note (2)]	...	...
Over 5/8 to 1 (16 to 25), incl.	20 (0.50)	15 (0.38)
Over 1 to 1½ (25 to 38), incl.	25 (0.64)	20 (0.50)
Over 1½ to 2½ (38 to 64), incl.	35 (0.89)	30 (0.75)
Over 2½ (64) [Note (3)]	45 (1.14)	40 (1.0)

GENERAL NOTES:
(a) Where weld metal tests of NCD-2400 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
(b) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of NCD-4330 shall conform to the requirements of either of the base materials.

NOTES:
(1) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels, use the least of
(a) the maximum radial thickness of the item exclusive of integral butt welded projections
(b) the vessel shell thickness to which the item is welded
(c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges
(2) No test required.
(3) For use with NCD-2332.2(a).

(b) drop weight testing to show that the Lowest Service Metal Temperature[5] (LST $- T_{NDT}$[3]) is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R.

NCD-2332 For Class 2 Only — Specific Test Methods and Acceptance Standards for Pressure-Retaining Material for Tests Based on Lowest Service Metal Temperatures

NCD-2332.1 Pressure-Retaining Material Other Than Bolting Material With 2½ in. (64 mm) Maximum Thickness[7]. Except as limited in NCD-4335, apply one of the methods of NCD-2331 to test: base material; the base material, the heat-affected zone, and weld metal for the weld procedure qualification tests of NCD-4335; and the weld metal for NCD-2431. The impact test results shall meet one of the acceptance standards applicable to the specified test method.

(a) Charpy V-Notch Testing for Lateral Expansion Values. The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NCD-2332.1-1.

(b) 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 NCD-2332.1-2.

(c) Drop Weight Testing. An acceptance test shall consist of at least two no-break specimens as described in ASTM E208.

Table NCD-2332.1-2
For Class 2 Only — Required C_v Energy Values for Pressure-Retaining Material Other Than Bolting Material

Nominal Wall Thickness, in. (mm) [Note (2)]	Specified Minimum Yield Strength of Base Material, ksi (MPa)	Energy, ft-lb (J) [Note (1)] Average of 3 Specimens	Energy, ft-lb (J) [Note (1)] Lowest 1 of 3 Specimens
≤5/8 (≤16) [Note (3)]	≤55 (≤380)	...	...
	>55 to 75 (>380 to 515), incl.	...	...
	>75 to 105 (>515 to 725), incl.	...	...
>5/8 to 1 (>16 to 25), incl.	≤55 (≤380)	20 (27)	15 (20)
	>55 to 75 (>380 to 515), incl.	25 (34)	20 (27)
	>75 to 105 (>515 to 725), incl.	30 (41)	25 (34)
>1 to 1½ (>25 to 38), incl.	≤55 (≤380)	25 (34)	20 (27)
	>55 to 75 (>380 to 515), incl.	30 (41)	25 (34)
	>75 to 105 (>515 to 725), incl.	35 (47)	30 (41)
>1½ to 2½ (>38 to 64), incl.	≤55 (≤380)	35 (47)	30 (41)
	>55 to 75 (>380 to 515), incl.	40 (54)	35 (47)
	>75 to 105 (>515 to 725), incl.	45 (61)	40 (54)
>2½ (>64) [Note (4)]	≤55 (≤380)	45 (61)	40 (54)
	>55 to 75 (>380 to 515), incl.	50 (68)	45 (61)
	>75 to 105 (>515 to 725), incl.	55 (75)	50 (68)

GENERAL NOTE: Where weld metal tests of NCD-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:
(1) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of NCD-4330 shall conform to the requirements of either of the base materials.
(2) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels, use the least of
 (a) the maximum radial thickness of the item exclusive of integral butt welded projections
 (b) the vessel shell thickness to which the item is welded
 (c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges
(3) No test required.
(4) For use with NCD-2332.2(b).

NCD-2332.2 Pressure-Retaining Material Other Than Bolting Material With Thickness[7] Exceeding 2½ in. (64 mm).

(a) The base material, and the weld procedure qualification weld metal tests of NCD-4335, shall be tested by the drop weight method as specified in NCD-2321.1 and NCD-2331(b).

(b) Except as limited in NCD-4335, apply one of the methods of NCD-2331 to test: the base material and the heat-affected zone of the weld procedure qualification tests for NCD-4335; and the weld metal for NCD-2431.

(c) The acceptance standards shall be as given in NCD-2332.1(a), NCD-2332.1(b), or NCD-2332.1(c), as applicable.

NCD-2332.3 Bolting Material. For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The tests shall be performed at or below the Lowest Service Metal Temperature, and all three specimens shall meet the requirements of Table NCD-2332.3-1.

Table NCD-2332.3-1
For Class 2 Only — Required C_v Values for Bolting Material Tested in Accordance With NCD-2332.3

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)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

Table NCD-2333.1-1
For Class 3 Only — Required C_v Lateral Expansion Values for Pressure-Retaining Material Other Than Bolting Material

Nominal Wall Thickness, in. (mm) [Note (1)]	Lateral Expansion, mils (mm)	
	Average of 3 Specimens	Lowest 1 of 3 Specimens
$^5/_8$ (16) or less [Note (2)]	...	...
Over $^5/_8$ to $^3/_4$ (16 to 19), incl.	13 (0.33)	10 (0.25)
Over $^3/_4$ to 1 (19 to 25), incl.	15 (0.38)	10 (0.25)
Over 1 to $1^1/_2$ (25 to 38), incl.	20 (0.50)	15 (0.38)
Over $1^1/_2$ to $2^1/_2$ (38 to 64), incl.	25 (0.64)	20 (0.50)
Over $2^1/_2$ (64)	30 (0.75)	25 (0.64)

GENERAL NOTE:
(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 (NCD-4330) shall conform to the requirements of either of the base materials.
(b) When the weld metal tests of NCD-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.

NCD-2333 For Class 3 Only — Pressure-Retaining Material Test Methods and Temperature

NCD-2333.1 Pressure-Retaining Material Other Than Bolting Material. 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).

(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 NCD-2333.1-1.

(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 NCD-2333.1-2.

(b) The following materials shall be tested as described in (a):

(1) the base material[6]

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

(3) the weld metal of NCD-2431

NCD-2333.2 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 NCD-2333.2-1.

NCD-2340 NUMBER OF IMPACT TESTS REQUIRED

NCD-2341 Plates

One test shall be made from 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.

NCD-2342 Forgings and Castings

(a) General

(1) Where 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.

(2) 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).

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

(4) As an alternative to (3), 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.

(b) For Class 2 Only

(1) Forgings or castings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v test specimens shall be selected so

Table NCD-2333.1-2
For Class 3 Only — Required C_v Energy Values for Pressure-Retaining Material Other Than Bolting Material

Nominal Wall Thickness, in. (mm) [Note (1)]	Specified Minimum Yield Strength of Material, ksi (MPa)	Energy, ft-lb (J)	
		Average of 3 Specimens	Lowest 1 of 3 Specimens
≤5/8 (≤16) [Note (2)]	≤40 (≤275)	...	...
	>40 to 55 (>275 to 380), incl.	...	...
	>55 to 105 (>380 to 725), incl.	...	...
>5/8 to 3/4 (>16 to 19), incl.	≤40 (≤275)	13 (18)	10 (14)
	>40 to 55 (>275 to 380), incl.	15 (20)	10 (14)
	>55 to 105 (>380 to 725), incl.	20 (27)	15 (20)
>3/4 to 1 (>19 to 25), incl.	≤40 (≤275)	15 (20)	10 (14)
	>40 to 55 (>275 to 380), incl.	20 (27)	15 (20)
	>55 to 105 (>380 to 725), incl.	25 (34)	20 (27)
>1 to 1 1/2 (>25 to 38), incl.	≤40 (≤275)	20 (27)	15 (20)
	>40 to 55 (>275 to 380), incl.	25 (34)	20 (27)
	>55 to 105 (>380 to 725), incl.	30 (41)	25 (34)
>1 1/2 to 2 1/2 (>38 to 64), incl.	≤40 (≤275)	25 (34)	20 (27)
	>40 to 55 (>275 to 380), incl.	35 (48)	30 (41)
	>55 to 105 (>380 to 725), incl.	40 (54)	35 (48)
>2 1/2 (>64)	≤40 (≤275)	30 (41)	25 (34)
	>40 to 55 (>275 to 380), incl.	40 (54)	35 (48)
	>55 to 105 (>380 to 725), incl.	45 (61)	40 (54)

GENERAL NOTE:
(a) When two base materials having different specified minimum energy values are joined, the weld impact energy requirements of the welding procedure qualification (NCD-4330) shall conform to the requirements of either of the base materials.
(b) When the weld metal tests of NCD-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.

Table NCD-2333.2-1
For Class 3 Only — 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)

that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(2) As an alternative to (1) for static castings, a separately cast coupon [NCD-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

(c) For Class 3 Only

(1) 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.

(2) As an alternative to (1) for static castings, a separately cast coupon [NCD-2226(b)(2)] may be used; one test shall be made for Charpy V-notch.

NCD-2343 Bars

One test shall be made for each lot of bars with a cross-sectional area greater than 1 in.^{2} (650 mm^2) 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).

NCD-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which 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 $^1/_4$ in. (6 mm) ; such a lot shall be in 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.

NCD-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, in. (mm)	Weight, lb (kg)
$1^3/_4$ (44) and less	1,500 (680)
Over $1^3/_4$ to $2^1/_2$ (44 to 64)	3,000 (1 350)
Over $2^1/_2$ to 5 (64 to 125)	6,000 (2 700)
Over 5 (125)	10,000 (4 500)

NCD-2350 RETESTS

NCD-2351 Retests for Material Other Than Bolting

NCD-2351.1 For Class 2 Only.

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

(1) The average value of the test results meets the average of three requirements specified in Table NCD-2332.1-1 or Table NCD-2332.1-2, as applicable.

(2) Not more than one specimen per test is below the lowest one of three requirements specified in Table NCD-2332.1-1 or Table NCD-2332.1-2, 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 NCD-2332.1-1 or Table NCD-2332.1-2, 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 NCD-2332.1-1 or Table NCD-2332.1-2, as applicable.

NCD-2351.2 For Class 3 Only.

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

(1) The average value of the test results meets the average of three requirements specified in Table NCD-2333.1-1 or Table NCD-2333.1-2, as applicable.

(2) Not more than one specimen per test is below the lowest one of three requirements specified in Table NCD-2333.1-1 or Table NCD-2333.1-2, 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 NCD-2333.1-1 or Table NCD-2333.1-2, 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 NCD-2333.1-1 or Table NCD-2333.1-2, as applicable.

NCD-2352 Retests for Bolting Material

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

(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.

NCD-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) or (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-4258.2 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-4258.2. 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-4255.3(c).

NCD-2400 WELDING MATERIAL

NCD-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 NCD-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 [NCD-2431.1(e)] of the material in either the as-welded or heat-treated condition, or both [NCD-2431.1(c)];

(5) for Class 2 only, drop weight test results for material in either the as-welded or heat-treated condition, or both (NCD-2332);

(6) Charpy V-notch test results for material in either the as-welded or heat-treated condition, or both (NCD-2331 for Class 2 or NCD-2333 for Class 3); both the test temperature and either the lateral expansion or the absorbed energy shall be provided;

(7) the preheat and interpass temperatures to be used during welding of the test coupon [NCD-2431.1(c)];

(8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NCD-2431.1(c)];

(9) elements for which chemical analysis is required per the SFA specification or WPS, and NCD-2432;

(10) minimum delta ferrite (NCD-2433).

NCD-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, QG-109); 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 electroslag flux. The definitions in SFA-5.01 and the Lot Classes specified in (a) through (e) below shall apply.

(a) each Lot Class C3 of covered electrodes.

(b) each Lot Class T2 of tubular-cored electrodes and rods (flux cored or fabricated).

(c) each Lot Class S2 of fully metallic solid welding consumables (bare electrode, rod, wire, consumable insert, or powdered filler metal).

(d) each Lot Class S2 of fully metallic solid welding electrodes or each Lot Class T2 of tubular-cored (fabricated) electrodes and each Lot Class F2 of submerged arc or electroslag welding flux.

(e) each Lot Class S2 of fully metallic solid welding electrodes or each Lot Class T2 of tubular-cored (fabricated) electrodes and each Lot Class F2 of submerged arc or electroslag welding flux and each Lot Class S2 of supplementary powdered filler metal. The chemical analysis range of the supplemental powdered filler metal 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.

In all cases, when filler metal of controlled chemical composition (as opposed to heat control) is used, each container of welding consumable shall be coded for identification and shall be traceable to the production period, the shift, the manufacturing line, and the analysis of the steel rod or strip. 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. The use of controlled chemical composition is only permitted for carbon and low alloy steel consumables. 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 Article NCD-4000 and this subarticle are made and the results conform to the requirements of this Article.

NCD-2430 WELD METAL TESTS

NCD-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 material used to join the listed P-Numbers;

(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 NCD-2311(a)(1) through NCD-2311(a)(7) or by NCD-2311(a)(8)(-b) for Class 2 or NCD-2311(a)(9)(-b) for Class 3 shall also be exempted from the impact testing required by this paragraph.

NCD-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 substantially eliminate 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 time[2] 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 NCD-4622.1-1 or Table NCD-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 NCD-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, where 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 parts of NCD-2321.1 and NCD-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 requirements shall conform to the specified minimum tensile strength requirement of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of NCD-2331, NCD-2332, or NCD-2333 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the requirements for either base material.

NCD-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NCD-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in NCD-2431, shall apply for this option. The limitations and testing under this 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 SFA-5.1 or SFA-5.5.

(b) The 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 impact specimens required by NCD-2331, NCD-2332, or NCD-2333, as 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 the postweld heat-treated condition. The postweld heat treatment temperatures shall be in accordance with Table NCD-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies

Table NCD-2432.1-1
Sampling of Welding Materials for Chemical Analysis

Welding Material	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

postweld heat treatments of 10 hr or less). When the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required, the general test of NCD-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. Drop weight impact test specimens, where required, shall be located and oriented as specified in NCD-2431.1(d).

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

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

NCD-2432 Chemical Analysis Test

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

NCD-2432.1 Test Method. The chemical analysis test shall be performed in accordance with this subparagraph and Table NCD-2432.1-1, and the results shall conform to NCD-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 the *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 weld[8] 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 NCD-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NCD-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 Section IX, QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

NCD-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.

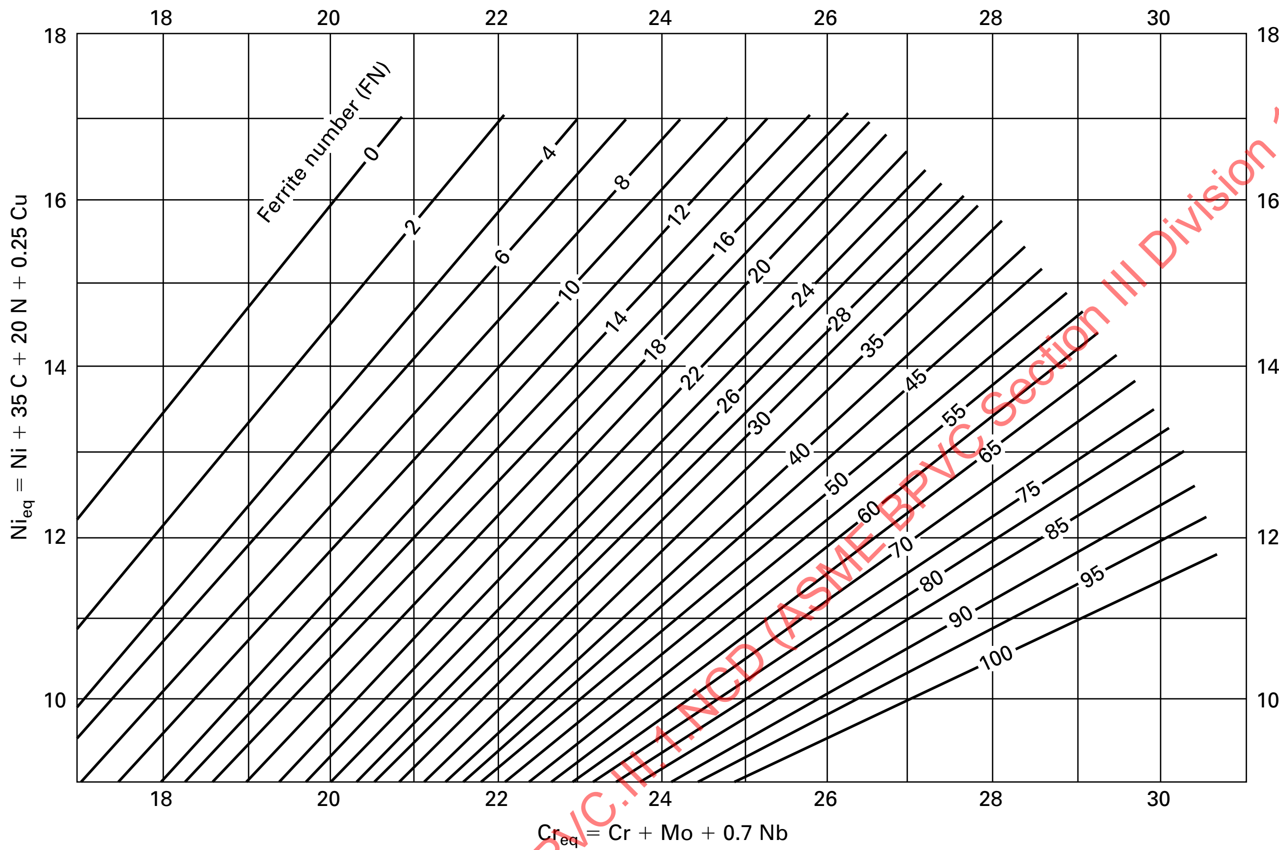
(a) Welding material of ferrous alloy A-No. 8 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table NCD-2432.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(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 NCD-2432.2-1
Welding Material Chemical Analysis

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

Figure NCD-2433.1-1
Weld Metal 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.

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 NCD-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

NCD-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table 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.

NCD-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 the chemical analysis of NCD-2432 in conjunction with Figure NCD-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 NCD-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).

NCD-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 NCD-2130 or NCD-4120.

NCD-2440 STORAGE AND HANDLING OF WELDING MATERIAL

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

NCD-2500 EXAMINATION AND REPAIR OF PRESSURE-RETAINING MATERIAL

NCD-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 (NCD-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 or quality factor pressure ratings of this subarticle shall not be applied so as to reduce the examination requirements of ASME B16.34 for Special Class category valves.

NCD-2530 EXAMINATION AND REPAIR OF PLATE

NCD-2531 Required Examination

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

NCD-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 postweld heat treatment, except for P-No. 1 material, which may be examined before or after any required postweld heat treatment.

NCD-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) When 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 NCD-2539.

NCD-2539 Repair by Welding

The Material Organization may repair by welding materials 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.

NCD-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 (NCD-4211.1).

NCD-2539.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NCD-4000 and Section IX.

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

NCD-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NCD-2545) or by the liquid penetrant method (NCD-2546). In addition, when the depth of the repair cavity exceeds the lesser of $^3/_8$ 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 NCD-5320. The image quality indicator (IQI) shall be based upon the section thickness of the repaired area.

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

NCD-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 which 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.

NCD-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NCD-2541 Required Examinations

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 NCD-2545 or NCD-2546, as applicable.

NCD-2545 Magnetic Particle Examination

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

NCD-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 which are not relevant.

(b) Any indication in excess of the NCD-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 which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which 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.

NCD-2545.3 Acceptance Standards.

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

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

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

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

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) 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.

NCD-2546 Liquid Penetrant Examinations

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

NCD-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 which are not relevant.

(b) Any indication in excess of the NCD-2546.3 acceptance standards, which 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 which would mask defects are unacceptable.

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

NCD-2546.3 Acceptance Standards.

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

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

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

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

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) 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.

NCD-2547 Time of Examination

The requirements for time of examination shall be the same as stated in NCD-2537 except that

(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

NCD-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 Article NCD-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 NCD-2545 or the liquid penetrant method in accordance with NCD-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 Article NCD-3000, the product shall be repaired in accordance with NCD-2549.

NCD-2549 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the requirements of NCD-2549.1 through NCD-2549.6 are met.

NCD-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 (NCD-4211.1).

NCD-2549.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NCD-4000 and Section IX.

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

NCD-2549.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NCD-2545) or by the liquid penetrant method (NCD-2546). In addition, when the depth of the repair cavity exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with NCD-5320. The image quality indicator (IQI) and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness at the repaired area.

NCD-2549.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the heat treatment requirements of NCD-4620.

NCD-2549.6 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3/_8$ 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.

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

NCD-2551 Required Examination

NCD-2551.1 For Class 2 Only.

(a) All seam welds in welded (without filler metal) tubular products shall be examined by one of the following methods:

(1) ultrasonic examination in accordance with NCD-2552;

(2) radiographic examination in accordance with NCD-2553;

(3) eddy current examination in accordance with NCD-2554.

(b) Wrought seamless and welded (without filler metal) tubular products and fittings, except copper alloy and nickel alloy tubular products and fittings, shall comply with the requirements of NCD-2557, NCD-2558, and NCD-2559, in addition to the basic material specification.

(c) Copper alloy and nickel alloy wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of NCD-2558, in addition to the basic material specification.

NCD-2551.2 For Class 3 Only. Wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of NCD-2557, NCD-2558, and NCD-2559 in addition to the basic material specification.

NCD-2552 For Class 2 Only — Ultrasonic Examination[9]

NCD-2552.1 Examination Procedure for Welds in Pipe and Tubing.

(a) Circumferential Direction — $6\frac{3}{4}$ in. (170 mm) O.D. and Smaller. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213, Standard Method for Ultrasonic Examination of Pipe and Tubing for Longitudinal Discontinuities, and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in NCD-2552.3.

(b) Pipe and Tubing Larger Than $6\frac{3}{4}$ in. (170 mm) O.D. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than $6\frac{3}{4}$ in. (170 mm) O.D. shall be in accordance either with the requirements of SA-388 for angle beam scanning in the circumferential direction, or with the requirements of SE-213. The reference standard shall be in accordance with NCD-2552.3.

(c) Acceptance Standard. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with NCD-2558 or NCD-2559.

NCD-2552.2 Examination Procedure for Welds in Fittings.

(a) Procedure. The procedure for ultrasonic examination of welds in fittings shall be in accordance with the requirements of Recommended Practice SA-388 for angle beam examination in two circumferential directions.

(b) Acceptance Standard. Fittings shall be unacceptable if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch.

NCD-2552.3 Reference Specimens.

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.5 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

NCD-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked, and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(a) at the beginning of each production run of a given size and thickness of a given material;

(b) after each 4 hr or less during the production run;

(c) at the end of the production run;

(d) at any time that malfunctioning is suspected.

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NCD-2553 For Class 2 Only — Radiographic Examination

(a) General. When radiographic examination is performed as an alternative to ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) Examination Procedure. The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NCD-5111.1.

(c) Acceptance Standard. Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(-a) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(-b) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(-c) $\frac{3}{4}$ 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;

(3) 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;

(4) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

NCD-2554 For Class 2 Only — Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

NCD-2554.1 Examination Procedure. The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in NCD-2552.3. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with NCD-2558 or NCD-2559 as applicable.

NCD-2554.2 Reference Specimens. The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $^1/_{16}$ in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $^1/_{16}$ in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in NCD-2552.3.

NCD-2554.3 Checking and Calibration of Equipment. The checking and calibration of examination equipment shall be the same as in NCD-2552.4.

NCD-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.

(4) In Addition for Class 2 Only

(-a) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment.

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

NCD-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 which originally disclosed the defect to assure 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 Article NCD-3000, the product shall be repaired in accordance with NCD-2559.

NCD-2559 Repair by Welding

Repair of defects shall be in accordance with NCD-2539, except repair by welding is not permitted on copper alloy and nickel alloy heat exchanger tubes.

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

NCD-2561 Required Examination

NCD-2561.1 For Class 2 Only.

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with 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, which are made by welding with filler metal, shall be treated as material. 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, a numeral 2 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with NCD-2563.

(c) Tubular products and fittings which 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.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 (see Section III Appendices, Mandatory Appendix V) in accordance with NCA-5290.

NCD-2561.2 For Class 3 Only.

(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 Section II, Part D, Subpart 1, Tables 1A and 1B 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 (see Section III Appendices, Mandatory Appendix V) in accordance with NCA-5290.

NCD-2563 For Class 2 Only — Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NCD-2553.

NCD-2567 Time of Examination

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

NCD-2568 Elimination of Surface Defects

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

NCD-2569 Repair by Welding

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

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

In addition to the requirements of the material specification and of this Article NCD-2000, statically and centrifugally cast products shall comply with the following paragraphs.

NCD-2571 Required Examination

NCD-2571.1 For Class 2 Only.

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table NCD-2571.1-1.

(b) For cast valves furnished to ASME B16.34 Special Class category, neither the size exclusions nor the quality factor pressure ratings of Table NCD-2571.1-1 shall be applied so as to reduce the required examinations of that Standard. The required examinations by ASME B16.34 for Special Class category valves shall be performed in accordance with the procedures and acceptance standards of this Subsection.

NCD-2571.2 For Class 3 Only.

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table NCD-2571.2-1.

(b) For cast valves furnished to ASME B16.34 Special Class category, neither the size exclusions nor the quality factor pressure ratings of Table NCD-2571.2-1 shall be applied so as to reduce the required examinations of that Standard. The required examinations by ASME B16.34 for Special Class category valves shall be performed in accordance with the procedures and acceptance standards of this Subsection.

NCD-2572 Time of Nondestructive Examination

NCD-2572.1 Acceptance Examinations. Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NCD-2571.1-1 for Class 2 or Table NCD-2571.2-1 for Class 3.

(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 reference radiographs shall be based on the finished thickness.

Table NCD-2571.1-1
Required Examinations for Class 2 Castings

Nominal Pipe Size	Item	Applicable Special Requirements for Class 2 Castings
Inlet piping connections of NPS 2 (DN 50) and less	Cast pipe fittings, pumps, and valves	None, except for ASME B16.34 Special Class category valves which shall be in accordance with NCD-2571.1(b).
	Cast pressure-retaining material other than pipe fittings, pumps, and valves	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods (NCD-2575).
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast pressure-retaining material other than pumps and valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, 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 NCD-2575.
Inlet piping connections over NPS 2 (DN 50) up to and including NPS 4 (DN 100)	Cast pumps and valves with a quality factor of 1.00	Magnetic particle or liquid penetrant examination may be performed on all external surfaces and on all accessible internal surfaces, in lieu of volumetric examination, except the weld ends of cast pumps and valves shall be radiographed for a minimum distance of *t* (where *t* is the design section thickness of the weld) from the final weld end. For ASME B16.34 Special Class category valves, see NCD-2571.1(b).
	Cast pumps and valves with a quality factor of 0.70	None
	Cast pressure-retaining material other than cast pumps and valves	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods.
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	None
	Repair welds in cast pressure-retaining material other than pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, 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 NCD-2575.
Inlet piping connections over NPS 4 (DN 100)	Cast pressure-retaining materials	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods. For ASME B16.34 Special Class category valves, see NCD-2571.1(b).
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the less of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NCD-2575.

Table NCD-2571.2-1
Required Examinations for Class 3 Castings

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 NCD-2571.2(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 $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NCD-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 NCD-2571.2(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 $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NCD-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.

(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) 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) 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 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.

NCD-2573 Provisions for Repair of Base Material by Welding

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

NCD-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.

NCD-2573.2 Repair by Welding. The Material Manufacturer 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 Manufacturer by welding in accordance with the requirements of this subparagraph, 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.

NCD-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 Article NCD-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 Article NCD-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

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

NCD-2573.5 Examination of Repair Welds.

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

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

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

NCD-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 NCD-2577, or the liquid penetrant method in accordance with NCD-2576, to assure 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 NCD-2539.

NCD-2573.8 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3/_8$ 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, when radiographs are specified in the order for the original casting.

NCD-2574 Ultrasonic Examination of Ferritic Steel Castings

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

NCD-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, in. (mm) [Notes (1)–(3)]
1	1.5 (38)
2	2.0 (50)
3	2.5 (64)
4	3.0 (75)

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 $^1/_2$ 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. (50 mm) through 4 in. (100 mm), and greater than permitted for 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.

NCD-2575 Radiographic Examination

NCD-2575.1 Examination. Cast pressure-retaining materials shall be examined by radiographic methods 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 radiographic methods.

NCD-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 NCD-2575.2-1.

NCD-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 Section V, Article 2, 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 techniques, 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 NCD-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.

NCD-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. (51 mm to 114 mm)] Steel Castings, or ASTM E280, Reference Radiographs for Heavy Walled [4½ in. to 12 in. (114 mm to 305 mm)] Steel Castings, as applicable for the thickness being radiographed, except Category D, E, F, or G defects are not acceptable. The requirements of ASTM E280 shall apply for castings over 12 in. (300 mm) in thickness.

NCD-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by 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 which 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 $^1/_{16}$ 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 $^1/_{16}$ in. (1.5 mm) long for materials less than ⅝ in. (16 mm) thick, greater than ⅛ in. (3 mm) long for materials from ⅝ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than ⅛ in. (3 mm) for thicknesses less than ⅝ in. (16 mm), and greater than $^3/_{16}$ in. (5 mm) for thicknesses ⅝ in. (16 mm) and greater;

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

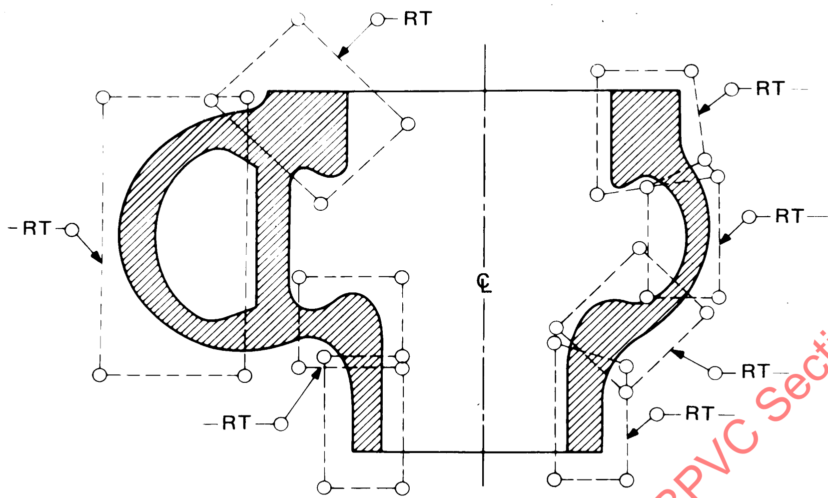
(4) ten or more indications in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

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

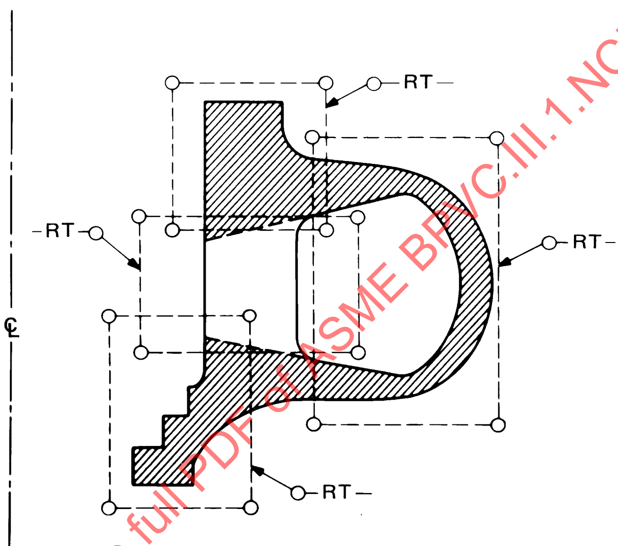
(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(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 which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than $^1/_{16}$ in. (1.5 mm). Linear indications are those whose length is

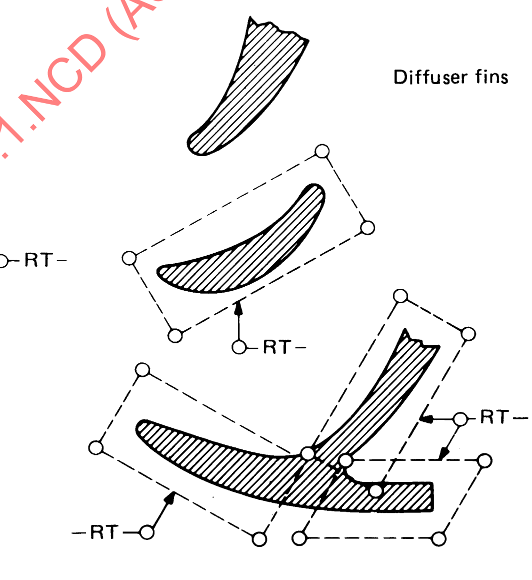
Figure NCD-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves



(a) Typical Volute-Type Pump Case

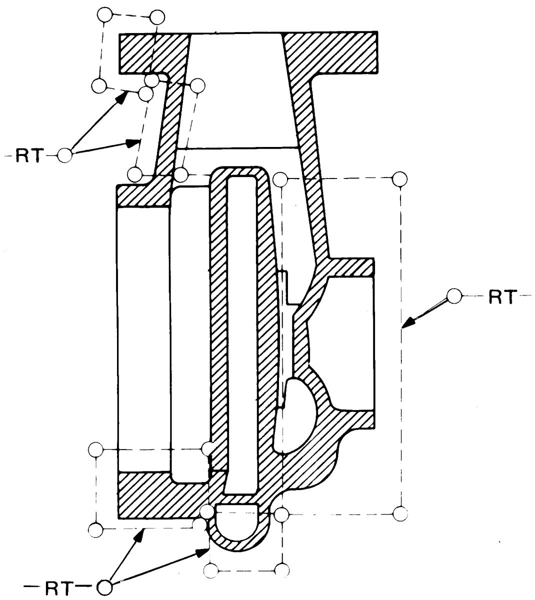


(b) Typical Diffuser-Type Pump Case

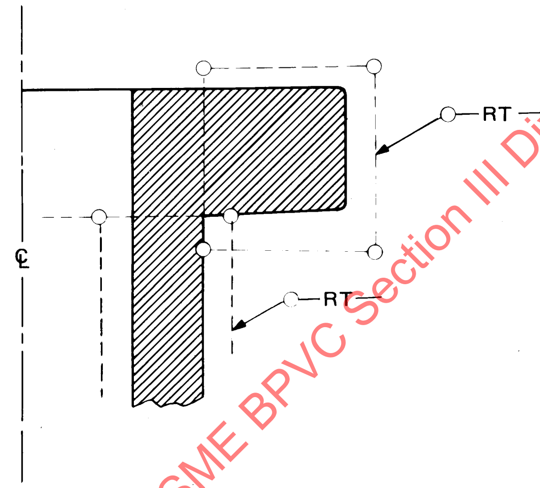


(c) Typical Diffuser-Type Pump Case Detail

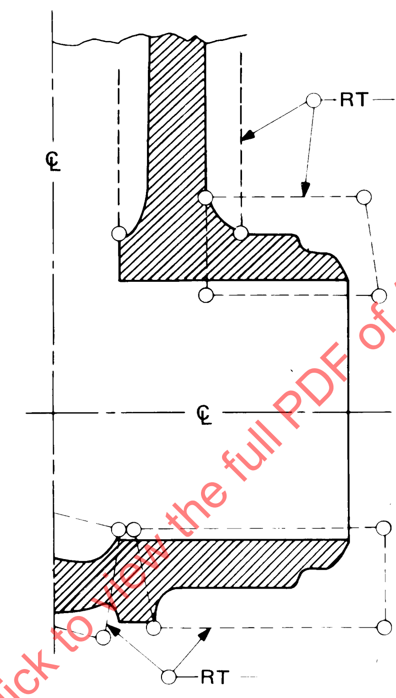
Figure NCD-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves (Cont'd)



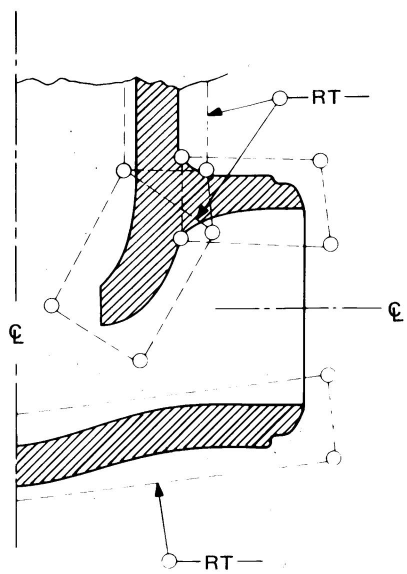
(d) Typical Single-Stage Pump Case



(e) Typical Flange



(f) Typical Gate Valve



(g) Typical Globe Valve

GENERAL NOTE:

(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.

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 1/16 in. (1.5 mm) long for materials less than 5/8 in. (16 mm) thick; greater than 1/8 in. (3 mm) long for materials from 5/8 in. (16 mm) thick to under 2 in. (50 mm) thick; and 3/16 in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than 1/8 in. (3 mm) for thicknesses less than 5/8 in. (16 mm), and greater than 3/16 in. (5 mm) for thicknesses 5/8 in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by 1/16 in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) 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.

NCD-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NCD-2581 Requirements

All bolting material shall be visually examined in accordance with NCD-2582.

NCD-2582 Visual Examination

The final surfaces of threads, shanks, and heads shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to NCD-5100 or by personnel qualified in accordance with NCD-5500.

NCD-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NCD-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 NCD-2130. The other requirements of NCA-3800 and NCA-4200 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4100) 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 (4) below:

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

(2) bolting materials, 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 mm^2) and less;

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

(5) materials exempted by NCD-2121(c).

NCD-2700 DIMENSIONAL STANDARDS

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

ARTICLE NCD-3000
DESIGN

NCD-3100 GENERAL DESIGN

NCD-3110 LOADING CRITERIA

NCD-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.

NCD-3112 Design Loadings

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

NCD-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).

NCD-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 the 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 the applicability column of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, nor exceed the maximum temperature limitations specified elsewhere in this Subsection.

NCD-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.

NCD-3112.4 Design Allowable Stress Values.

(a) Allowable stresses for design for materials are listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3. Design stress intensity values for Class 2 vessels designed to NCD-3200 are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The materials shall not be used at metal and design temperatures that exceed the temperature limit in the applicability column for which stress or stress intensity 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 NCD-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 NCD-3111 which are expected to occur simultaneously during a condition of loading for which service Level A is designated for the component does not exceed[10] 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 Temperature.

(d) *For Class 3 Items*

(1) 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.

(2) When welding or brazing is performed 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 Section II, Part D, Subpart 1, Tables 1A and 1B 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.

NCD-3113 Service Conditions

(a) Each service condition to which the components may be subjected shall be classified in accordance with NCA-2142, and Service Limits [NCA-2142.4(b)] shall be designated in the Design Specifications in such detail as will provide a complete basis for design in accordance with this Article.

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

NCD-3115 For Class 3 Only — Casting Quality Factors

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

NCD-3120 SPECIAL CONSIDERATIONS

NCD-3121 Corrosion

(a) General. Materials subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specifications for these effects by indicating the increase in the thickness of the base metal over that determined by the design equations. Other suitable methods of protection may be used. Material added or included 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) For Class 3 Only

(1) For Class 3 items only, except as required in (3), 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.

(2) Class 3 vessels constructed of materials listed in Section II, Part D, Subpart 1, Tables 1A and 1B with a required minimum thickness of less than $^1/_4$ 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.

(3) For Class 3 items only, 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 $^3/_{16}$ 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.

NCD-3122 Cladding

The rules of this paragraph apply to the design of clad components constructed of material permitted in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NCD-3122.1 Stresses. For Class 2 vessels, no structural strength shall be attributed to cladding except as permitted by NCD-3214.

NCD-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.

NCD-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this subarticle, 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.

NCD-3124 For Class 2 Only — Ductile Behavior Evaluation

For Class 2 items, the use of material below the temperature established by the methods of NCD-2331(a) may be justified by methods equivalent to those contained in Section III Appendices, Nonmandatory Appendix G.

NCD-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.

NCD-3130 GENERAL DESIGN RULES

NCD-3131 General Requirements

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

Table NCA-7100-1. Use of the maximum allowable stress values of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 does not apply to Class 2 vessels designed to the rules of NCD-3200.

(21) **NCD-3131.1 Design Reports.**

(a) 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-3211.40(h).

(b) The Certificate Holder for construction of a Class 2 vessel conforming to the design requirements of NCD-3200 shall provide a Design Report conforming to the requirements of NCD-3211 and NCD-3223.2.

NCD-3131.2 Proof Test to Establish Maximum Design 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 Design Pressure shall be determined by proof testing in accordance with the rules of NCD-6900 except for piping as otherwise provided in this Article. This procedure does not apply to Class 2 vessels designed to the requirements of NCD-3200.

NCD-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.

NCD-3133 Components Under External Pressure

NCD-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. For Class 2 vessels designed to NCD-3200, see NCD-3240.

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

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NCD-3133.3(b).
= 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

$D_o/2h_o$ = for Class 2 spherical shells and formed heads only, outside diameter of the head skirt or outside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis of the cone
= for Class 3 only, 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 NCD-3332.2-1)

D_s = for Class 3 only, outside diameter at small end of conical section under consideration

E = modulus of elasticity of material at Design Temperature, psi (MPa) . 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 Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.

h_o = for Class 3 only, 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, which 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 stiffening ring about its neutral axis parallel to the axis of the shell

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

K_1 = for Class 2 only, factor depending on the ellipsoidal head proportions (see Table NCD-3332.2-1)

= for Class 3 only, factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table NCD-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

(f) the axial length of the conical heads and sections as given in NCD-3133.4(e), and Section III Appendices, Mandatory 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 center line of the stiffening ring to the next line of support on one side, plus one-half of the center line 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, psi (MPa) (gage or absolute, as required)

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

R = for Class 2 only, the following:

(a) the inside radius of spherical shell, cylindrical shell, or tubular product

(b) for hemispherical heads, the inside radius in the corroded condition

(c) for ellipsoidal heads, the equivalent inside spherical radius taken as K_1D_o

(d) for torispherical heads, the inside radius of the crown portion of the head in the corroded condition

= for Class 3 only, the following:

(a) the inside radius of cylindrical shell or tubular product in the corroded condition

(b) for hemispherical heads, the outside radius in the corroded condition

(c) for ellipsoidal heads, the equivalent outside spherical radius taken as K_1D_o in the corroded condition

(d) 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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

T = minimum required thickness of cylindrical shell or tube, spherical shell, or formed head after forming. For Class 2 applications, this does not consider the corroded condition. For Class 3 applications, this does consider 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

NCD-3133.3 Cylindrical Shells and Tubular Products. The thickness of cylinders under external pressure shall be 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 Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o = 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o 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 immediate 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.

NCD-3133.4 Spherical Shells and Formed Heads.

(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:

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

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 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:

$$P_a = \frac{B}{(R/T)}$$

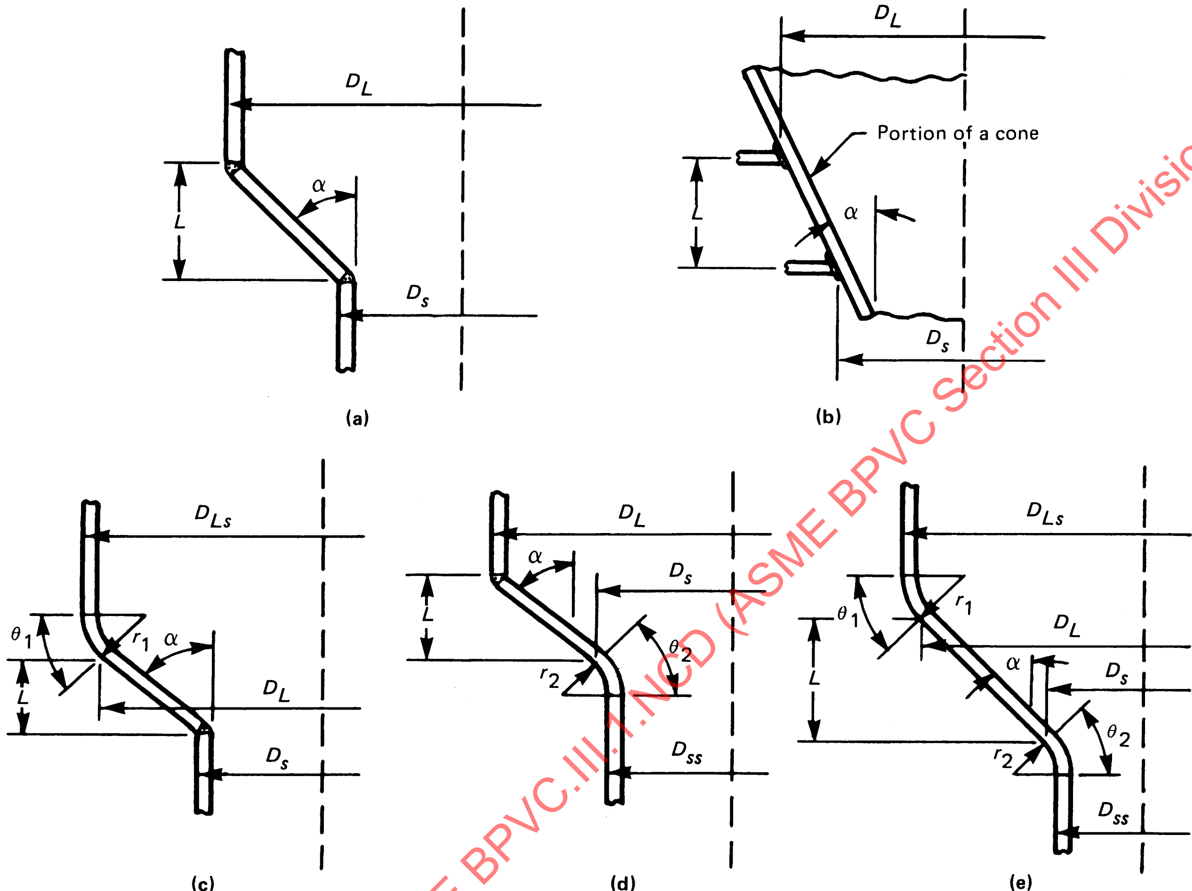
Step 5. For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following equation:

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

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

(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.

Figure NCD-3133.4-1
For Class 3 Only — Length *L* of Some Typical Conical Sections



(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:

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

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

(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.

(e) *For Class 3 Items Only*

(1) 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 NCD-3133.7(b) with the exception that L_e shall be determined as follows:

(-a) For Figure NCD-3133.4-1, sketch (c)

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

(-b) For Figure NCD-3133.4-1, sketch (d)

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

(-c) For Figure NCD-3133.4-1, sketch (e)

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

(2) 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.

(3) The required length of skirt on heads convex to pressure shall comply with the provisions of NCD-3324.5(c), and NCD-3324.5(g)(3) for heads concave to pressure.

(4) Openings in heads convex to pressure shall comply with the requirements of NCD-3330.

(5) 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 NCD-3111).

NCD-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:

$$I_s = \frac{D_o^{\,2} L_s (T + A_s / L_s) A}{14} \qquad (1)$$

$$I_s' = \frac{D_o^{\,2} L_s (T + A_s / L_s) A}{10.9} \qquad (2)$$

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 using the following equation:

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

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 Step 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.

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

$$A = \frac{2B}{E}$$

Step 6. Compute the value of the required moment of inertia from eqs. (1) and (2) provided in (a).

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 NCD-4437.

NCD-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive stress 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) or (b) below:

(a) the S value for the applicable material at design temperature given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3;

(b) the value of the 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 Step 3 or Step 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R. 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 which is greater than the compressive stress computed for the loading on the cylindrical shell or tube. For Class 3 only, the joint efficiency for butt-welded joints may be taken as unity.

NCD-3133.7 Conical Heads and Sections.

(a) For Class 2 Items Only. The required thickness of a conical head under external pressure shall not be less than that determined by the rules of (1), (2), and (3) below.

(1) When one-half of the included apex angle of the cone is equal to or less than 22½ deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the length of which equals the axial length of the cone or the axial distance center to center of stiffening rings, if used, and the outside diameter of which is equal to the outside diameter at the large end of the cone or section between stiffening rings.

(2) When one-half of the included apex angle of the cone is greater than 22½ deg and not more than 60 deg the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the outside diameter of which equals the largest inside diameter of the cone measured perpendicularly to the cone axis, and the length of which equals an axial length that is the lesser of either the distance center to center of stiffening rings, if used, or the largest inside diameter of the section of the cone considered.

(3) When one-half of the included apex angle 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 inside diameter of the cone (NCD-3325).

(b) For Class 3 Items Only. 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:

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

(-a) Cones Having D_L/T_e Values ≥10

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

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

Step 3. Move horizontally to the line for the value of D_o/T equivalent to the value of D_L/T_e determined in Step 1. Interpolation is permitted 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 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 NCD-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 Step 7 with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

Step 9. Provide adequate reinforcement of the cone-to-cylinder juncture according to Section III Appendices, Mandatory 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 may 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 the value P_{a1} using the following equation:

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

Step 3. Calculate the value of 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 the calculated value of 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 Section III Appendices, Mandatory 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 NCD-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.

(21) **NCD-3133.8 Internal Tubes and Pipes When Used as Tubes in Shell-and-Tube Heat Exchangers.** As an alternative to NCD-3133.3, for internal tubes in shell-and-tube heat exchangers, the required wall thickness for tubes and pipes under external pressure may be determined in accordance with Figure NCD-3133.8-1.

NCD-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in NCD-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. For Class 2 vessels designed to NCD-3200, thermal stresses, stress concentrations, and restraint of the pressure-retaining portion of the component shall be considered.

(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 Article NF-3000 may be used as a substitute for the design rules of Article NCD-3000 for portions of attachments which are in the component support load path.

(d) Nonstructural attachments shall meet the requirements of NCD-4435.

NCD-3200 ALTERNATIVE DESIGN RULES FOR CLASS 2 VESSELS

NCD-3210 GENERAL REQUIREMENTS

NCD-3211 Basis for Use

NCD-3211.1 Scope. (21)

(a) This subarticle contains design rules for Class 2 vessels which may be used as an alternative to the design rules in NCD-3300. When these requirements are met for design, the stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 may be used.

(b) These requirements provide specific design rules for some commonly used vessel shapes under pressure loadings and, within specified limits, rules for treatment of other loadings. Simplified rules are also included for the approximate evaluation of design cyclic service life. Rules are not given which cover all details of design.

(c) When complete rules are not provided or when the vessel designer chooses, a complete stress analysis of the vessel or vessel region shall be performed considering all the loadings of NCD-3212 and the Design Specifications. This analysis shall be done in accordance with Section III Appendices, Mandatory Appendix XIII for all applicable stress categories. Alternatively, an experimental stress analysis shall be performed in accordance with Section III Appendices, Mandatory Appendix II.

(d) When these alternative design rules are used, the special requirements of NCD-4260, NCD-5250, NCD-6221, and NCD-6222 shall be met.

(e) A Design Report shall be prepared by the Certificate Holder showing compliance with this subarticle. This Design Report shall meet the requirements of NCA-3211.40 for a Design Report (Section III Appendices, Nonmandatory Appendix C).

(f) The rules of this subarticle do not apply to Class 3 vessels except under the provisions of NCA-2134(b).

NCD-3211.2 Requirements for Acceptability.

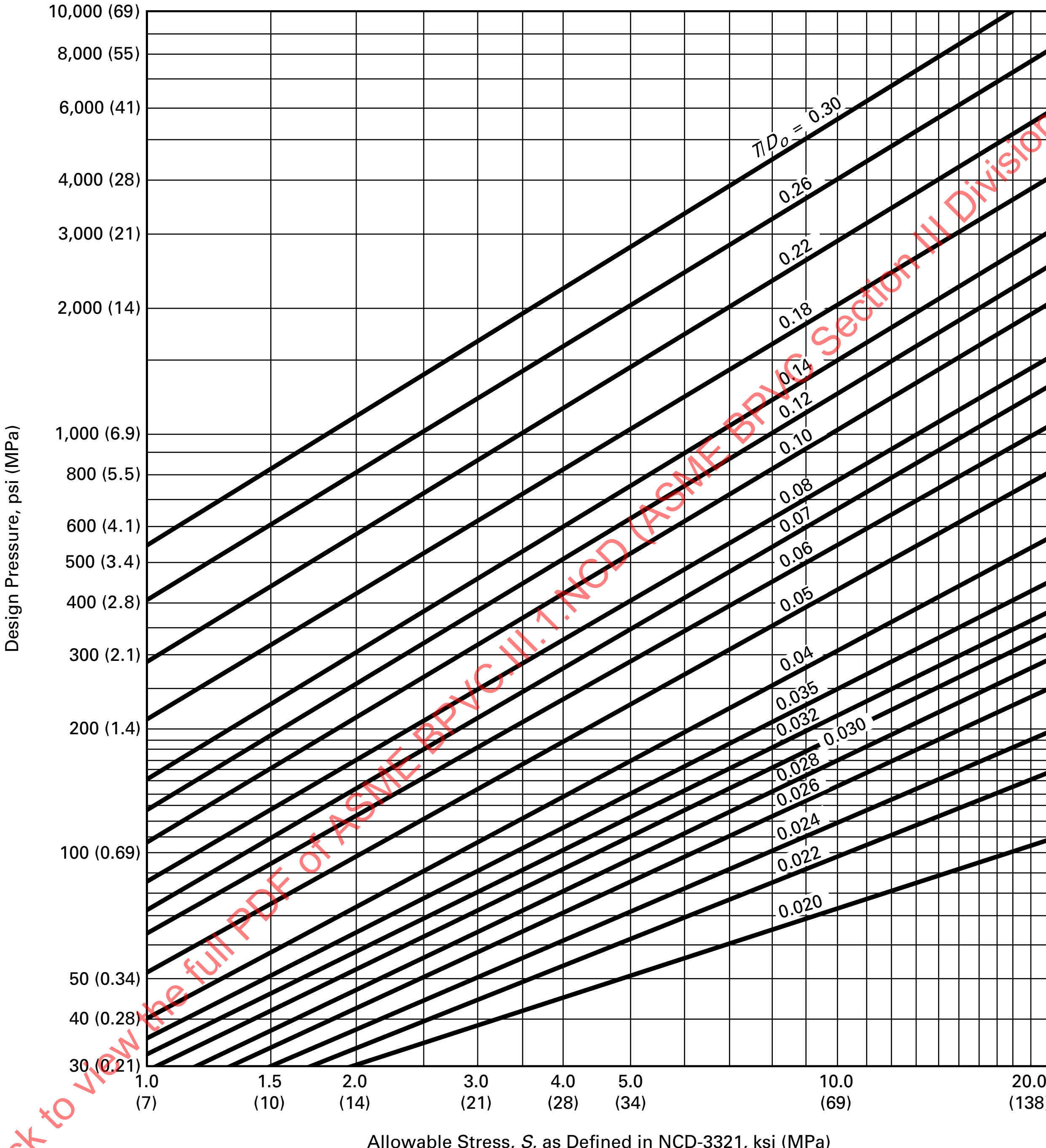
(a) The design shall be such that the requirements of NCD-3100 and this subarticle are satisfied. In cases of conflict, the requirements of this subarticle shall govern.

(b) The design shall be such that stress intensities do not exceed the limits given in NCD-3216.

(c) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account. For the special case of external pressure, the rules of NCD-3133 shall be met.

Figure NCD-3133.8-1
Chart for Determining Wall Thickness of Tubes Under External Pressure

(21)



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

NCD-3211.3 Materials in Combination.

(a) A vessel may be designed for and constructed of any combination of materials permitted in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

(b) A stress analysis of a vessel region shall be made in accordance with Section III Appendices, Mandatory Appendix XIII unless all of the provisions of (c) or (d) below apply. This does not obviate the need for such analysis where required by other provisions of this subarticle.

(c) See below.

(1) The junction is a girth seam between pressure parts.

(2) Any taper required because of different thickness shall be in the material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(3) No discontinuity is involved except that due to thickness and modulus of elasticity difference.

(4) $S_{m2} \leq 1.2\ S_{m1}\ (E_2/E_1)$ where subscripts 1 and 2 denote the material having the lower and higher design stress intensity value, respectively, and S_m and E are as defined in NCD-3216 and NCD-3219 respectively.

(d) See below.

(1) The junction is at a seam between pressure parts other than a girth seam covered by (c) above.

(2) Any taper required because of different thickness is in material having the higher design stress intensity or in weld deposit appropriate for the stronger material.

(3) $S_{m2} \leq 1.1\ S_{m1}\ (E_2/E_1)$ where subscripts and symbols are as given in (c)(4) above.

NCD-3211.4 Combination Units. When a vessel unit consists of more than one independent chamber, operating at the same or different pressures and temperatures, each chamber or vessel shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected. Chambers which come within the scope of this subarticle may be connected to chambers constructed to the rules of NCD-3300, provided the connection between such chambers meets all of the requirements of this subarticle.

NCD-3211.5 Minimum Thickness of Shell or Head. The thickness after forming and without allowance for corrosion of any shell or head subject to pressure shall be not less than $^1/_4$ in. (6 mm) for carbon and low alloy steels or $^1/_8$ in. (3 mm) for stainless steel.

NCD-3211.6 Selection of Material Thickness. The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by these rules.

NCD-3212 Loadings

The requirements of NCD-3111 shall apply.

NCD-3214 Cladding

The design calculations shall be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding, less any allowance provided for corrosion, provided the conditions of (a), (b), and (c) below are met.

(a) The clad product conforms to one of the clad plate products referenced in NCD-2121 or is overlay weld clad.

(b) The joints are completed by depositing corrosion resisting weld metal over the weld in the base material to restore the cladding.

(c) The S_m value of the weaker material is at least 70% of the S_m value of the stronger. Where

S_b = design stress intensity value for the base material at the Design Temperature, psi

S_c = design stress intensity value for the cladding or, for the weld overlay, that of the wrought material whose chemistry most closely approximates that of the cladding, at the Design Temperature, psi

the design stress intensity value shall be that given for base material in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. When S_c is greater than S_b, the multiplier S_c/S_b shall be taken equal to unity.

NCD-3215 Design Basis

NCD-3215.1 Pressure and Temperature Relationships.

(a) Table NCD-3215.1(a)-1 sets forth the pressure, temperature, and static head relationships which shall be considered by the designer.

(b) The design for a vessel part is usually controlled by coincident pressure and temperature at a point. The design shall take into account the maximum difference in fluid pressure, which exists under the specified service conditions, between the inside and outside of the vessel at any point or between two chambers of a combination unit. The design thickness for pressure shall not include any metal added as corrosion or erosion allowance or any metal required for any combination of loadings listed in NCD-3218 which are likely to occur coincident with the service pressure and temperature.

NCD-3215.2 Definitions.

(a) Design Pressure. The provisions of NCD-3112.1 shall apply.

(b) Design Temperature. The provisions of NCD-3112.2 shall apply.

(c) Service Conditions. The provisions of NCD-3113 shall apply.

Table NCD-3215.1(a)-1
Pressure and Temperature Relationships

Condition	Pressure at Top of Vessel	Pressure Due to Static Head [Note (1)]	Temperature	Remarks
Condition 1				
For vessel as a whole	Design Pressure	None	Coincident metal	Pressure and temperature to be stamped on nameplate
At any point	Coincident pressure	Pressure to point under consideration due to static head of vessel contents	Design coincident temperature	Temperature at various points may vary, in which case the maximum for these conditions shall be used for the vessel as a whole or coincident conditions for specific locations shall be listed on the Certificate Holder's Data Report and Stamping
Condition 2				
At any point	Coincident pressure	Coincident pressure to point under consideration due to static head	Design Temperature	Higher temperature and lower pressure combinations (than Condition 1) shall be checked or a part may be designed for the Maximum Design Pressure and the Design Temperature
Condition 3				
For vessel as a whole	Test pressure	None	Test temperature	...
At any point	Test pressure	Pressure at point under consideration due to static head	Test Temperature	...
Condition 4				
For vessel as a whole or any part	Coincident pressure	...	Minimum permissible temperature	Minimum permissible temperature is used together with impact testing to determine suitability of material at service temperature
	Safety value setting	...	...	Usually set above the service pressure but not over the limits set in Article NCD-7000

NOTE: (1) Similar applications shall be made for other sources of pressure variation such as that resulting from flow.

(d) Test Pressure. The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable equation to check the vessel under test conditions.

(e) Safety Valve Setting. The pressure for which the safety or safety relief valves are set to open is established by Article NCD-7000.

NCD-3216 Design Stress Intensity Values

NCD-3216.1 Stress Tables. The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. Values for intermediate temperatures may be found by interpolation. These S_m values form the basis for the various stress limits which are described in Section III Appendices, Mandatory Appendix XIII and are used in determining the membrane stress intensity limits for the various load combinations given in Table NCD-3217-1.

NCD-3216.2 Coefficients of Thermal Expansion and Moduli of Elasticity. Values of the coefficients of thermal expansion are in Section II, Part D, Subpart 2, Tables TE, and values of the moduli of elasticity are in Section II, Part D, Subpart 2, Tables TM.

NCD-3216.3 Special Stress Limits. The deviations given in (a), (b), and (c) below from the basic stress limits are provided to cover special conditions or configurations.

(a) Bearing Loads

(1) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength S_y at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(2) When bearing loads are applied on parts having free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress

shall be limited to $0.6S_m$ in the case of design load stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(m)] and to $0.5S_y$ in the case of design load stress plus secondary stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(ab)]. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the S_y value at temperature is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

(b) *Pure Shear*. The average primary shear stress across a section under Design Loadings in pure shear, for example, keys, shear rings, and screw threads, shall be limited to $0.6S_m$. The maximum primary shear under Design Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) *Progressive Distortion of Nonintegral Connections*. Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (Section III Appendices, Mandatory Appendix XIII, XIII-3420), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y given in Section II, Part D, Subpart 1, Table Y-1.

NCD-3217 Design Criteria

These design requirements provide specific design rules for certain commonly used pressure vessel shapes under pressure loading and, within prescribed limits, rules for the treatment of other loadings. Simplified criteria are included for determining whether an analysis for cyclic operation shall be made. The thickness of the vessel parts and attached supports covered by these rules shall be determined by the applicable equation using the most severe combination of loadings and design stress intensities kS_m expected to occur simultaneously during design and service conditions. The basis for these equations is given in (a) through (d) below. Table NCD-3217-1 lists values of k that are appropriate for various load combinations.

(a) The theory of failure used in this subarticle is the maximum shear stress theory, except in the case of some specifically designated configurations, shapes, or design rules included as a part of this subarticle. Stress intensity is defined as two times the maximum shear stress.

(b) The average value of the general primary membrane stress intensity across the thickness of the section under consideration P_m, due to any combination of pressure and mechanical loadings expected to occur simultaneously, should not exceed the design stress intensity value kS_m.

(c) The local primary membrane stress intensity P_L due to any combination of pressure and mechanical loadings expected to occur simultaneously is limited to $1.5kS_m$. The distance over which the stress intensity exceeds $1.1kS_m$ shall not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the mean radius at the midsurface of the shell or head and t is the nominal thickness of the shell or head at the point under consideration. Examples of local primary membrane stress include

(1) membrane stress in a shell produced locally by an external load

(2) membrane stress in a shell at a permanent support or nozzle connection

(3) circumferential membrane stress at the intersection of a cylindrical shell with a conical shell due to internal pressure, as illustrated in Figure NCD-3217-1

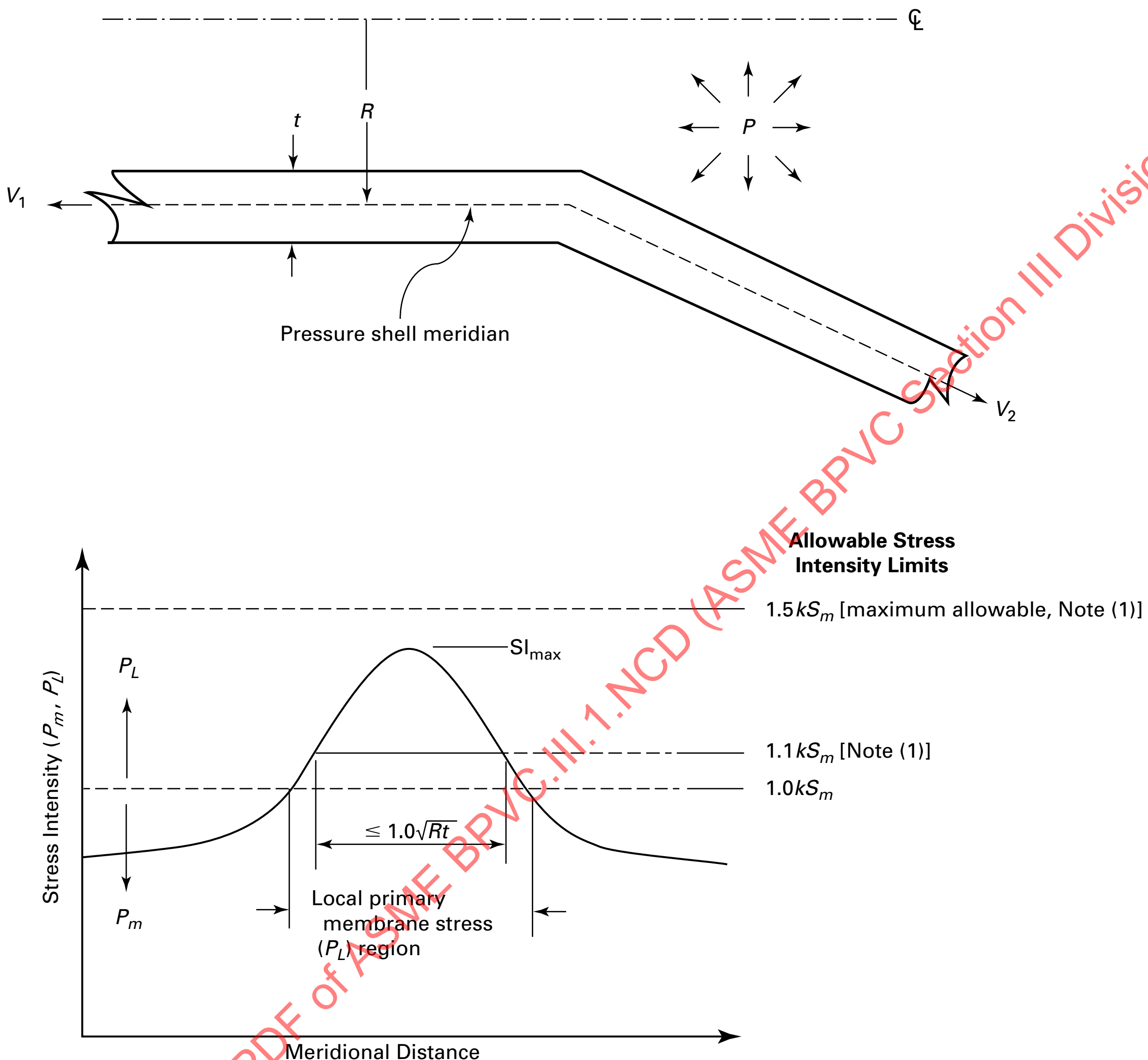
(d) The general or local primary membrane plus bending stress intensity (P_m or P_L) + P_b due to any combination of pressure and mechanical loadings expected to

Table NCD-3217-1
Stress Intensity *k* Factors for Design and Service Load Combinations

Service Limits [Note (1)]	*k* [Note (2)]
Design	1.0
Level A [Note (3)]	1.0
Level B [Note (3)]	1.1
Level C	1.2
Level D [Note (4)]	2.0

NOTES:
(1) For Design Limits, use Design Pressure at design metal temperature; for Service Limits, use service pressure at service metal temperature.
(2) The condition of structural instability or buckling must be considered.
(3) See NCD-3219 and Section III Appendices, Mandatory Appendix XIII.
(4) When a complete analysis is performed in accordance with NCD-3211.1(c), Section III Appendices, Mandatory Appendix XXVII may be applied.

Figure NCD-3217-1
Example of Acceptable Local Primary Membrane Stress Due to Pressure



Legend:

P = pressure
R = minimum midsurface radius curvature
t = minimum thickness in stressed region considered
P_L = primary local membrane stress intensity limit applies within local region
P_m = primary general membrane stress intensity limit applies outside the local region
SI_{max} = maximum stress intensity
kS_m = allowable stress intensity for the material at service temperature, see NCD-3216.1; for values of stress intensity k factor, see Table NCD-3217-1
V_1 and V_2 = meridional forces

NOTE: (1) See NCD-3217(c) for limits.

occur simultaneously shall not exceed 1.5 kS_m. When the design of vessels involves combinations of calculated stresses, the provisions of Section III Appendices, Mandatory Appendix XIII apply.

NCD-3217.1 Secondary Stresses. Secondary stresses may exist in vessels designed and fabricated in accordance with the rules of this subarticle, but limitations are provided to restrict such stresses to levels consistent with the rules in Section III Appendices, Mandatory Appendix XIII. Where details are not covered or where design conditions exceed the equation limitations, a detailed stress analysis in accordance with the rules of Section III Appendices, Mandatory Appendix XIII shall be made. Secondary stresses need be evaluated only for Level A and Level B Limits.

NCD-3217.2 Definitions.

P_b = primary bending stress intensity, psi (MPa). This stress intensity is the component of primary stress proportional to the distance from the centroid of the solid section. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

P_L = local primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It considers discontinuities but not concentrations.

P_m = general primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

S_m = design stress intensity values given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, psi (MPa)

S_y = yield strength values given in Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

NCD-3218 Upper Limits of Test Pressure

The evaluation of pressure test loadings shall be in accordance with (a) through (d) below.

(a) Test Pressure Limit. If the calculated pressure at any point in a vessel, including static head, exceeds the required test pressure defined in NCD-6221 or NCD-6321 by more than 6%, the resulting stresses shall be calculated using all the loadings that may exist during the test. The stress allowables for this situation are given in (b) and (c) below.

(b) Hydrostatically Tested Vessels. The hydrostatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

(1) a calculated primary membrane stress intensity P_m of 90% of the tabulated yield strength S_y at test temperature as given in Section II, Part D, Subpart 1, Table Y-1.

(2) a calculated primary membrane plus primary bending stress intensity $P_m + P_b$ shall not exceed the applicable limits given in (-a) or (-b) below:

(-a) $P_m + P_b \le 1.35S_y$ for $P_m \le 0.67S_y$

(-b) $P_m + P_b \le (2.15S_y - 1.2P_m)$ for $0.67S_y < P_m \le 0.90S_y$

where S_y is the tabulated yield strength at test temperature. For other than rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.9S_y$, where the factor α is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(c) Pneumatically Tested Vessels. The limits given in (b) above shall apply to pneumatically tested vessels, except that the calculated membrane stress intensity shall be limited to 80% of the yield strength at the test temperature. For other than rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.8S_y$, where the factor α is defined in (b)(2) above.

(d) Multichamber Vessels. In the case of multichamber vessels, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits given in (b) and (c) above (NCD-6600).

NCD-3219 Fatigue Evaluation

When determining whether or not a fatigue analysis shall be specified, the Owner may consider experience with comparable vessels under similar conditions in accordance with the provisions of NCD-3219.1. When not based upon significant applicable service experience, the need for a fatigue analysis shall be determined in accordance with the provisions of NCD-3219.2 and NCD-3219.3.

NCD-3219.1 Service Experience. When the Owner is considering experience with comparable vessels under similar service conditions as related to the design and service contemplated, particular attention shall be given to the possible deleterious effects of the design features of (a) through (e) below:

(a) nonintegral construction, such as the use of pad type reinforcements or of fillet welded attachments, as opposed to integral construction;

(b) use of pipe threaded connections, particularly for diameters in excess of $2^3/_4$ in. (70 mm);

(c) stud bolted attachments;

(d) partial penetration welds;

(e) major thickness changes between adjacent members.

NCD-3219.2 Rules to Determine Need for Fatigue Analysis of Integral Parts of Vessels. A fatigue analysis need not be made, provided *all* of Condition A or *all* of Condition B is met. If neither Condition A nor B is met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendices XIII for those parts which do not satisfy the conditions. The rules of Condition A or Condition B are applicable to all integral parts of the vessel, including integrally reinforced type nozzles. For vessels having pad-type nozzles or nonintegral attachments, the requirements of NCD-3219.3 apply.

NCD-3219.2.1 Condition A. Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1,000 cycles:

(a) is *the expected design number of full range pressure cycles* including startup and shutdown;

(b) is *the expected number of service pressure cycles* in which the range of pressure variation exceeds 20% of the Design Pressure. Cycles in which the pressure variation does not exceed 20% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered;

(c) is *the effective number of changes in metal temperature*[11] *between any two adjacent points* in the pressure vessel, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential, °F (°C)	Factor
50 (28) or less	0
51 to 100 (29 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
Excess of 450 (250)	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
40 (22)	1,000
90 (50)	250
400 (220)	5

The effective number of changes in metal temperature is

$$1{,}000(0) + 250(1) + 5(12) = 310$$

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.)

NOTE: *Adjacent points* are defined in (a) and (b) below.

(a) For surface temperature differences:

(1) on surfaces of revolution, in the meridional direction, adjacent points are defined as points that are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface from the axis of rotation to the midjoint wall, and t is the thickness of the part at the point under consideration; if the product of Rt varies, the average value of the points shall be used;

(2) on surfaces of revolution, in the circumferential direction and on flat parts (such as flanges and flat heads) adjacent points are defined as any two points on the same surface.

(b) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

(d) for vessels with welds between materials having different coefficients of expansion, is *the number of temperature cycles* which causes the value of $(\alpha_1 - \alpha_2) \Delta T$ to exceed 0.00034 where α_1 and α_2 are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE), and ΔT is the operating temperature range, °F (°C). This does not apply to cladding.

NCD-3219.2.2 Condition B. Fatigue analysis is not mandatory when all of the conditions of Section III Appendices, Mandatory Appendix XIII, XIII-3510 are met.

NCD-3219.3 Rules to Determine Need for Fatigue Analysis of Nozzles With Separate Reinforcement and Nonintegral Attachments. A fatigue analysis of pad-type nozzles and nonintegral attachments need not be made, provided *all* of Condition AP or *all* of Condition BP is met. If neither Condition AP nor BP is met, a detailed fatigue analysis must be made in accordance with the rules of Section III Appendices, Mandatory Appendix XIII. NCD-3237 gives further limitations on pad-type nozzles.

NCD-3219.3.1 Condition AP. Fatigue analysis of pad-type nozzles and nonintegral attachments is not mandatory for materials having specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 400:

(a) is *the expected design number of full range pressure cycles* including startup and shutdown;

(b) is *the expected number of service pressure cycles* in which the range of pressure variation exceeds 15% of the Design Pressure. Cycles in which the pressure variation does not exceed 15% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered.

(c) is *the effective number of changes in metal temperature*[11] *between any two adjacent points* in the pressure vessel, including nozzles. In calculating the temperature difference between adjacent points, conductive heat transfer shall be considered only through welded or integral cross sections with no allowance for conductive heat transfer across unwelded contact surfaces. The effective number of changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor, given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential,°F (°C)	Factor
50 (28) or less	0
51 to 100 (29 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
Excess of 450 (250)	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
50 (28)	1,000
90 (50)	250
400 (220)	5

The effective number of changes in metal temperature is

$$1{,}000(0) + 250(1) + 5(12) = 310$$

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.)

Adjacent points are defined as points that are spaced less than the distance $2\sqrt{Rt}$ from each other, where R and t are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other part in which the points are located.

(d) for vessels with welds between materials having different coefficients of expansion, is *the number of temperature cycles* which causes the value of $(\alpha_1 - \alpha_2)$ ΔT to exceed 0.00034, where α_1 and α_2 are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE), and ΔT is the service temperature range, °F (°C). This does not apply to cladding.

NCD-3219.3.2 Condition BP All of the requirements of NCD-3219.2.2, Condition B, are met using the adjusted values in (a) through (c) below.

(a) Use a value of 4 instead of 3 in Section III Appendices, Mandatory Appendix XIII, XIII-3510(a).

(b) Use a value of one-quarter instead of one-third in Section III Appendices, Mandatory Appendix XIII, XIII-3510(b).

(c) Use a value of 2.7 instead of 2 in the denominator of Section III Appendices, Mandatory Appendix XIII, XIII-3510(c), XIII-3510(d), and XIII-3510(e).

NCD-3220 DESIGN CONSIDERATIONS

NCD-3221 Design Loadings

The provisions of NCD-3210 apply.

NCD-3222 Special Considerations

The provisions of NCD-3121 and NCD-3214 apply.

NCD-3223 General Design Rules

NCD-3223.1 General Requirements. The design shall be such that the design rules of NCD-3200 are satisfied for all configurations and loadings, using the design stress intensity values S_m of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 in the various equations.

NCD-3223.2 Design Reports. The Certificate Holder shall provide a Design Report conforming to the requirements of NCD-3211.1(e).

NCD-3224 Vessels and Parts Under Internal Pressure

NCD-3224.1 General Requirements. The thickness of vessels and parts under internal pressure shall be not less than that computed by the equations in the following paragraphs. In addition, provision shall be made for the applicable load combinations listed in NCD-3218 in establishing the value of F as defined below.

NCD-3224.2 Nomenclature. The symbols used are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition.

D = inside diameter of a 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 axis of revolution.

F = meridional membrane force in the shell wall at the point under consideration resulting from primary loadings other than internal pressure, lb/in. (N/mm) length of circumference. If this force is not uniform, as when resulting from wind or earthquake moment loading, the loading requiring the greatest shell thickness shall be used where the tensile load is positive.

h = one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line

k = stress intensity factor for design, service, and test load combination from Table NCD-3217-1
L = inside spherical or crown radius of torispherical and hemispherical heads
P = internal pressure at the top of vessel plus any pressure due to the static head of the fluid, at any point under consideration, psi (MPa)
Q = a factor in the equations for cone to cylinder junctions depending on P/S and α
R = inside radius of the shell under consideration. This radius is measured normal to the surface from the of revolution
R_L = radius of a cylinder at the large end of a cone to cylinder junction
R_s = radius of a cylinder at the small end of a cone to cylinder junction
r = inside knuckle radius of torispherical and toriconical heads
S = membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by the stress intensity factor in Table NCD-3217-1
= kS_m, psi (MPa)
t = minimum required thickness of shell
t_r = Q times the required thickness of a cylinder calculated in accordance with NCD-3224.13(b)(6)(-b)
α = one-half of the apex angle of a cone to cylinder junction

NCD-3224.3 Minimum Thickness of Cylindrical Shells. The minimum thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$, the following equation must be used:

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

where ln is the natural log.

(b) If F is positive and exceeds $0.5PR$,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling shall be considered separately (see NCD-3245).

NCD-3224.4 Minimum Thickness of Spherical Shells. The minimum thickness of spherical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{0.5PR}{S - 0.25P}$$

If $P > 0.4S$, the following equation may be used:

$$\ln \frac{(R + t)}{R} = \frac{0.5P}{S}$$

(b) If F is positive,

$$t = \frac{0.5PR + F}{S - 0.25P}$$

(c) If F is negative, the condition of instability shall be considered. NCD-3245 for cylinders may be used for spheres, provided biaxial compression does not exist.

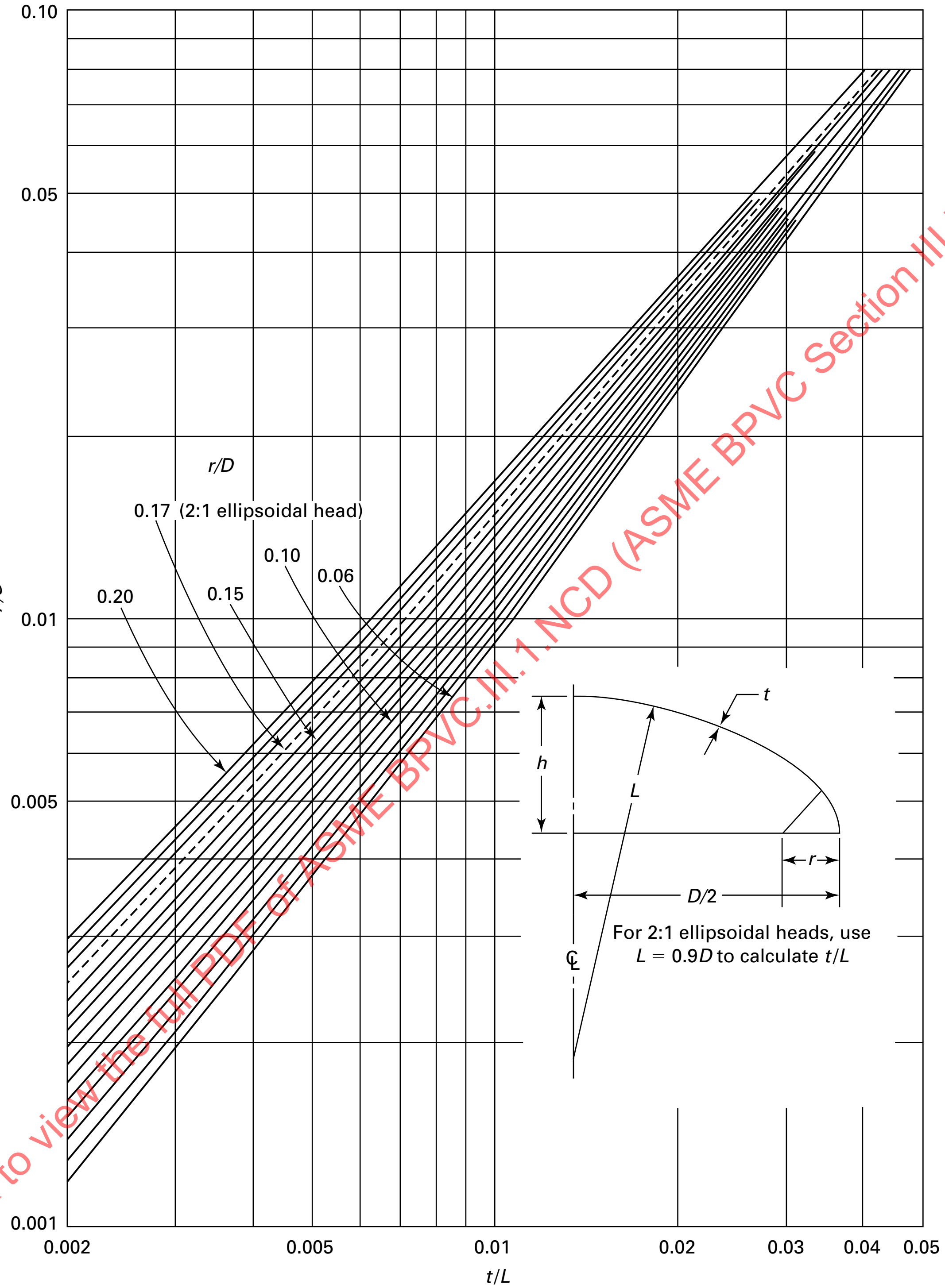
NCD-3224.5 Minimum Thickness of Formed Heads. The minimum thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure acting against the concave surface shall be determined by the appropriate rule or equation in the following subparagraphs.

NCD-3224.6 Minimum Thickness of Ellipsoidal Heads[12]**.** The minimum thickness of a 2:1 ellipsoidal head shall be established using the procedures given in NCD-3224.8 and the curve of Figure NCD-3224.6-1 which is labeled "2:1 ellipsoidal head." Ellipsoidal head designs which have $D/2h$ values different from 2 shall be analyzed as equivalent torispherical heads or according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within the minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NCD-3361 and Figure NCD-3358.1(a)-1. Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $L/D = 0.90$ and $r/D = 0.17$.

NCD-3224.7 Minimum Thickness of Hemispherical Heads. For hemispherical heads, the thickness shall be as required for spherical shells, NCD-3224.4. The requirements for the transition to cylindrical shells of different thickness, given in NCD-3361 and Figure NCD-3361.1-1, shall be met.

NCD-3224.8 Minimum Thickness of Torispherical Heads. The minimum thickness of a torispherical head having $t/L \geq 0.002$ up to a t/L where $P/S \leq 0.08$ (approximately $t/L = 0.04$ to 0.05) shall be established by using the curves in Figure NCD-3224.6-1. Interpolation may be used for r/D values which fall within the range of the curves; however, no extrapolation of the curves is permitted. For

Figure NCD-3224.6-1
Design Curves for Torispherical Heads and 2:1 Ellipsoidal Heads for Use With NCD-3224.8 and NCD-3224.6



designs where $P/S > 0.08$, which is above the upper limit of Figure NCD-3224.6-1 the thickness shall be set by the following equation:

$$t = \frac{D}{2}\left(e^{P/S} - 1\right)$$

Where $t/L < 0.002$, which is below the lower limit of Figure NCD-3224.6-1, the head design must be analyzed according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within this minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NCD-3361 and Figure NCD-3358.1(a)-1. Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $L/D = 0.90$ and $r/D = 0.17$.

NCD-3224.8.1 Crown and Knuckle Radii. In connection with the design procedures of NCD-3224.8 and Figure NCD-3224.6-1 the inside crown radius to which an unstayed head is formed shall not be greater than the inside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt nor less than three times the head thickness.

NCD-3224.9 Minimum Thickness of Integral Head Skirts. In addition to the requirements of NCD-3224.8 or NCD-3224.6 when an integral head skirt is provided, the skirt thickness shall not be less than the required thickness of a seamless shell of the same diameter. All transition joints shall be in accordance with NCD-3361 and Figure NCD-3358.1(a)-1.

NCD-3224.10 Composite Head Shapes. A head for a cylindrical shell may be built up of several head shapes, the thicknesses of which satisfy the requirements of the appropriate equations above. The adjoining shapes must be so formed that they have a common tangent transverse to the joint. Any taper at a joint shall be within the boundary of the shape having the thinner wall (Figure NCD-3361.1-1).

NCD-3224.11 Loadings on Heads Other Than Pressure. Provision shall be made for other loadings given in NCD-3212. For torispherical and ellipsoidal heads, the effect of other loadings must be determined in accordance with Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. For the conical or spherical portions of heads, the effect of composite loading may be treated as in NCD-3224.3, NCD-3224.4, and NCD-3224.13(a)(4).

NCD-3224.12 Toriconical Heads. (In preparation.)

NCD-3224.13 Reducer Sections.

(a) General Requirements

(1) Applicable Equations and Rules. These rules apply to concentric reducer sections when all the longitudinal loads are transmitted wholly through the shell of the reducer. When loads are transmitted in part or as a whole by other elements, such as inner shells, stays, or tubes, these rules do not apply.

(2) Minimum Thickness of Reducer Elements. The thickness of each element of a reducer 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 NCD-3212.

(3) Transition Section Reducers Joining Two Cylindrical Shells. 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 these requirements are met.

(4) Minimum Thickness of Conical Shells. The minimum thickness of conical shells shall be determined by the same equations as for cylindrical shells in which R is the radius measured normal to the wall surface at the point under consideration. Subparagraphs (b) and (c) give rules for cone to cylinder junctions of the large and small end, respectively.

(-a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$,

$$\ln\frac{(R + t)}{R} = \frac{P}{S}$$

(-b) If F is positive and exceeds 0.5 PR,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

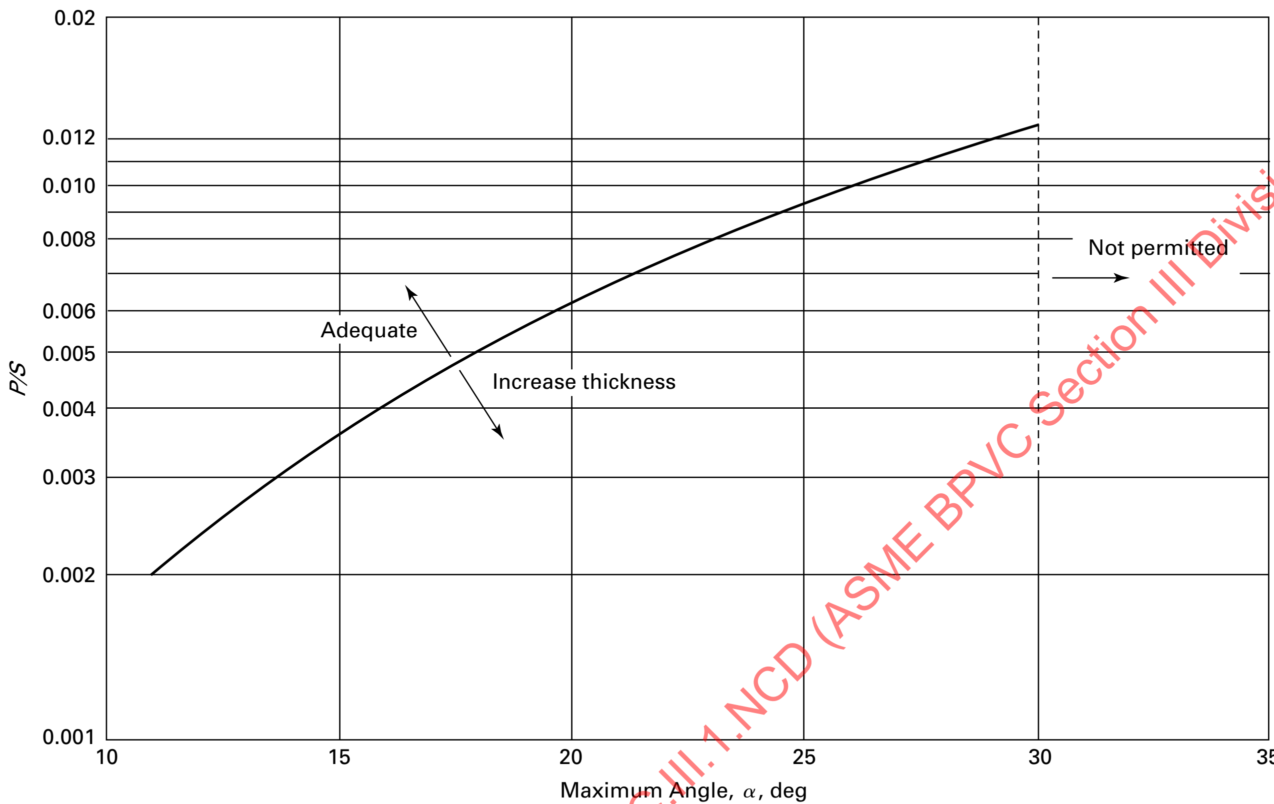
(-c) If F is negative, the condition of axial structural instability or buckling must be considered separately. NCD-3245 for cylinders may be used for conical sections.

(5) Knuckle Tangent to the Larger Cylinder. When a knuckle is used at the large end of a reducer section, it shall have a shape that is a portion of an ellipsoidal, hemispherical, toriconical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of NCD-3224.5.

(6) Combination of Elements to Form a Reducer. When elements having different thicknesses are combined to form a reducer, the joints including the plate taper shall lie entirely within the limits of the thinner element being joined.

(7) Combination of Shapes to Form a Toriconical Reducer. A toriconical reducer may be shaped as a portion of a toriconical head or a portion of an ellipsoidal

Figure NCD-3224.13(b)(6)(-a)-1
Inherent Reinforcement for Large End of Cone–Cylinder Junction



GENERAL NOTE: Curve governed by maximum stress intensity at surface primarily due to axial bending stress, limited to 3S.

head plus a conical section, provided the design of the small end of the reducer element satisfies the requirements of (c).

(b) *Supplementary Requirements for Reducer Sections and Conical Heads, Large End*. These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis

(2) the load is internal pressure (see NCD-3224.11)

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness

(4) the weld at the junction is radiographed and meets the requirements of NCD-5250

(5) the junction is not closer than $4\sqrt{R_L \times t_r}$ to another junction or major discontinuity

(6) *Reinforcement Requirements*

(-a) *When Inherent Reinforcement Is Adequate*. The thickness of the cone and cylinder forming a junction at the large end for half apex angles up to 30 deg need not be thicker than required by NCD-3224.3 or (a)(4)(-a) if the point representing the junction lies in the Adequate region of Figure NCD-3224.13(b)(6)(-a)-1.

(-b) *Requirements for Integral Reinforcement*. When the half-apex angle exceeds the maximum permitted by Figure NCD-3224.13(b)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NCD-3224.13(b)(6)(-b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness extends a minimum distance of $2.0\sqrt{R_L t_r}$ from the junction, where R_L is the radius of the cylinder at the large end of the cone.

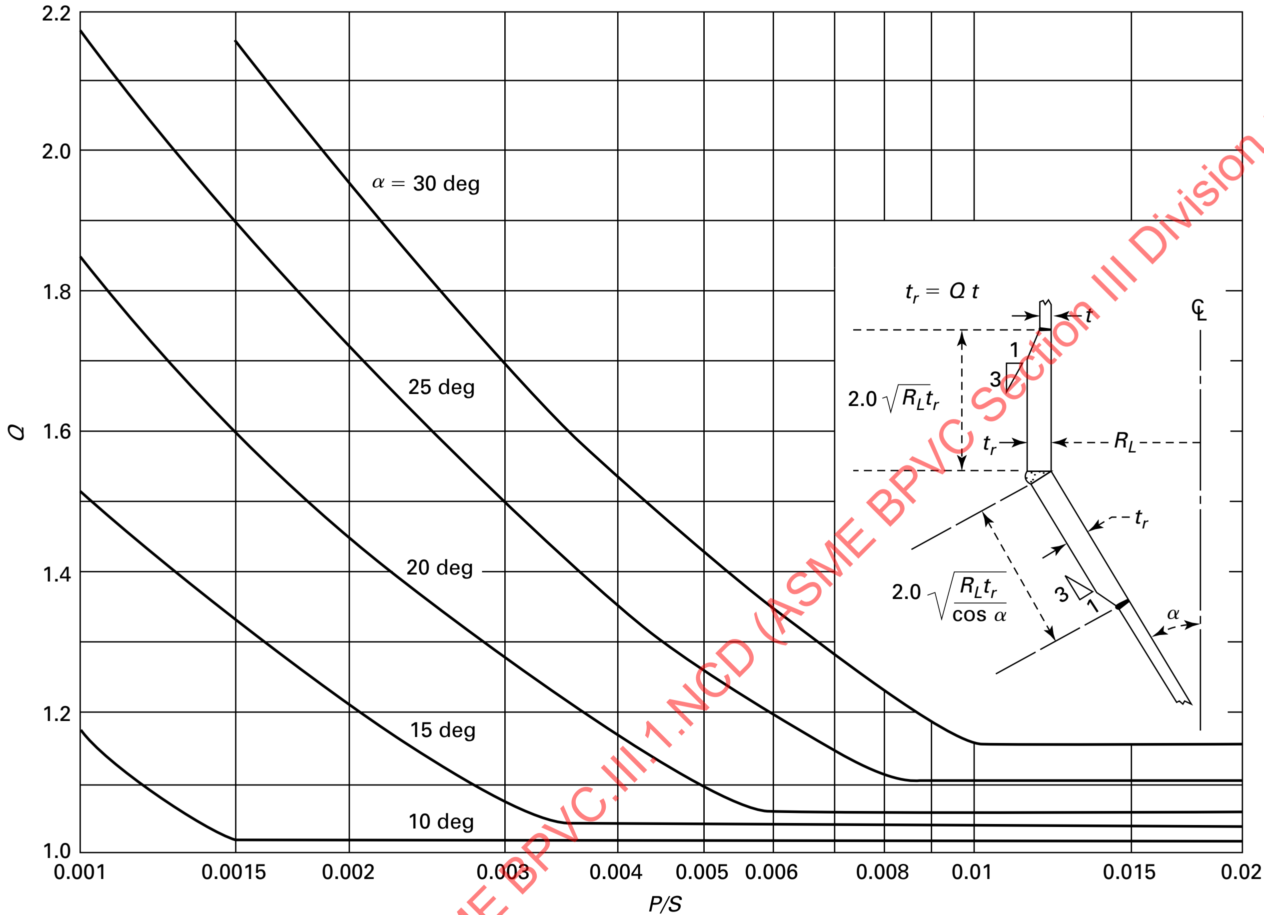
(-2) The increased cone thickness extends a minimum distance of $2.0\sqrt{R_L t_r / \cos \alpha}$ from the junction.

(-3) In no case shall t be less than the thickness required for the cone in accordance with NCD-3224.3.

(c) *Supplementary Requirements for Reducer Section's Small End*. These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis

Figure NCD-3224.13(b)(6)(-b)-1
Values for Q for Large End of Cone–Cylinder Junction



GENERAL NOTE: Curves governed by maximum stress intensity at surface primarily due to axial bending stress limited to $3S_m$.

(2) the load is internal pressure (NCD-3224.11)

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness

(4) the weld at the junction is radiographed and meets the requirements of NCD-5250

(5) the junction is not closer than $2.8\sqrt{R_s t_r}$ to another junction or discontinuity, where R_s is the radius of the cylinder at the small end of the cone

(6) Reinforcement Requirements:

(-a) When Inherent Reinforcement Is Adequate. The thickness of the cone and cylinder forming a junction at the small end of half apex angles up to 30 deg need not be thicker than required by NCD-3224.3 if the point representing the junction lies in the Adequate region of Figure NCD-3224.13(c)(6)(-a)-1.

(-b) Requirements for Integral Reinforcement. When the half apex angle exceeds the maximum permitted by Figure NCD-3224.13(c)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NCD-3224.13(c)(6)(-b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r}$ from the junction.

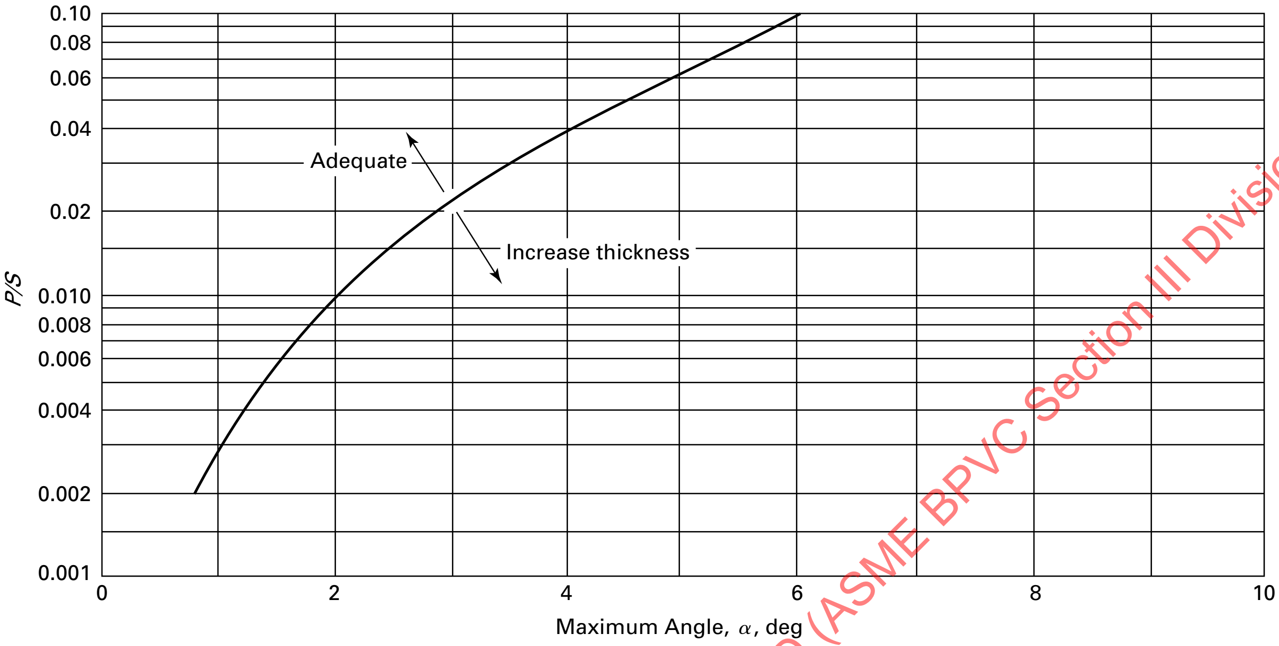
(-2) The increased cone thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r / \cos \alpha}$ from the junction.

(-3) In no case shall t_r be less than the thickness required for the cone in accordance with NCD-3224.3 at a distance $1.4\sqrt{R_s t_r / \cos \alpha}$ from the junction.

(d) Supplementary Requirements for Reducer Sections, Small End, Treated As Openings. Cone to cylinder junctions at the small ends of reducers as shown in Figure NCD-3224.13(d)-1 may be treated as openings in

(21)

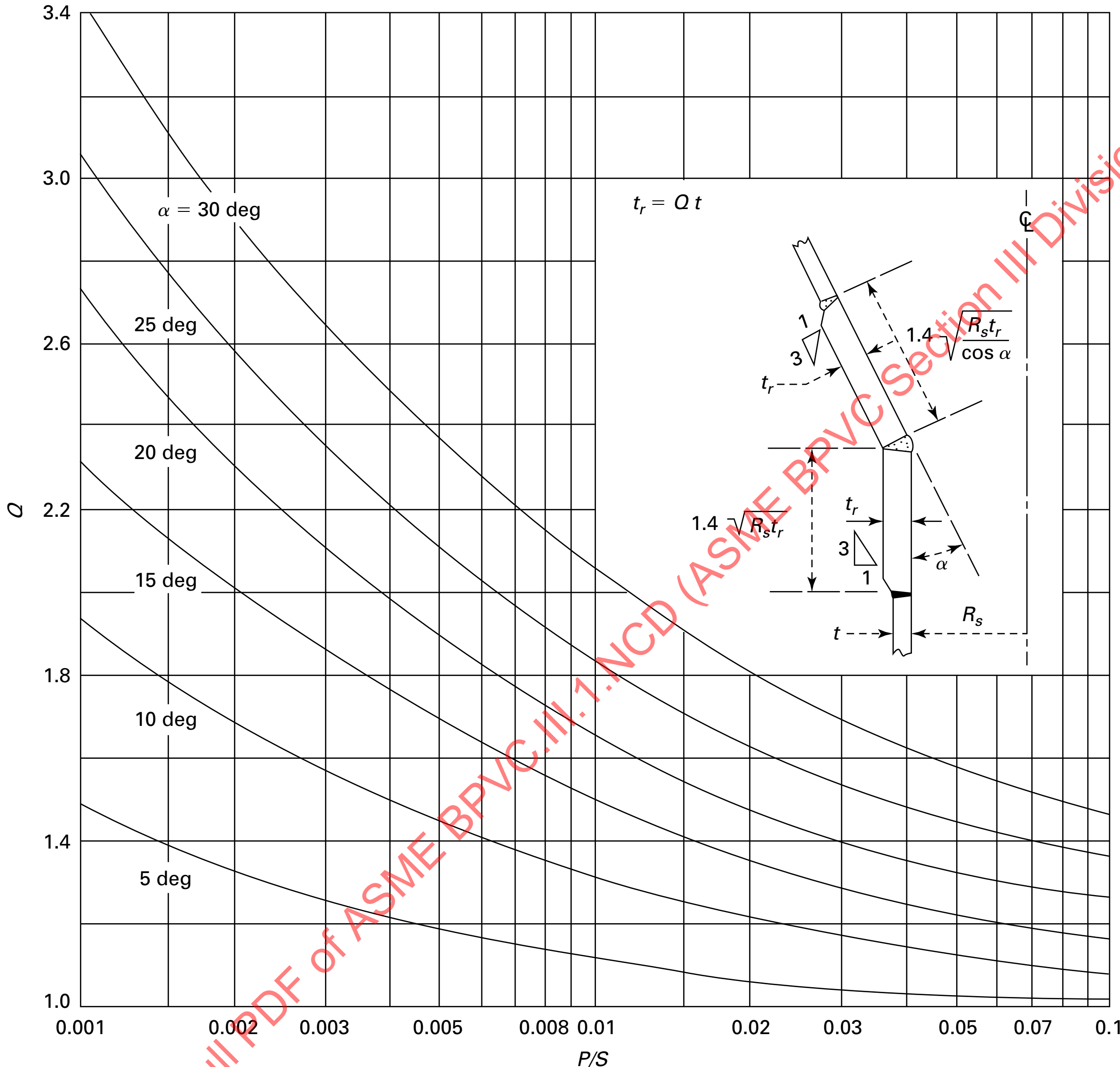
Figure NCD-3224.13(c)(6)(-a)-1
Inherent Reinforcement for Small End of Cone–Cylinder Junction



GENERAL NOTE: Curve governed by membrane stress intensity due to average circumferential tension stress and average radial compression stress limited by $1.1S_m$ at $0.5\sqrt{\text{radius} \times t}$ either side of junction, where radius = $R_s + t_r/2$ on the cylinder side and $(R_s + t_r/2)/\cos\alpha$ on the cone side.

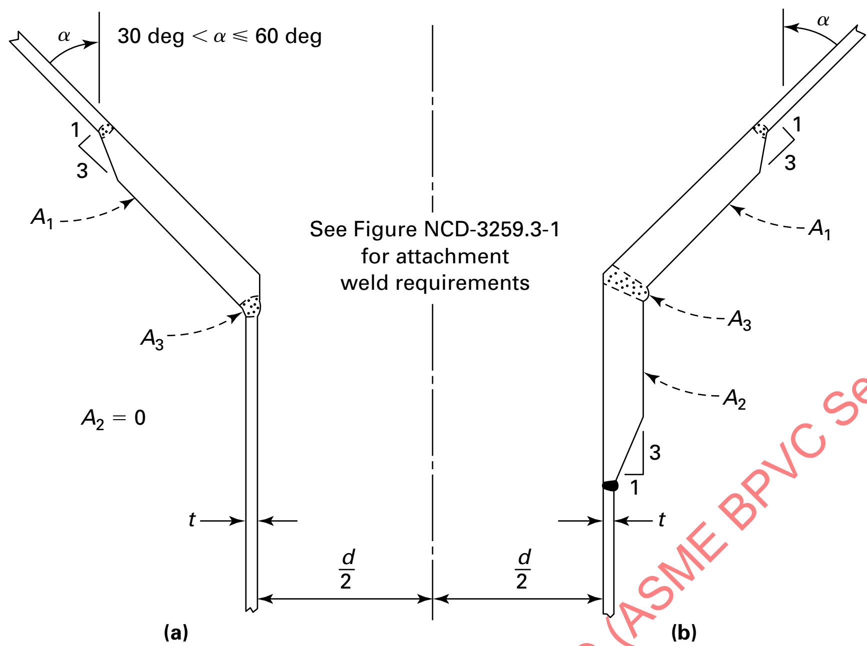
Figure NCD-3224.13(c)(6)(-b)-1
Values for Q for Small End of Cone–Cylinder Junction

(21)



GENERAL NOTE: Curves governed by membrane stress intensity due to average circumferential tension stress and average radial compression stress limited by $1.1S_m$ at $0.5\sqrt{\text{radius} \times t}$ either side of junction, where radius = $R_s + t_r/2$ on the cylinder side and $(R_s + t_r/2)/\cos\alpha$ on the cone side.

Figure NCD-3224.13(d)-1
Cone–Cylinder Junction at Small End Treated as Opening



$$A \le A_1 + A_2 + A_3$$

where

A_1 = reinforcement area integral with cone
A_2 = reinforcement area integral with cylinder
A_3 = area of fillet weld

conical heads provided the requirements of (1) through (4) below are met.

(1) The diameter d of the small end is not more than one-half the diameter of the large end.

(2) The half apex angle α is greater than 30 deg but not greater than 60 deg.

(3) The reinforcement meets the requirements of NCD-3232 and NCD-3234.1 except that the total cross-sectional area of reinforcement A required at the junction in any plane for a vessel under internal pressure shall not be less than $A = dt \tan \alpha/2$ and two-thirds of this area shall be provided within a limit of $0.5\sqrt{dt/2}$ measured along the cylinder and $0.5\sqrt{dt/2 \cos^2 \alpha}$ measured along the cone.

(4) Reinforcement shall be integral with cone or cylinder and all other applicable requirements of NCD-3230 are met.

NCD-3224.14 Minimum Thickness of Nozzle Necks and Other Connections. The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings plus the thickness added for corrosion and erosion allowance and, except for access openings and openings for inspection only, not less than the smaller of (a) and (b) below:

(a) 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;

(b) the minimum thickness of standard wall pipe plus the corrosion allowance on the connections. The minimum thickness for all pipe materials is the nominal thickness listed in Table 2 of ASME B36.10M less $12\frac{1}{2}$%. For diameters other than those listed in the table, the minimum thickness shall be that of the next larger pipe size.

NCD-3224.15 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 NCD-3111 other than pressure and temperature.

NCD-3225 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. Some acceptable types of flat heads and covers are shown in Figure NCD-3225-2. The dimensions are exclusive of extra metal added for corrosion allowance.

NCD-3225.1 Nomenclature. The notations used are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NCD-3225.2, dimensionless (Figures NCD-3225-1 through NCD-3225-3)
D = bolt circle diameter
d = diameter
h_G = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction (Figure NCD-3225-2)
L = distance from center line of head to shell weld to tangent line on formed heads, as indicated in Figure NCD-3225-2 sketch (a)
m = the ratio t_r/t_s, dimensionless
P = Design Pressure, psi (MPa)
r = inside corner radius on a head formed by flanging or forging
S = design stress intensity S_m from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by tabulated stress intensities, psi (MPa)
T = minimum required thickness of flat head, cover, or flange, exclusive of corrosion allowance
t_f = actual thickness of the flange on a formed head, at the large end, 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 shell or nozzle for pressure
t_s = actual thickness of shell or nozzle
W = total bolt load

NCD-3225.2 Equations for Minimum Thickness[13].

(a) The thickness of flat heads, as shown in Figures NCD-3225-1 through NCD-3225-3, shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S}$$

(b) The thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in Figure NCD-3225-2 shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S + 1.27\ Wh_G/Sd^3}$$

NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the service bolt load. The thickness should be checked for both the service condition and the initial bolt load required to seat the gasket.

NCD-3227 Quick Actuating Closures

The requirements for quick actuating closures are given in NCD-3327.

NCD-3230 OPENINGS AND THEIR REINFORCEMENT

NCD-3231 General Requirements

The rules contained in this subarticle provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of its opening shape, area replacement, and distribution, provided a fatigue analysis is not required. These rules do not include design requirements for piping loads that may be imposed on the nozzle or shell portion or both and that may be added to the pressure loadings. Such additional loadings shall be considered by the designer.

NCD-3231.1 Dimensions and Shape of Openings.

(a) Openings, except as permitted under (b), shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with vessels of the shapes for which equations are given in NCD-3220, provided the requirements of (1) through (4) below are met.

(1) The ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less.

(2) The ratio $d/D \leq 0.50$ where d is the largest inside diameter of the intersecting nozzle and D is the inside diameter of the vessel.

(3) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or for openings along the longitudinal axis of a shell and is not less than two times the sum of their inside radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along the inside surface of the shell shall be such that $[(L_c/2)^2 + (L_l/3)^2]^{1/2}$ is not less than the sum of their inside radii, where L_c is the component of the center line distance in the circumferential direction and L_l is the component of the center line distance in the longitudinal direction.

Figure NCD-3225-1
Typical Flat Heads and Supported and Unsupported Tubesheets With Hubs

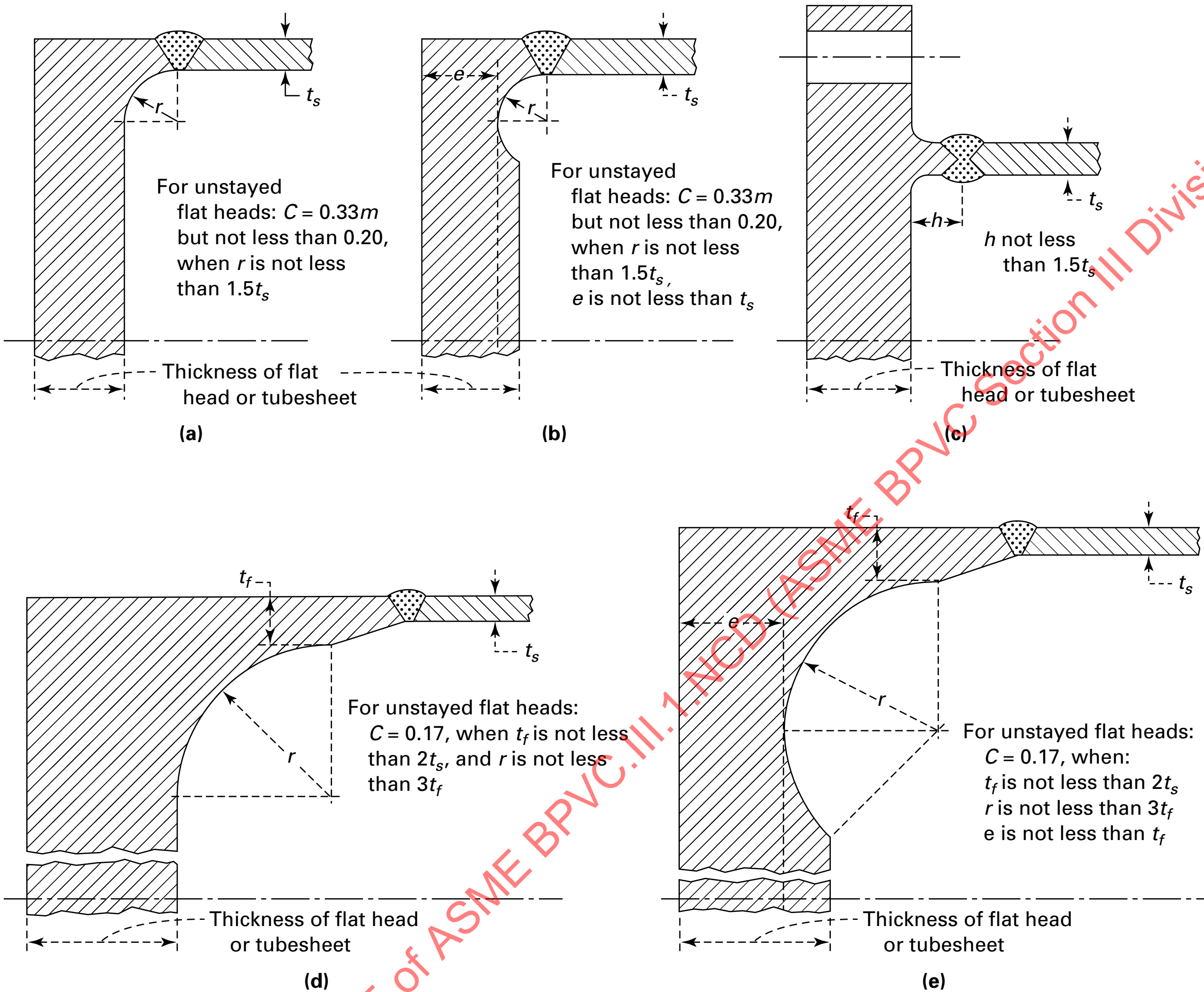
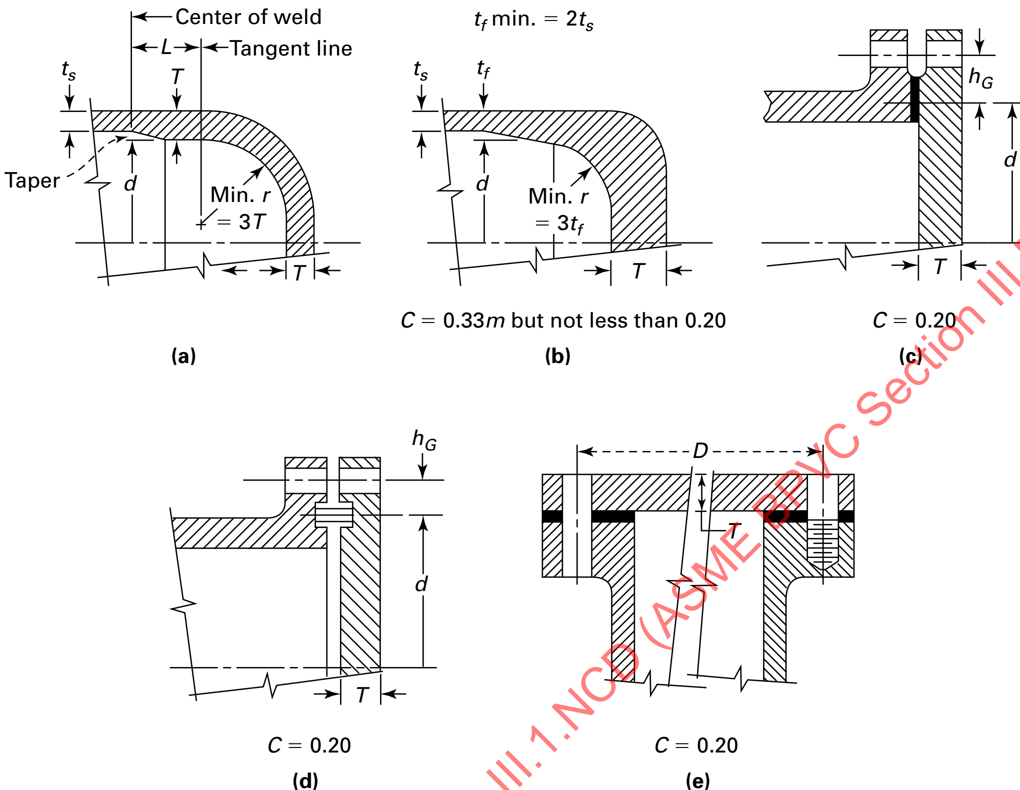
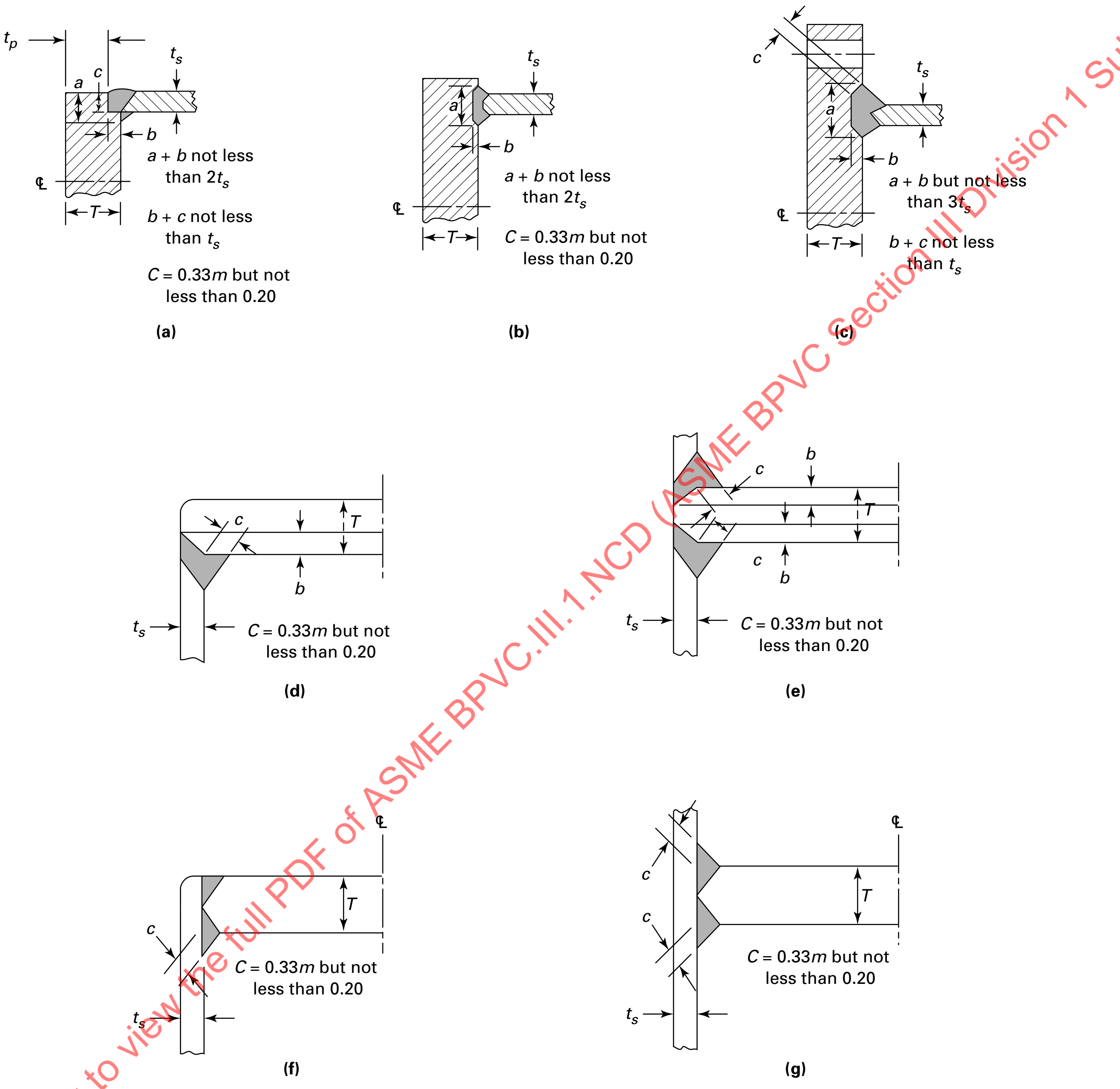


Figure NCD-3225-2
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: All these illustrations are diagrammatic only. Other designs that meet the requirements of NCD-3225.2 are acceptable.

Figure NCD-3225-3
Attachment of Pressure Parts to Plates to Form a Corner Joint



C min. = 0.7 t_s or 1/4 in. (6 mm), whichever is less
b = the lesser of t_s or $T/2$

(4) Reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in NCD-3232.2.

(b) Openings of other shapes or dimensions may be used subject to the requirements of Section III Appendices, Mandatory Appendix XIII or Mandatory Appendix XIII.

(c) Any type of opening permitted by these rules may be located in a butt welded joint.

NCD-3232 Reinforcement Requirements for Openings in Shells and Formed Heads

NCD-3232.1 Circular Openings Not Requiring Reinforcement. Circular openings need not be provided with reinforcement if all the requirements in (a), (b), and (c) below are satisfied.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter, $2.5\sqrt{Rt}$, then the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the shell where R is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the openings and where locally stressed area means any area in the shell where the primary local membrane stress exceeds $1.1kS_m$, but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

NCD-3232.2 Required Area of Reinforcement.

(a) The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall be not less than

$$A = dt_rF$$

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 = 1.00 when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of F determined from Figure NCD-3332.2-1 except that, for reinforcing pads, F = 1.

t_r = the thickness which meets the requirements of NCD-3220 in the absence of the opening

(b) Not less than one-half the required material shall be on each side of the center line of the opening [NCD-3234.1(b)].

NCD-3233 Required Reinforcement 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 A, not less than that given by the equation

$$A = 0.5dt_r$$

where

d = the diameter of the finished opening in its corroded condition

t_r = the thickness that meets the requirements of NCD-3225.2 in the absence of the opening

(b) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter shall be designed according to Section III Appendices, Mandatory Appendix XIX.

NCD-3234 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 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 as described in the following subparagraphs.

NCD-3234.1 Limit of Reinforcement Along the Vessel Wall. The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the vessel, shall meet the following:

(a) 100% 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 of shell or head, t is the nominal vessel wall thickness, r is the radius 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.

NCD-3234.2 Limit of Reinforcement Normal to Vessel Wall. The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the limits given in (a), (b), and (c) below.

(a) For Figure NCD-3234.2(a)-1 sketches (a) and (b), the limit is the larger of $(0.5\sqrt{r_m t_n} + k)$ or $(1.73x + 2.5t_p + k)$, but not to exceed either $2.5t$ or $(L + 2.5t_p)$, where

k = $0.73r_2$ when a transition radius (r_2) is used
= the smaller of two legs of the fillet when a fillet transition is used
L = length along nozzle with thickness of t_n plus transition length
r = inside radius of nozzle
r_2 = transition radius between nozzle and wall
r_m = mean nozzle radius = $r + 0.5t_n$
t = nominal vessel wall thickness
t_n = nominal nozzle thickness
t_p = nominal thickness of connecting pipe
x = $t_n - t_p$

(b) For Figure NCD-3234.2(a)-1 sketch (c), when $45 \geq \theta \geq 30$ deg, the limit is the larger of $(0.5\sqrt{r_m t_n'})$ or $(L' + 2.5t_p)$, but not to exceed $2.5t$; when $\theta < 30$ deg, the limit is the larger $(0.5\sqrt{r_m t_n'})$ or $(1.73x + 2.5t_p)$, but not to exceed $2.5t$, where

L' = length of tapered section along nozzle
r_m = $r + 0.5t_n'$
t_n' = $t_p + 0.667x$
x = slope offset distance
θ = angle between vertical and slope

Other terms are defined in (a) above.

(c) For Figure NCD-3234.2(a)-1 sketch (d), when reinforcing pads or insert plates are used, the limit is the larger of $(0.5\sqrt{r_m t_n} + t_e)$ or $(2.5t_n + t_e)$, but not to exceed $2.5t$. In no case can the thickness t_e, used to establish the limit normal to the shell, exceed $1.5t$ or $1.73W$, where

t_e = thickness of added reinforcing element
W = width of added reinforcing element

Other terms are defined in (a) above.

NCD-3234.3 Nozzle Piping Transitions. The stress limits of NCD-3200 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NCD-3234, except as noted in NCD-3234.4. Stresses in the extension of any nozzle beyond the limits of reinforcement shall meet the stress limits of NCD-3600.

NCD-3234.4 Consideration of Standard Reinforcement. Where a nozzle-to-shell juncture is reinforced in accordance with the rules of NCD-3234, the stresses in this region due to internal pressure may be considered to satisfy the limits of NCD-3217. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region. Where external piping loads are to be designed for, membrane plus bending stresses 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 NCD-3217 for (P_m or P_L) + P_b. In this case, the pressure-induced stresses in the (P_m or P_L) + P_b category may be assumed to be no greater than the limit specified for P_m in NCD-3217 for a given condition.

NCD-3235 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcement called for in NCD-3232.2 and NCD-3233 provided it lies within the area of reinforcement specified in NCD-3234 and shall be limited to material which meets the requirements of (a) through (e) below:

(a) metal forming a part of the vessel wall which is in excess of that required on the basis of primary stress intensity (NCD-3221 through NCD-3224 and NCD-3225.2) and is exclusive of corrosion allowance;

(b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal which is fully continuous with the vessel wall;

(d) metal not fully continuous with the shell, such as a pad continuously welded around its periphery, may be counted as reinforcement, provided the requirements of NCD-3237 are met;

(e) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b), (c), and (d) above shall be within 15% of the value for the metal in the vessel wall.

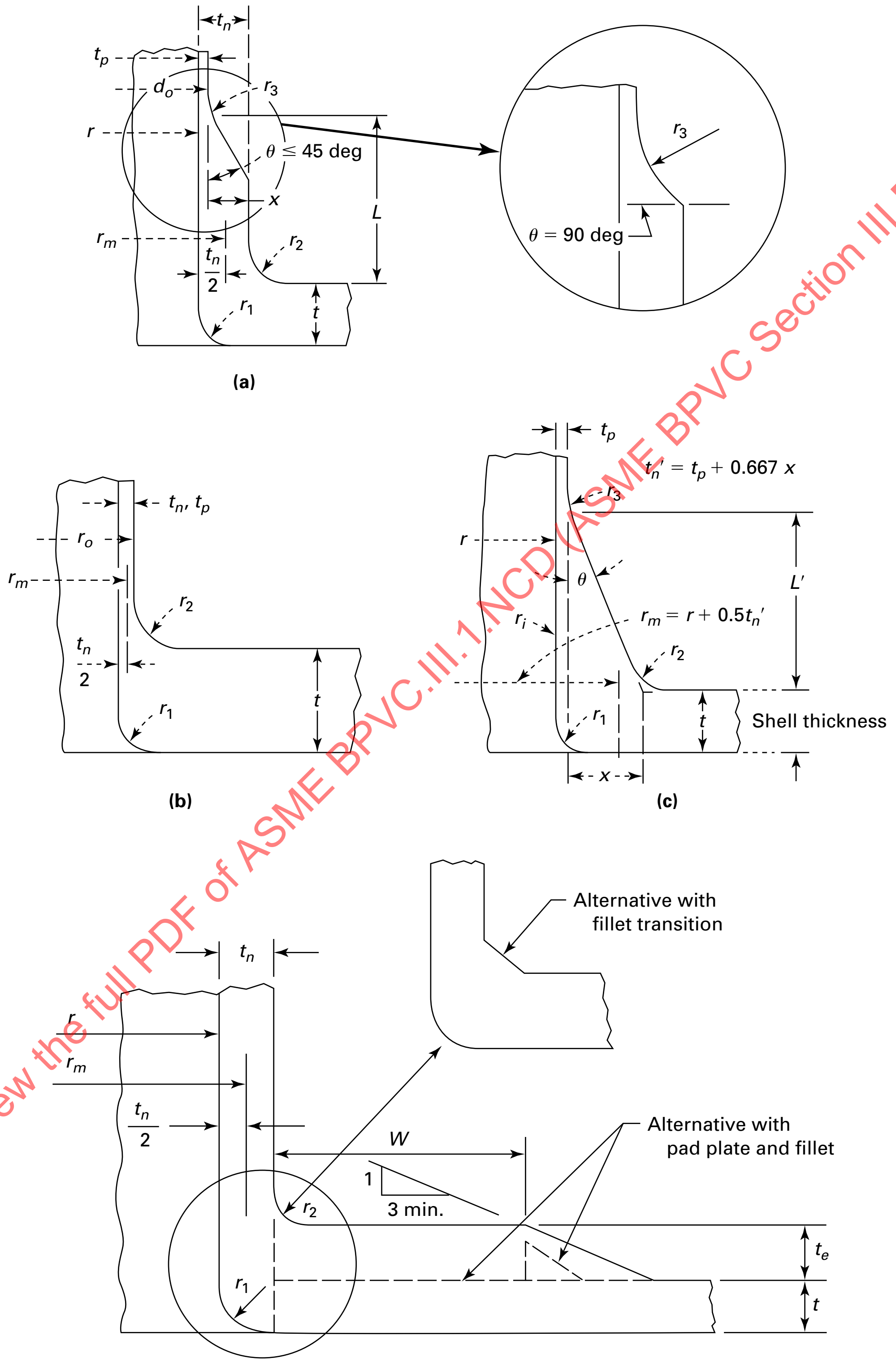
NCD-3235.1 Metal Not Available for Reinforcement. Metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement.

NCD-3235.2 Reinforcement Metal Limited to One Opening. Metal available for reinforcement shall not be considered as applying to more than one opening.

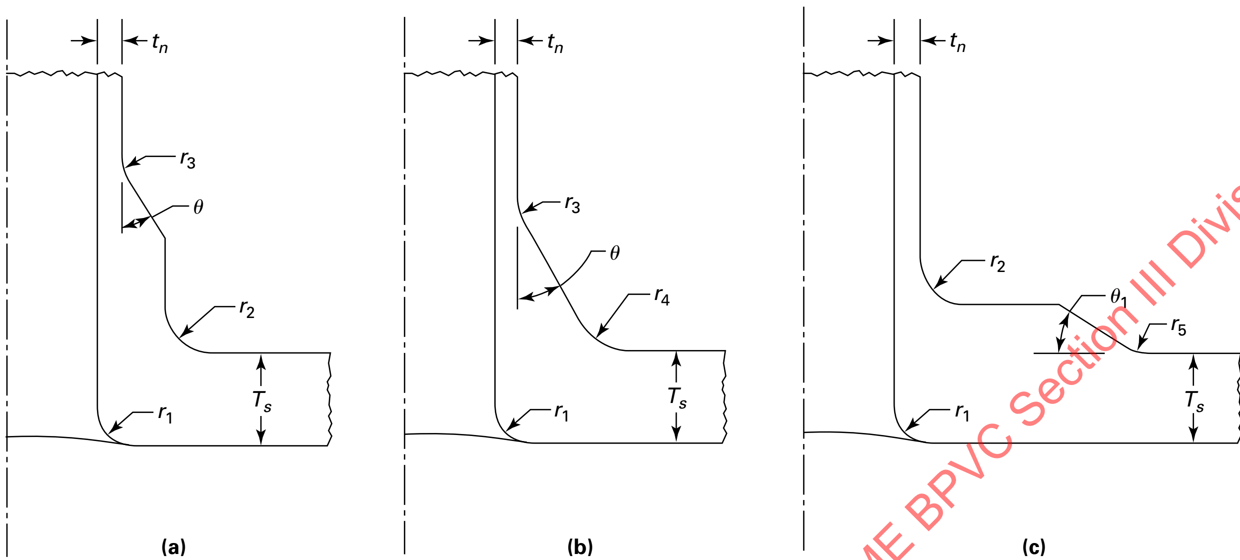
NCD-3236 Strength of Reinforcement Material

Material used for reinforcement shall preferably have the same design stress intensity value as that of the vessel wall. In no case shall material with an allowable design stress intensity value less than 80% of the value of the vessel wall material at the Design Temperature be used in determining area available for reinforcement. If the material of the nozzle wall or reinforcement has a lower design stress intensity value S_m than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NCD-3232 shall be taken as the actual area provided multiplied by the ratio of the nozzle or

Figure NCD-3234.2(a)-1
Nozzle Nomenclature and Dimensions
Depicts Configuration Only



(21) **Figure NCD-3239.1(b)-1**
Examples of Acceptable Transition Details



$r_1 = 0.1T_s$ to $0.5T_s$; $r_2 \geq$ larger of $\sqrt{dt}$ or $T_s/2$; $r_3 \geq$ larger of $\sqrt{\frac{\theta}{90}(dt)}$ or $\frac{\theta}{90}\, t_n$

$r_4 \geq$ larger of $\left(1 - \sqrt{\frac{\theta}{90}}\right)\sqrt{dt}$ or $1 - \frac{\theta}{90}\,(T_s/2)$; $r_5 = \frac{\theta_1}{90}\,T_s$; θ and θ_1 in degrees

reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcement requirement may be made if the reinforcing material or weld metal has a design stress intensity value higher than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

NCD-3237 Requirements for Nozzles With Separate Reinforcing Plates

Except for nozzles at small ends of cones reinforced in accordance with the requirements of NCD-3224.13(d), added reinforcement in the form of separate reinforcing plates may be used, provided the vessel and the nozzles meet all the conditions of (a) through (d) below.

(a) The specified minimum tensile strengths of the materials do not exceed 80 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the added reinforcement does not exceed $1\frac{1}{2}$ times the shell thickness.

(d) The requirements of NCD-3219 for pads in cyclic service are met.

NCD-3239 Alternative Rules for Opening Reinforcement

The requirements of this paragraph constitute an acceptable alternative to the rules of NCD-3231 through NCD-3237.

NCD-3239.1 Limitations. These rules are applicable only to openings utilizing nozzles in vessels within the limitations of (a) through (f) below.

(a) The nozzle is circular in cross section and its axis is perpendicular to the vessel or head.

(b) The nozzle and required reinforcing are welded integrally into the vessel with full penetration welds between all parts. Details such as those shown in Figures NCD-4266(a)-1; NCD-4266(b)-1 sketches (a), (b), and (c); and NCD-4266(c)-1 are acceptable. However, fillet welds must be ground to a radius in accordance with Figure NCD-3239.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of 1.25 $(d_1 + d_2)$ and $2.5\sqrt{Rt_r}$, but in any case, not less than 1.0 $(d_1 + d_2)$, where d_1 and d_2 are the inside diameters of the openings.

Table NCD-3239.3(a)-1
Required Minimum Reinforcing Area, A_r

Value of $d/\sqrt{Rt_r}$	Required Minimum Reinforcing Area, A_r — Nozzles in Cylinders	Required Minimum Reinforcing Area, A_r — Nozzles in Spherical Vessels or Heads
Less than 0.20	None Note (1)	None Note (1)
Greater than 0.20 and less than 0.40	$\{4.05\,[d/\sqrt{Rt_r}]^{1/2} - 1.81\}\,dt_r$	$\{5.40\,[d/\sqrt{Rt_r}]^{1/2} - 2.41\}\,dt_r$
Greater than 0.40	$0.75\,dt_r$	$dt_r \cos \Phi$ $\Phi = \sin^{-1}(d/D)$

NOTE: (1) The transition radius r_2 shown in Figure NCD-3239.1(b)-1 or equivalent, is required.

(e) The materials used in the nozzle reinforcement and vessel wall adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength
YS = specified minimum yield strength

(f) The following dimensional limitations are met:

	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Heads
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n r_2/t}$	1.5 max.	...

NCD-3239.2 Nomenclature.

A_a = available reinforcing area
A_r = required minimum reinforcing area
D = inside diameter, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
d = inside diameter of the nozzle in its corroded condition
R = inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
r = inside radius of the nozzle in its corroded condition
t = nominal wall thickness of vessel or head, less corrosion allowance
t_n = nominal wall thickness of nozzle, less corrosion allowance
t_r = wall thickness of vessel or head, computed by the equation given in NCD-3224.3 for cylindrical vessels; by NCD-3224.4 for spherical vessels or spherical heads
t_{rn} = wall thickness of nozzle, computed by the equation given in NCD-3224.3

See Figure NCD-3239.1(b)-1 for r_1, r_2, r_3, r_4, r_5, θ, and θ_1. See Figure NCD-3239.4-1 for L_c and L_n. See NCD-3239.7 for S, σ_t, σ_n, σ_r, and σ.

NCD-3239.3 Required Reinforcement Area.

(a) The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ shown in Table NCD-3239.3(a)-1.

(b) The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

NCD-3239.4 Limits of Reinforcing Zone. Reinforcing metal included in meeting the minimum reinforcing area specified in NCD-3239.3 must be located within the reinforcing zone boundary shown in Figure NCD-3239.4-1.

NCD-3239.5 Strength of Reinforcing Material Requirements. Material in the nozzle wall used for reinforcing should preferably be the same as that of the vessel wall. If material with a lower design stress intensity value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement may be taken for the increased strength of nozzle material or weld metal which has a higher design stress value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

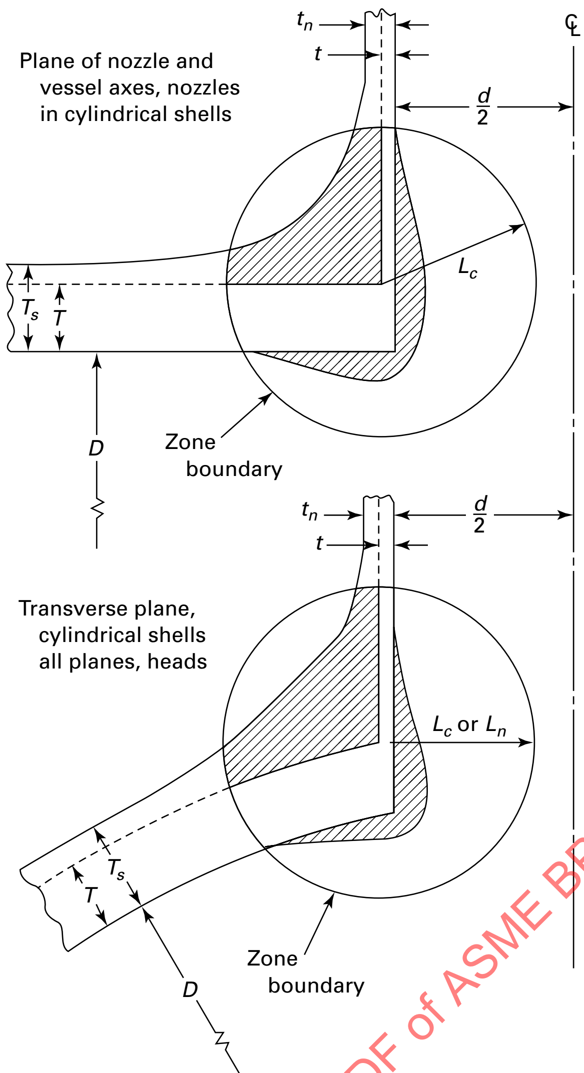
NCD-3239.6 Transition Details. Examples of acceptable transition tapers and radii are shown in Figure NCD-3239.1(b)-1. Other configurations which meet the reinforcing area requirements of NCD-3239.3 and with equivalent or less severe transitions are also acceptable, such as larger radius–thickness ratios.

NCD-3239.7 Stress Indices.

(a) The term stress index is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r under consideration to the computed stress S. The symbols for the stress components are shown in Figure NB-3338.2(a)-1 and are defined as follows:

P = service pressure, psi (MPa)
S = $P(2R + t)/2t$ for nozzles in cylindrical vessels, psi (MPa)
= $P(2R + t)/4t$ for nozzles in spherical vessels or heads, psi (MPa)
σ = the stress intensity, combined stress, at the point under consideration, psi (MPa)
σ_n = the stress component normal to the plane of the section, ordinarily the circumferential stress around the hole in the shell, psi (MPa)

(21) **Figure NCD-3239.4-1**
Limits of Reinforcing Zone



GENERAL NOTES:

(a) *Reinforcing Zone Limit*

(1) $L_c = 0.75\ (T/D)^{2/3}D$ for nozzles in cylindrical shells.

(2) $L_n = (T/D)^{2/3}(d/D\ + 0.5)D$ for nozzles in heads.

(3) The center of L_c or L_n is at the juncture of the outside surfaces of the shell and nozzles of thickness, T and t.

(4) In constructions where the zone boundary passes through a uniform thickness wall segment, the zone boundary may be considered as L_c or L_n through the thickness.

(b) *Reinforcing Area*

(1) Hatched areas represent available reinforcement area, A_a.

(2) Metal area within the zone boundary, in excess of the area formed by the intersection of the basic shells, shall be considered as contributing to the required area A_r. The basic shells are defined as having inside diameter D, thickness T, inside diameter of the nozzle d, and thickness t.

(3) The available reinforcement area, A_a, shall be at least equal to $A_r/2$ on each side of the nozzle centerline and in every plane containing the nozzle axis.

σ_r = the stress component normal to the boundary of the section, psi (MPa)

σ_t = the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi (MPa)

(b) When the conditions of NCD-3239.1 through NCD-3239.6 are satisfied, the stress indices given in Table NCD-3239.7-1 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses should be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Section III Appendices, Mandatory Appendix II, the stresses are also to be added algebraically.

NCD-3240 VESSELS UNDER EXTERNAL PRESSURE

NCD-3241 General Requirements

These rules are applicable to spherical and cylindrical shells with or without stiffening rings and to formed heads and to tubular products (NCD-4221.2). Charts for use in determining the thicknesses of these components are given in Section II, Part D, Subpart 3.

NCD-3241.1 Nomenclature. The symbols used in this Article are defined below. Except for the test condition, dimensions used or calculated shall be in the corroded condition.

Table NCD-3239.7-1
Stress Indices for Internal Pressure Loading

Nozzles in Spherical Shells and Spherical Heads		
Stress	**Inside**	**Outside**
σ_n	$2.0 - (r/R)$	$2.0 - (r/R)$
σ_t	-0.2	$2.0 - (r/R)$
σ_r	$-4t_r/(2R + t_r)$	0
σ	larger of: $2.2 - (r/R)$, or $2.0 + [4t_r/(2R + t_r)] - (r/R)$	$2.0 - (r/R)$

Nozzles in Cylindrical Shells				
	Longitudinal Plane		**Transverse Plane**	
Stress	**Inside**	**Outside**	**Inside**	**Outside**
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-2t_r/(2R + t_r)$	0	$-2t_r/(2R + t_r)$	0
σ	3.3	1.2	1.2	2.6

A = factor determined from the appropriate chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B and the Design Temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor from the charts in Section II, Part D, Subpart 3, psi (MPa)

D_o = outside diameter of the cylindrical shell course under consideration

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

L = design length of a vessel section, using the applicable definition as follows: the distance between head bend lines plus one-third of the depth of each head if there are no stiffening rings; the greatest center to center distance between any two adjacent stiffening rings; or the distance from the center of the first stiffening ring to the head bend line plus one-third of the depth of the head, all measured parallel to the axis of the vessel.

L_s = one-half of the distance from the center line 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, if any, on the other side of the stiffening ring, both measured parallel to the axis of the vessel. (A line of support is a stiffening ring that meets the requirements of this paragraph; a circumferential line on a head at one-third the depth of the head from the head bend line; a circumferential connection to a jacket.)

P = external Design Pressure, psi (MPa)

R = inside radius of spherical shells

T = minimum required thickness of the cylindrical or spherical shell or tubular product, exclusive of corrosion allowance

NCD-3242 Cylindrical Shells

NCD-3242.1 For $D_o/T \geq 10$. The minimum thickness of pipes or shell under external pressure having D_o/T values equal to or greater than 10 shall be determined by the procedure given in NCD-3133.3.

When axial compressive loadings occur in addition to the external pressure, the combined axial loading shall meet the requirements of NCD-3245.

NCD-3242.2 For $D_o/T < 10$. The minimum thickness of pipes or tubes under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below:

Step 1. Compute a value for factor A from the equation

$$A = 1.1/(D_o/T)^2$$

Step 2. Enter the appropriate chart with the calculated value of A and move vertically to the material line for the Design Temperature or to the horizontal projection of the upper end of this material line where A falls to the right of the end of the material line. From this intersection, move horizontally to the right and read the value of B.

Step 3. Using this value of B, calculate the maximum allowable pressure by the following equation:

$$P_a = \left[\frac{2.167}{D_o/T} - 0.0833\right]B$$

Step 4. If P_a is less than the external Design Pressure P, repeat the procedure using a larger value for T.

NCD-3243 Spherical Shells

The minimum thickness of a spherical shell under external pressure shall be determined by the procedure given in NCD-3133.4.

NCD-3244 Stiffening Rings for Cylindrical Shells

NCD-3244.1 Required Moment of Inertia for Circumferential Stiffening Rings. The required moment of inertia of the combined ring shell section is given by the equation:

$$I_s = \frac{D_o^2 L_s (T + A_s/L_s) A}{10.9}$$

The moment of inertia for a stiffening ring shall be determined by the procedure given in Step 1 through Step 6 below.

Step 1. Assuming that the shell has been designed and D_o, L_s, and T are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I_s. Calculate B by the equation:

$$B = \left[\frac{PD_o}{T + A_s/L_s}\right]\frac{3}{4}$$

Step 2. Enter the right hand side of the chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1.

Step 3. Move horizontally to the material line for the Design Temperature.

Step 4. From this intersection move vertically to the bottom of the chart and read the value of A.

Step 5. Compute the value of the required moment of inertia I_s from the equation given above.

Step 6. If the required I_s is greater than the computed moment of inertia for the combined ring shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is less than the computed moment of inertia for the section selected in Step 1, that section should be satisfactory.

NCD-3244.2 Permissible Methods of Attaching Stiffening Rings. Stiffening rings shall be attached to either the outside or the inside of the vessel in accordance with NCD-4267.

NCD-3245 Cylinders Under Axial Compression

The maximum allowable compressive stress in cylindrical shells subjected to loadings that produce longitudinal compressive stresses shall be the smaller of the values determined by (a) and (b) below:

(a) the S_m value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4;

(b) the value of the factor B determined in accordance with NCD-3133.6(b).

NCD-3250 WELDED JOINTS

NCD-3251 Welded Joint Categories

Welded joint categories are defined in NCD-3351.

NCD-3252 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 NCD-3352-1 shows typical butt welds for each category joint.

NCD-3252.1 Joints of Category A. All welded joints of Category A shall meet the fabrication requirements of NCD-4263 and shall be capable of being examined in accordance with NCD-5251.

NCD-3252.2 Joints of Category B. All welded joints of Category B shall meet the fabrication requirements of NCD-4264 and shall be capable of being examined in accordance with NCD-5252. When fatigue analysis of Type 2 joints is required and backing strips are not removed, stress concentration factors of 2.0 for membrane stresses and of 2.5 for bending stresses shall be applied in the design of the joints.

NCD-3252.3 Joints of Category C. All welded joints of Category C shall meet the fabrication requirements of NCD-4265 and shall be capable of being examined in accordance with NCD-5253. Minimum dimensions shall be as specified in NCD-3258.3 and NCD-3258.4.

NCD-3252.4 Joints of Category D. All welded joints of Category D shall be in accordance with the requirements of NCD-3259 and one of (a) through (d) below.

(a) Butt Welded Nozzles. Nozzles shall meet the fabrication requirements of NCD-4266(a) and shall be capable of being examined in accordance with NCD-5254. The minimum dimensions and geometrical requirements of Figure NCD-4266(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) min.
t = nominal thickness of part penetrated
t_n = nominal thickness of penetrating part

(b) Full Penetration Corner Welded Nozzles. Nozzles shall meet the fabrication requirements of NCD-4266(b) and shall be capable of being examined as required in NCD-5254. The minimum dimensions of Figure NCD-4266(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) min.
r_3 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm) whichever is less, or chamfer at 45 deg to at least $\frac{5}{16}$ in. (8 mm).
t = thickness of part penetrated
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n = thickness of penetrating part

(c) Pad and Screwed Fitting Types of Welded Nozzles. Nozzles and fittings shall meet the fabrication requirements of NCD-4266(c) and shall be capable of being examined in accordance with NCD-5254. The minimum dimensions and geometrical requirements of Figure NCD-4266(c)-1 shall be met, where

c = smaller of $0.7t_e$ or $0.7t$
r_1 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm) whichever is less
r_3 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm) whichever is less, or chamfer at 45 deg to at least $\frac{5}{16}$ in. (8 mm)
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_n = nominal thickness of neck

(d) Attachment of Nozzles Using Partial Penetration Welds. Partial penetration welds shall meet the fabrication requirements of NCD-4266(d) and shall be capable of being examined in accordance with NCD-5254. They shall be used only for attachments such as instrumentation openings and inspection openings, which are subjected to essentially no external mechanical loadings and on which there will be no thermal stresses greater than in the vessel itself. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the neck shall be used for reinforcement in the attachment. The inside diameter of such openings shall not exceed 4 in. (100 mm). The minimum dimensions of Figure NCD-4266(d)-1 shall be met where

C = maximum diametral clearance between nozzle and vessel penetration, in. (mm)
= 0.010 in. for $d \leq$ 1 in. (0.25 mm for $d \leq$ 25 mm)
= 0.020 in. for 1 in. < $d \leq$ 4 in. (0.50 mm for 25 mm < $d \leq$ 100 mm)
= 0.030 in. for $d >$ 4 in. (0.75 mm for $d >$ 100 mm), except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limit on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection.
d = outside diameter of nozzle
r_1 = $^1\!/_4 t_n$ or $^3\!/_4$ in. (19 mm) whichever is less
t = nominal thickness of vessel
t_c = $0.7t$ or $^1\!/_4$ in. (6 mm), whichever is less
t_n = nominal thickness of neck
t_w = depth of weld penetration, not less than $1^1\!/_4 t_n$, in. (mm)

NCD-3254 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NCD-4267.

NCD-3255 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NCD-3252.4.

NCD-3257 Welded Joints Subject to Bending Stress

The requirements of NCD-3357 shall be met.

NCD-3258 Design Requirements for Head Attachments

NCD-3258.1 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 NCD-3358.1(a)-1.

(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 NCD-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 $^1\!/_8$ in., whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Figure NCD-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NCD-3258.2 Unstayed Flat Head Welded to Shells. The requirements of welded unstayed flat heads to shells are given in NCD-3225, NCD-3258.3, and NCD-3258.4.

NCD-3258.3 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, the welds shall meet the requirements given in (a) through (e) below.

(a) On the cross section through the welded joint, the line 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 supported and unsupported tube sheets with a projection 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 parts.

(c) For other parts, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure parts. Examples of such parts are flat heads and supported and unsupported tubesheets without a projection for a bolted connection and the side plates of a rectangular vessel.

(d) 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 permitted.

(e) The minimum dimensions in Figures NCD-4265-1 and NCD-4265-2 are as follows:

(1) *Figure NCD-4265-1*

Sketch (a)
$a + b$ not less than $2t_s$
$b + c$ not less than t_s
t_p not less than t_s

Sketch (b)
$a + b$ not less than $2t_s$

Sketch (c)
$a + b$ not less that $3t_s$
$b + c$ not less than t_s

Sketches (d) and (e)

(-a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

b = the lesser of $t_s/2$ or $T/4$
c = $0.7t_s$ or $^1\!/_4$ in. (6 mm), whichever is less
T, t_s = nominal thickness of welded parts

(-b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

b = the lesser of t_s or $T/2$

c = $0.7t_s$ or $\frac{1}{4}$ in. (6 mm), whichever is less
T, t_s = nominal thickness of welded parts sketches (f) and (g)

(2) *Figure NCD-4265-2*
Sketch (a)
(-a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_w = the lesser of $t_n/2$ or $t/4$

(-b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$
Sketch (b)
t and t_n = nominal thickness of welded parts
h or g_1 = $0.25t_n$ but not less than $\frac{1}{4}$ in. (6 mm)
Sketch (c)
t_n = nominal thickness of neck
$a + b$ not less than $3t_n$
c not less than t_n

NCD-3258.4 Head Attachments Using Butt Welds. When flat heads are attached using butt welds, as shown in Figure NCD-4243.3-1, the minimum dimensions are as follows:

Sketch (a)

r not less than $1.5t_s$

Sketch (b)

r not less than $1.5t_s$
e not less than t_s

Sketch (c)

h not less than $1.5t_s$

Sketch (d)

t_f not less than $2t_s$
r not less than $3t_f$

Sketch (e)

t_f not less than $2t_s$
r not less than $3t_f$
e not less than t_f

NCD-3259 Design Requirements for Nozzle Attachment Welds and Other Connections

The minimum design requirements for nozzle attachment welds and other connections are set forth in (a) through (c) below.

(a) Permitted Types of Nozzles and Other Connections. Nozzles and other connections may be any of the types for which rules are given in this subarticle, provided the requirements of (1) through (7) below are met.

(1) Nozzles shall meet requirements regarding location.

(2) The attachment weld shall meet the requirements of NCD-3252.4.

(3) The requirements of NCD-3230 shall be met.

(4) Type No. 1 full penetration joints shall be used when the openings are in shells $2\frac{1}{2}$ in. (64 mm) or more in thickness.

(5) The welded joints shall be examined by the methods stipulated in NCD-5250.

(6) Studded connections shall meet the requirements of NCD-3262.4.

(7) Threaded connections shall meet the requirements of NCD-3266.

(b) Provision of Telltale Holes for Air Testing. Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one telltale hole, of maximum size $\frac{1}{4}$ in. (6 mm) pipe tap, that may be tapped for a preliminary compressed air and soap solution or equivalent 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. Telltale holes shall not be plugged during heat treatment.

(c) Attachments. Typical attachments are shown in Figure NCD-4267-1. The minimum dimensions in this figure are as follows:

$$a \geq t/4; \; b \geq t/2; \; C \geq t$$

where

c = minimum thickness of weld metal from the root to the face of the weld
t = thickness of attached member

NCD-3260 SPECIAL VESSEL REQUIREMENTS

NCD-3261 Transition Joints Between Sections of Unequal Thickness

Unless the requirements of Section III Appendices, Mandatory Appendix XIII, or Mandatory Appendix II are shown to be satisfied, a tapered transition as shown in Figures NCD-3358.1(a)-1 and NCD-3361.1-1 shall be provided at joints of Categories A and B 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). The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section. When Section III Appendices, Mandatory Appendix XIII, or Mandatory Appendix II are not used, the following requirements of (a) through (e) below shall also apply.

(a) The length of taper shall be not less than three times the offset between adjacent surfaces.

(b) Figure NCD-3361.1-1 shall apply to all joints of Categories A and B except joints connecting formed heads to main shells, for which case Figure NCD-3358.1(a)-1 shall apply.

(c) When a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(d) An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter.

(e) The requirements of this paragraph are not applicable to flange hubs.

NCD-3262 Bolted Flanged Connections

NCD-3262.1 Flanges and Flanged Fittings Conforming to ASME B16.5. Except as provided in NCD-3262.3, the dimensional requirements of flanges used in bolted flange connections to external piping shall conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings. Flanges and flanged fittings conforming to ASME B16.5 and listed in Tables 8 through 28 of that Standard, with the exception of threaded and socket welding types, may be used at the pressure–temperature ratings specified in that Standard.

NCD-3262.2 Slip-On Flanges Conforming to ASME B16.5. Slip-on flanges conforming to ASME B16.5 may be used, provided all the conditions of (a) through (e) below are met.

(a) The specified minimum tensile strengths of materials do not exceed 80.0 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the materials to which the flange is welded does not exceed $1\frac{1}{4}$ in. (32 mm).

(d) The throat thickness, taken as the minimum thickness in any direction through the attaching fillet welds, is at least 0.7 times the thickness of the material to which the flange is welded.

(e) The fatigue analysis required for nozzles with separate reinforcement and nonintegral attachments, as set forth in NCD-3219.3, is applied to the design.

NCD-3262.3 Flanges Not Conforming to ASME B16.5. Flanges that do not conform to ASME B16.5 shall be designed in accordance with the Rules for Bolted Flange Connections, Section III Appendices, Mandatory Appendix XI, or by the rules of Section III Appendices, Mandatory Appendices II and XIII.

NCD-3262.4 Studded Connections. 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 or

$$0.75d_s \times \frac{\text{Design stress intensity value of stud material at Design Temperature}}{\text{Design stress intensity value of tapped material at Design Temperature}}$$

in which d is the root diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}d_s$.

NCD-3263 Access and Inspection Openings

The requirements for access and inspection openings are given in NCD-3363.

NCD-3264 Attachments and Supports

NCD-3264.1 General Requirements. Supports, lugs, brackets, stiffeners, and other attachments may be welded or stud bolted to the outside or inside of a vessel wall. All stud bolted attachments require a detailed fatigue analysis in accordance with the requirements of Section III Appendices, Mandatory Appendix XIII unless the conditions of NCD-3219 are met. Attachments shall conform reasonably to the curvature of the shell to which they are to be attached. The fabrication requirements of NCD-4267 and the examination requirements of NCD-5250 shall be met.

NCD-3264.2 Attachment Materials. Materials welded directly to pressure parts shall meet the requirements of NCD-2190.

NCD-3264.3 Design of Attachments. The effects of attachments, including external and internal piping connections, shall be taken into account in the design. Attachments shall meet the requirements of NCD-3135.

(21) **NCD-3264.4 Design of Supports.**

(a) All vessels shall be so supported and the supporting members so arranged and attached to the vessel as to provide for the maximum imposed loadings. Wind and earthquake loads need not be assumed to occur simultaneously.

(b) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure.

(c) Horizontal vessels supported by saddles shall provide bearing extending over at least one-third of the shell circumference.

(d) Additional requirements for the design of supports are given in NCA-3211.18 and Subsection NF.

NCD-3264.5 Types of Attachment Welds. Welds attaching nonpressure parts or stiffeners to pressure parts shall meet the requirements of NCD-4267.

NCD-3264.6 Stress Values for Weld Material. Attachment weld strength shall be based on the nominal weld area and the design stress intensity values in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 and stress criteria in NCD-3200 for the weaker of the two materials joined, or, where weaker weld metal is permitted, the design stress intensity values of the weld metal multiplied by the following reduction factors: 0.5 for fillet welds NCD-3264.5; 0.75 for partial penetration groove or partial penetration groove plus fillet welds NCD-3264.5; 1.0 for complete weld penetration. The nominal weld area for fillet welds is the throat area; for groove welds, the depth of penetration times the length of weld; and for groove welds with fillet welds, the combined throat and depth of penetration, exclusive of reinforcement, times the length of weld.

(a) Attachment Welds — Evaluation of Need for Fatigue Analysis. In applying Condition AP or BP of NCD-3219.3, fillet welds and partial penetration welds are considered nonintegral attachments, except that the following welds need not be considered:

(1) welds for minor attachments

(2) welds for supports which may be considered integral as covered by Conditions A and B of NCD-3219.2

NCD-3266 Threaded Connections

(a) Threads

(1) 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 NCD-3266-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting shall be used to provide the metal thickness and number of threads required in Table NCD-3266-1 or to furnish reinforcement when required.

(2) Straight threaded connections may be employed as provided for in (b)(2).

(b) Restrictions on the Use of Threaded Connections

(1) Taper Threaded Connections. Internal taper pipe thread connections larger than NPS 2 (DN 50) shall not be used.

(2) Straight Threaded Connections

(-a) Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. Straight thread center openings in vessel heads shall meet the requirements of NCD-3230. The length of the thread shall be calculated for the opening design and they shall not exceed the smaller of one-half the vessel diameter or NPS 8 (DN 200). In addition, they shall be placed at a point where the calculated stress without a hole, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, is not more than $0.5S_m$.

(-b) Threaded connections above $2^3/_4$ in. (70 mm) in diameter may be used only if they meet the requirements of NCD-3219, or, if these requirements are not met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendix XIII.

Table NCD-3266-1
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, NPS (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
$^1/_2$ (15)	6	0.43 (11)
$^3/_{24}$ (20)	6	0.43 (11)
1 (25)	6	0.61 (16)
$1^1/_4$ (32)	6	0.61 (16)
$1^1/_2$ (40)	6	0.61 (16)
2 (50)	8	0.70 (18)

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

Service Limit	Stress Limits [Note (1)]
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	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

GENERAL NOTE: See NCD-3321 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.

NCD-3300 VESSEL DESIGN

(21) ### NCD-3310 GENERAL REQUIREMENTS

Class 2 and Class 3 vessel requirements as stipulated in the Design Specifications (NCA-3211.19) shall conform to the design requirements of this Article.

NCD-3320 DESIGN CONSIDERATIONS

NCD-3321 Stress Limits for Design and Service Loadings

Stress[14] limits for Design and Service Loadings are specified in Table NCD-3321-1. The symbols used in Table NCD-3321-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3. 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 NCD-3321-2.

NCD-3322 Special Considerations

The provisions of NCD-3120 apply.

NCD-3323 General Design Rules

The provisions of NCD-3130 apply except as modified by the rules of this subarticle. In case of conflict, this subarticle governs the design of vessels.

NCD-3324 Vessels Under Internal Pressure

NCD-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 NCD-3111 when such loadings are specified.

NCD-3324.2 Nomenclature. The symbols used in this paragraph and Figure NCD-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_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

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 NCD-3324.2-1

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 NCD-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.

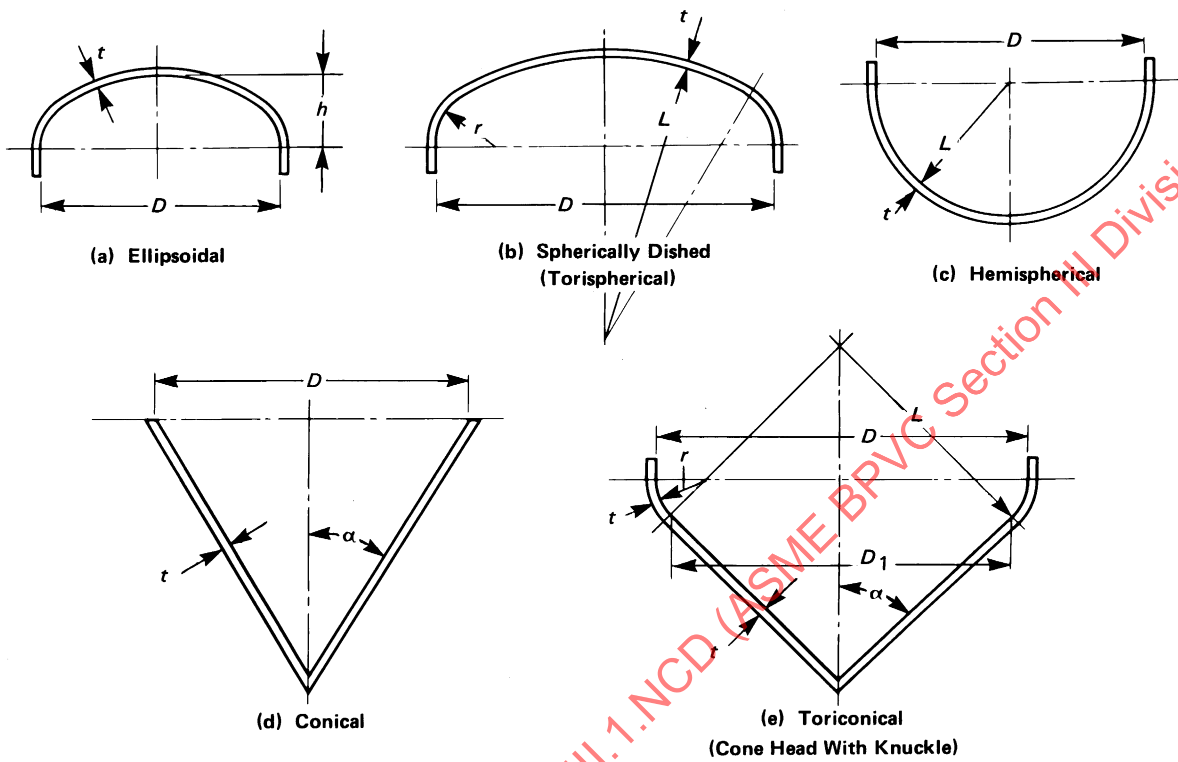
= 1 for Class 2 vessels

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)

Table NCD-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	σ_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q
			Bending	Q
	Junction with head or flange	Internal pressure	Membrane	σ_L
			Bending	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	σ_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temperature difference between shell and head	Membrane	Q
			Bending	Q
Dished head or conical head	Crown	Internal pressure	Membrane	σ_m
			Bending	σ_b
	Knuckle or junction to shell	Internal pressure	Membrane	σ_L [Note (2)]
			Bending	Q
Flat head	Center region	Internal pressure	Membrane	σ_m
			Bending	σ_b
	Junction to shell	Internal pressure	Membrane	σ_L [Note (1)]
			Bending	Q
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section)	σ_m
			Bending (averaged through width of ligament, but gradient through plate)	σ_b
			Peak	F
	Isolated or atypical ligament	Pressure	Membrane	Q
			Bending	F
			Peak	F

Figure NCD-3324.2-1
Principal Dimensions of Typical Heads



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

L = inside spherical or crown radius for torispherical and hemispherical heads

= K_1D for ellipsoidal heads in which K_1 is obtained from Table NCD-3332.2-1

L_o = outside spherical or crown radius

P = Design Pressure

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

r = inside knuckle radius

R_o = outside radius of the shell course under consideration

S = maximum allowable stress value (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

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

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

Table NCD-3324.2-1
Values of Factor *K*

D*/2*h	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*/2*h	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.

(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:

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

where

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

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

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

where

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

When t is known and P is desired

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

where

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

NCD-3324.4 Spherical Shells. (21)

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

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

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

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

NCD-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 NCD-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 NCD-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of NCD-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) 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 NCD-3325.2(b) eq. (4) or eq. (5) using $C = 0.25$.

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

(g) *For Class 3 Only*

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

(2) 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 NCD-6900.

(3) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints (NCD-4500).

NCD-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 NCD-3324.2-1.

NCD-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:

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

Table NCD-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 NCD-3324.5(d) when L equals the outside diameter of the skirt of the head.

where

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

or

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

where

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

NCD-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

$$t = \frac{PLM}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{LM + 0.2t} \qquad (1)$$

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

or

$$P = \frac{2SEt}{ML_o - t(M - 0.2)} \qquad (3)$$

where

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

Numerical values of the factor M are given in Table NCD-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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NCD-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

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

For $\alpha > 30$ deg, see NCD-3324.11(b)(5). A compression ring shall be provided when required by the rule in NCD-3324.11(b).

NCD-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 3 times the knuckle thickness shall be used when the angle α exceeds 30 deg except when the design complies with NCD-3324.11. The required thickness of the knuckle shall be determined by NCD-3324.8(b) eq. (1) in which

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

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

NCD-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

$$\left[\frac{t_s}{t}\cos\left(\alpha - \Delta\right)\right] \quad \text{or} \quad \left[\frac{t_c \cos\alpha \cos\left(\alpha - \Delta\right)}{t}\right]$$

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 $\alpha \le 30$ deg. When $\Delta \ge \alpha$, no reinforcement at the junction is required [Tables NCD-3324.11(b)(2)-1 and NCD-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 NCD-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 NCD-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 NCD-3324.

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

(6) A reducer may be a simple conical shell section [Figure NCD-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 NCD-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.

(8) Reverse curve reducers [Figure NCD-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 $\alpha \le 30$ deg. In (5) below, provision is made for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where $\alpha > 30$ 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 NCD-3324.11(b)(2)-1, using the appropriate ratio P/SE, is less than α. Interpolation may be made in the Table.

(-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:

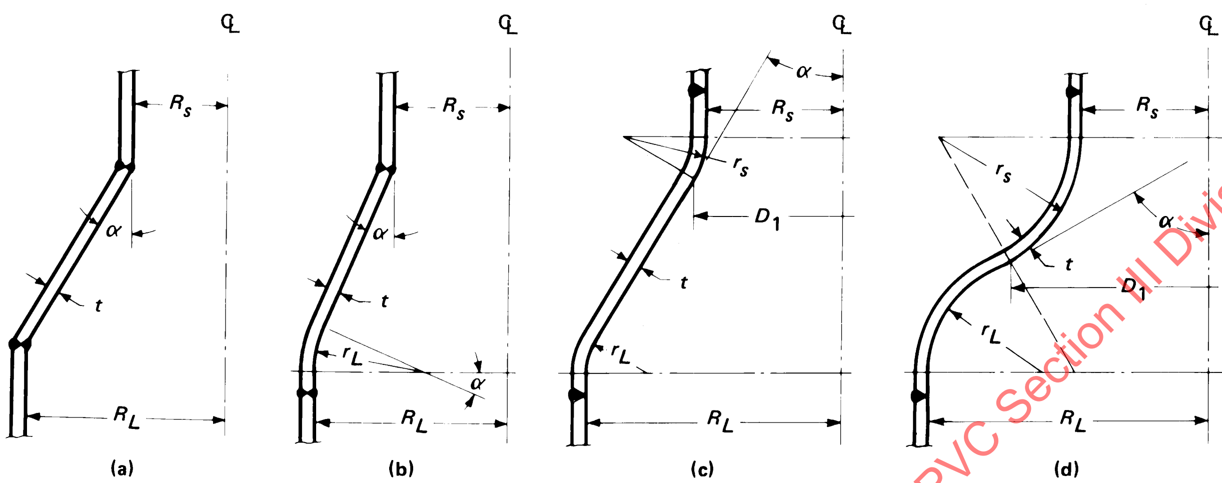
$$A_e = 4t_e\sqrt{R_L t_s}$$

(-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 NCD-3324.11(b)(3)-1, using the appropriate ratio P/SE, is less than α.

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

Figure NCD-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.

Table NCD-3324.11(b)(2)-1
Values of Δ for Junctions at the Large Cylinder for α ≤ 30 deg

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

NOTE: (1) Δ = 30 deg for greater values of P/SE.

Table NCD-3324.11(b)(3)-1
Values of Δ for Junctions at the Small Cylinder for α ≤ 30 deg

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

NOTE: (1) Δ = 30 deg for greater values of P/SE.

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

(-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:

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

(-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.

(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 3*SE*.

(-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.

NCD-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 NCD-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 nominal wall thickness of standard wall pipe listed in ASME B36.10M less 12.5% plus the corrosion allowance on the connection. For diameters other than those listed in ASME B36.10M, nominal wall shall be based on the next larger pipe size; for nozzles larger than the largest pipe size included in ASME B36.10M, the nominal wall shall be based on largest size listed.

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

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

NCD-3324.14 Consideration of Standard Reinforcement.

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NCD-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NCD-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 NCD-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 NCD-3321-1 for a given condition.

NCD-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 NCD-3111 other than pressure and temperature.

NCD-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 noncircular heads and covers. Some acceptable types of flat heads and covers are shown in Figure NCD-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.

Special consideration shall be given to the design of shells, nozzle necks, or flanges to which noncircular heads or covers are attached.

NCD-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 NCD-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 NCD-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 Section III Appendices, Mandatory Appendix XI, 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 NCD-3325-1 sketches (a) and (c)

m = the ratio t_r/t_s; dimensionless

P = Design Pressure

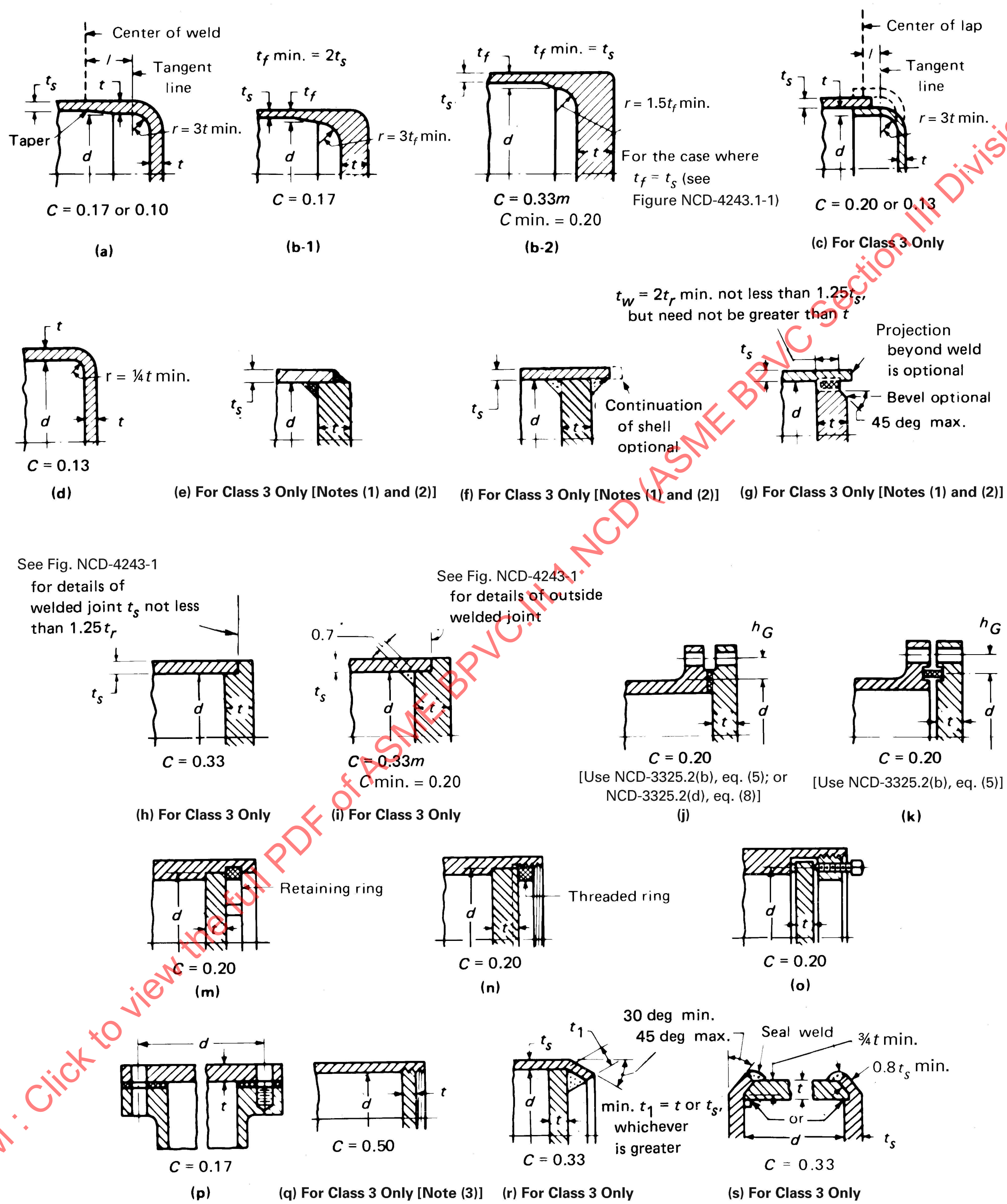
r = inside corner radius on a head formed by flanging or forging

S = maximum allowable stress value, from Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

t = minimum required thickness of flat head or cover, exclusive of corrosion allowance

t_1 = throat dimension of the closure weld, as indicated in Figure NCD-3325-1 sketch (r)

Figure NCD-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 NCD-3325 are acceptable.

Figure NCD-3325-1
Some Acceptable Types of Unstayed Flat Heads and Covers (Cont'd)

NOTES:
(1) Circular covers, $C = 0.33m$, C min. = 0.20.
(2) Noncircular covers, $C = 0.33$.
(3) When pipe threads are used, see Table NCD-3361.2.2-1.

t_f = actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Figure NCD-3325-1 sketches (b-1) and (b-2)

t_h = actual thickness of flat head or cover, exclusive of corrosion allowance

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 NCD-3325-1 sketch (g)

W = total bolt load, given for circular heads for Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4)

Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span (NCD-3325.2), dimensionless

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

NOTE: The equations provide structural integrity as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

(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 through 8 of that Standard, when of the types shown in Figure NCD-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)

$$t = d\sqrt{CP/S} \tag{4}$$

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

$$t = d\sqrt{CP/S + 1.27\,Wh_G/Sd^3} \tag{5}$$

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 Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (3) shall be used. For gasket seating, P equals zero and the values of S at atmospheric temperature and W from Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (4) shall be used.

(c) For Class 3 vessels only, 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)

$$t = d\sqrt{ZCP/S} \tag{6}$$

where

$$Z = 3.4 - \frac{2.4d}{D} \tag{7}$$

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

(d) For Class 3 vessels only, (c) eq. (6) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [Figure NCD-3325-1 sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

$$t = d\sqrt{ZCP/S + 4\,Wh_G/SLd^2} \tag{8}$$

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

NCD-3325.3 Values of C. For the types of construction shown in Figures NCD-3325-1, NCD-4243.1-1, NCD-4243.1-2, and NCD-4243.3-1, the minimum values of C to be used in NCD-3325.2(b) eqs. (4) and (5), NCD-3325.2(c) eq. (6), and NCD-3325.2(d) eq. (8) are given in (a) through (q) below.

(a) In sketch (a), $C = 0.17$ for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

(1) $C = 0.10$ for circular heads, when the flange length 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

$$t_s = 1.12 t_h \sqrt{1.1 - l / \sqrt{d t_h}}$$

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 noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Article NCD-4000.

(c) In sketch (b-2), C = 0.33m but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than 1.5 times the flange thickness, and the welding meets all the requirements for circumferential joints given in Article NCD-4000. [See Figure NCD-4243.3-1 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 NCD-3358 are met. This sketch is for Class 3 vessels only.

(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 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least 0.7t_s. The size of the weld t_w in sketch (g) shall be not less than 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. These sketches are for Class 3 vessels only.

(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 NCD-3358.3(g) and Figure NCD-4243.2-1 sketches (a) through (g). This sketch is for Class 3 vessels only.

(h) In sketch (i), C = 0.33m but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of 0.7t_s is used and the details of the outside weld conform to the requirements of NCD-3358.3(g) and Figure NCD-4243.2-1 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. This sketch is for Class 3 vessels only.

(i) In sketches (j) and (k), C = 0.20 for or Class 2 circular heads and Class 3 circular heads, noncircular heads, and bolted to the vessel as indicated in the figures. Noncircular heads and covers bolted to the vessel are not permitted for Class 2 vessels. Note that NCD-3325.2(b) eq. (5) or NCD-3325.2(d) eq. (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

$$d \sqrt{1.27\, W h_G / S d^3}$$

for circular heads and covers, nor less than

$$d \sqrt{4\, W h_G / S L d^2}$$

for noncircular heads and covers.

(j) In sketches (m), (n), and (o), C = 0.20 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 NCD-3361.2.2 shall also be met. Seal welding may be used, if desired. This sketch is for Class 3 vessels only.

(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. This sketch is for Class 3 vessels only.

(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 $P = S/5d$. This sketch is for Class 3 vessels only.

(o) In Figure NCD-4243.3-1, $C = 0.33m$ but is not less than 0.20 when the dimensional requirements of NCD-3358.4 are met.

(p) In Figure NCD-4243.1-1, sketches (b), (c), (e), and (f), $C = 0.33m$ but is not less than 0.20 when the dimensional requirements of NCD-3358.3 are met. These sketches are for Class 2 vessels only.

(q) In Figure NCD-4243.1-2, sketches (a) and (b), $C = 0.33m$ but is not less than 0.20 when the dimensional requirements of NCD-3358.3 are met. These sketches are for Class 2 vessels only.

NCD-3326 Spherically Dished Covers With Bolting Flanges

NCD-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 NCD-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 included

NOTE: 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.

P = Design Pressure

r = inside knuckle radius

S = maximum allowable stress value

T = flange thickness

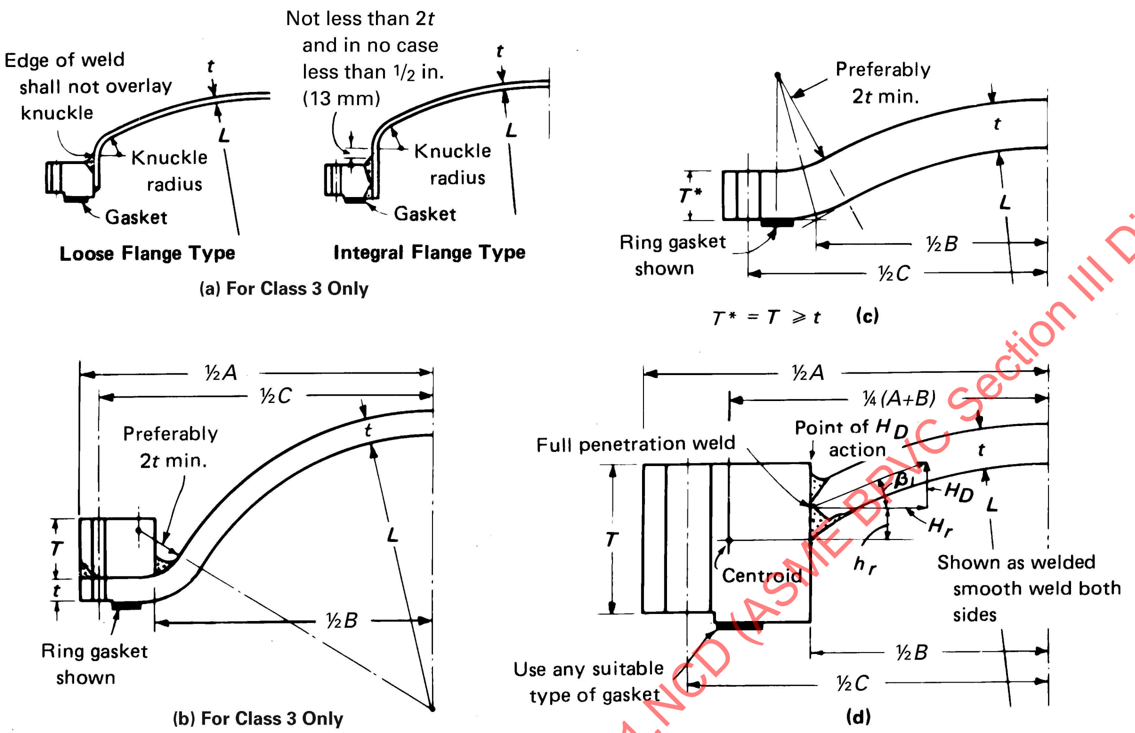
t = minimum required thickness of head plate after forming

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

$$\beta_1 = \arcsin\left(\frac{B}{2L + t}\right)$$

NCD-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 NCD-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 NCD-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.

Figure NCD-3326.1-1
Spherically Dished Covers With Bolting Flanges



(a) *Heads of the Type Shown in Figure NCD-3326.1-1 Sketch (a).* This sketch is for Class 3 only.

(1) The thickness of the head t shall be determined by the appropriate equation in NCD-3324.

(2) The head radius L or the knuckle radius r shall not exceed the limitations given in NCD-3324.

(3) The flange shall comply at least with the requirements of Section III Appendices, Mandatory Appendix XI, Figure XI-3120-1 and shall be designed in accordance with the applicable provisions of Section III Appendices, Mandatory 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.

(b) *Heads of the Type Shown in Figure NCD-3326.1-1 Sketch (b).* This sketch is for Class 3 only.

(1) Head thickness

$$t = \frac{5PL}{6S}$$

(2) Flange thickness T

(-a) For ring gasket

$$T = \sqrt{\frac{M_o}{SB}\left(\frac{A + B}{A - B}\right)}$$

(-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 NCD-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 (2)(-a) eq. (11) for round bolting holes or by (2)(-b) eq. (13) for bolting holes slotted through the edge of the head [see (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 NCD-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

$$F = \frac{PB\sqrt{4L^2 - B^2}}{8S(A - B)} \quad (17)$$

$$J = \left(\frac{M_o}{SB}\right)\left(\frac{A + B}{A - B}\right) \quad (18)$$

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 Section III Appendices, Mandatory Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

NCD-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.

NCD-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.

NCD-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 NCD-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.

NCD-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.

NCD-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.

NCD-3329 Ligaments, Braced and Stayed Surfaces, Staybolts

NCD-3329.1 Ligaments.

(a) The symbols used in the equations and chart of this paragraph are defined as follows:

d = diameter of tube holes
n = number of tube holes in length p_1
p = longitudinal pitch of tube holes
p' = diagonal pitch of tube holes
p_1 = unit length of ligament

(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 NCD-3329.1(b)-1 through NCD-3329.1(b)-3, the efficiency of the ligaments between the tube holes shall be determined by (1) or (2) below:

(1) when the pitch of the tube holes on every row is equal [Figure NCD-3329.1(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 NCD-3329.1(b)-2 and NCD-3329.1(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 NCD-3329.1(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure NCD-3329.1(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 NCD-3329.1(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 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.

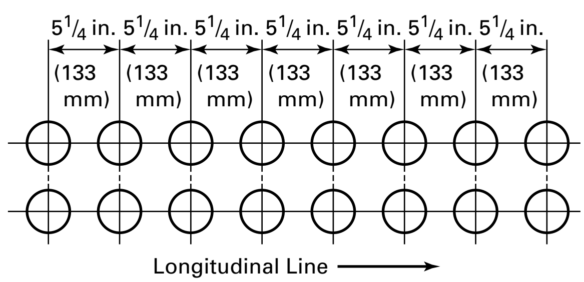
(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.

NOTE: These rules 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 (e). When this occurs, the efficiencies computed by the rules under (b) shall govern.

(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.

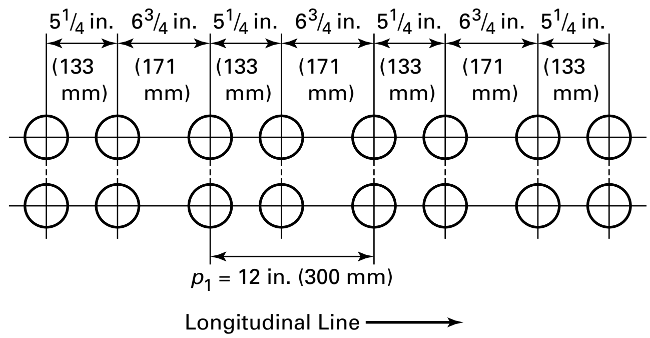
(2) For a length equal to the inside radius of the shell for the position that gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (750 mm), the length shall be taken as 30 in. (750 mm) in applying this rule.

Figure NCD-3329.1(b)-1
Example of Tube Spacing With Pitch of Holes Equal in Every Row



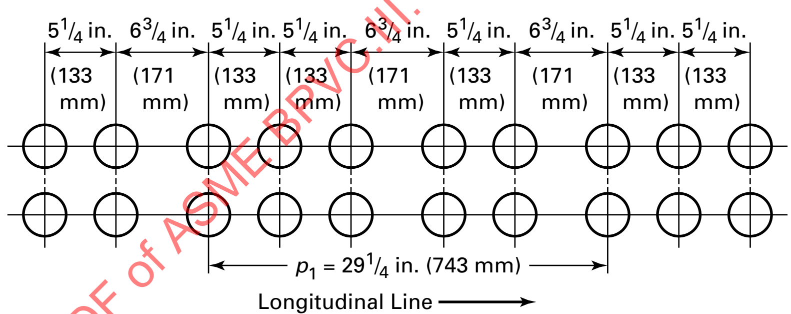
GENERAL NOTE: $5^1/_4$ in. = 133 mm

Figure NCD-3329.1(b)-2
Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row



GENERAL NOTES:
(a) $5^1/_4$ in. = 133 mm
(b) $6^3/_4$ in. = 171 mm
(c) 12 in. = 300 mm

Figure NCD-3329.1(b)-3
Example of Tube Spacing With Pitch of Holes Varying in Every Second and Third Row



GENERAL NOTES:
(a) $5^1/_4$ in. = 133 mm
(b) $6^3/_4$ in. = 171 mm
(c) $29^1/_4$ in. = 743 mm

Figure NCD-3329.1(d)-1
Example of Tube Spacing With Tube Holes on Diagonal Lines

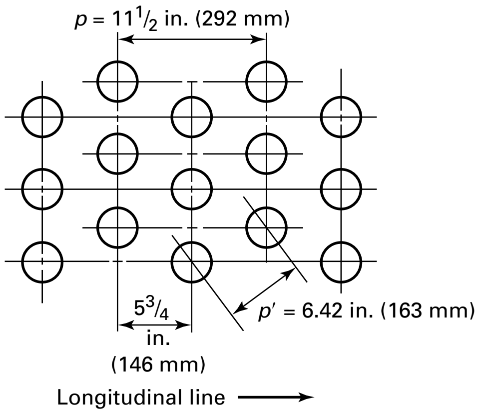
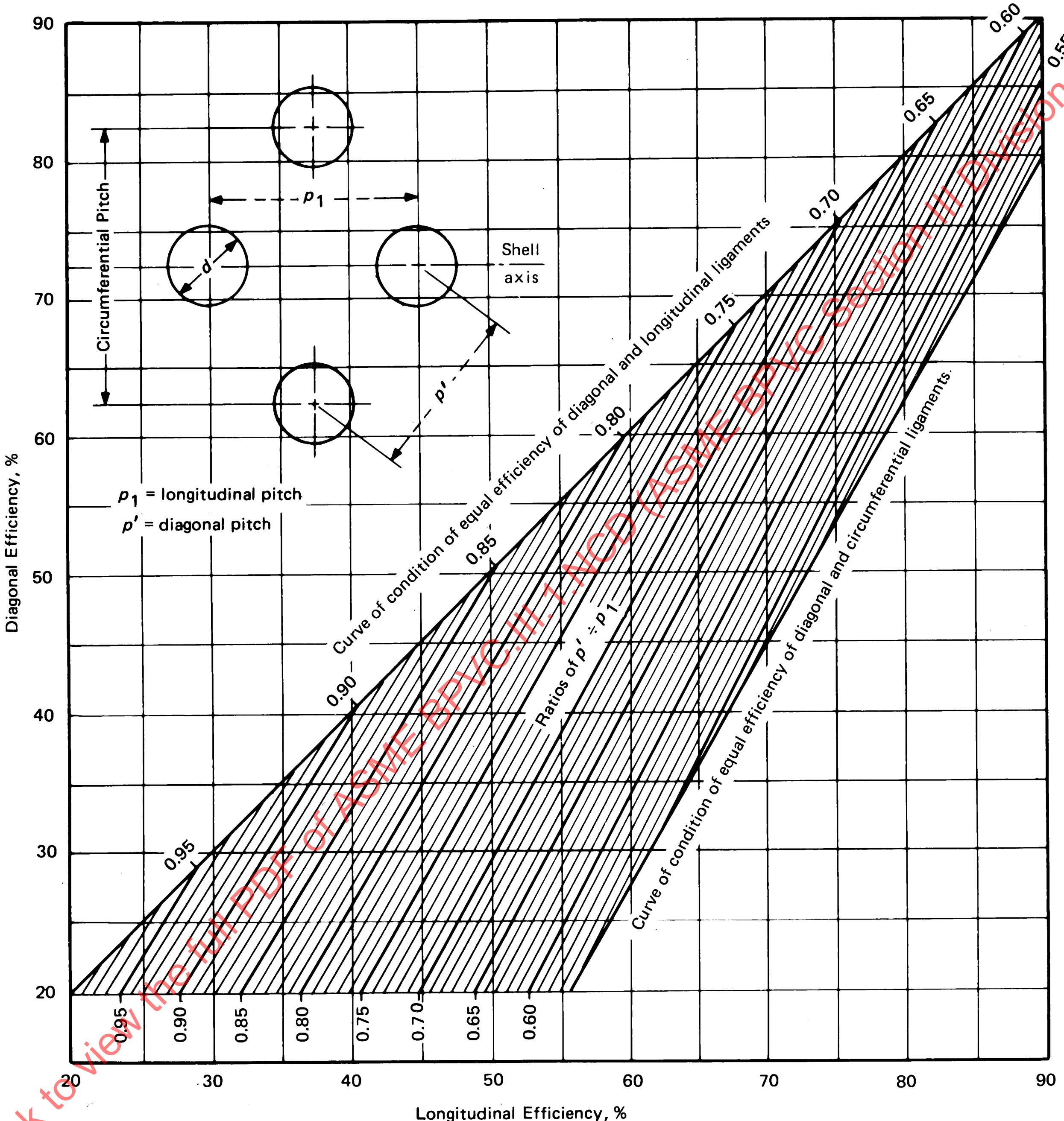


Figure NCD-3329.1(d)-2
Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells



(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 NCD-3329.1(g)-1.

NCD-3329.2 For Class 3 Only.

NCD-3329.2.1 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:

$$t = p\sqrt{\frac{P}{SC}} \qquad (19)$$

$$P = \frac{t^2 SC}{p^2} \qquad (20)$$

where

C = 2.1 for welded stays or stays screwed through plates not over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.2 for welded stays or stays screwed through plates over $^7/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.5 for stays screwed through plates and fitted with single nuts outside of plate or with inside and outside nuts, omitting washers
= 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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

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 $^5/_{16}$ in. (8 mm) except for welded construction (NCD-3329.2.3).

(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 (NCD-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 NCD-3329.2.1-1.

(f) The maximum pitch shall be $8^1/_2$ 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.

NCD-3329.2.2 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.

NCD-3329.2.3 Welded Stayed Construction. For welded stayed construction, the provisions of NCD-4470 and NCD-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 NCD-4470-1.

(2) The required thickness of the plate shall not exceed $1^1/_2$ in. (38 mm) but, if greater than $^3/_4$ in. (19 mm), the staybolt pitch shall not exceed 20 in. (500 mm).

(3) The provisions of NCD-3329.2.1 and NCD-3329.2.4 shall be met.

(4) The required area of the staybolt shall be determined in accordance with NCD-3329.2.5.

(b) Welded stays, as shown in Figure NCD-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).

Figure NCD-3329.1(g)-1
Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments

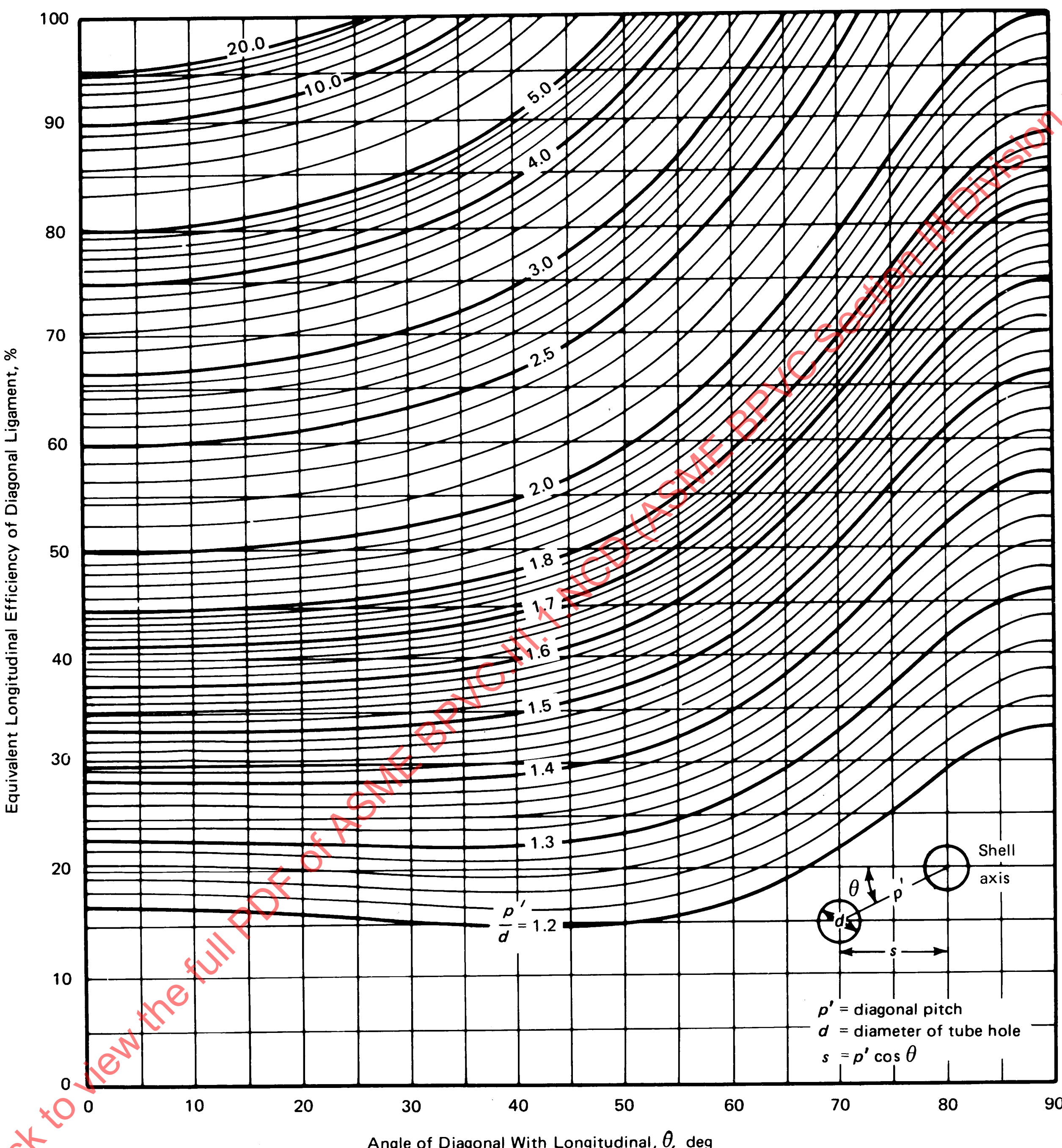
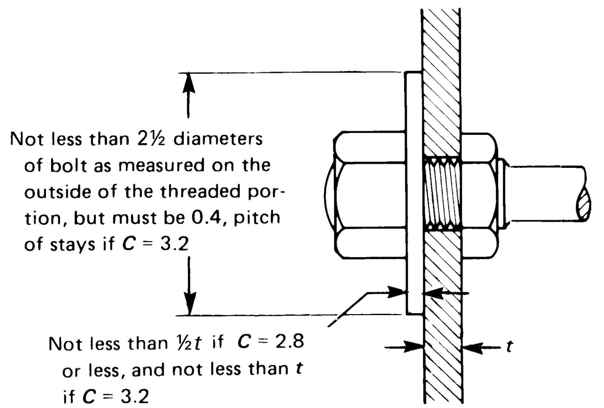


Figure NCD-3329.2.1-1
Acceptable Proportions for Ends or Through Stays



(2) The required thickness of the plate does not exceed $^1/_2$ 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 NCD-3356.1(c).

(6) The maximum diameter or width of the hole in the plate does not exceed $1^1/_4$ 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 NCD-3329.2.1(a), using

C = 2.1 if either plate is not over $^7/_{16}$ in. (11 mm) thick
C = 2.2 if both plates are over $^7/_{16}$ 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 NCD-4470-1 and is calculated in accordance with NCD-4470.

(3) The maximum allowable pressure of the dimpled or embossed components is established in accordance with the requirements of NCD-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.

NCD-3329.2.4 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.

NCD-3329.2.5 Dimensions of Staybolts. (21)

(a) The required area of a staybolt at its minimum cross section and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt, computed in accordance with (b) below, by the allowable stress for the material used (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3) and multiplying the result by 1.10.

NOTE: The minimum cross section is usually at the root of the thread.

(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.

NCD-3330 OPENINGS AND REINFORCEMENT[15]

NCD-3331 General Requirements for Openings

(a) Openings[16] in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround.[17] 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.

(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 NCD-6900.

(c) See below.

(1) The rules for reinforcement of openings given in NCD-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 $^{1}/_{2}r$ 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 NCD-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 NCD-3330 apply to the finished dimensions, excluding material added as corrosion allowance.

(e) Any type of opening may be located in a welded joint.

NCD-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NCD-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).

NCD-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 with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure NCD-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 NCD-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 NCD-3332.2-1.

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

NCD-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 NCD-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 NCD-3332.2 when the shell is subject to internal pressure.

NCD-3332.4 Reinforcement for Internal and External Pressure. Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of NCD-3332.2 for internal pressure and of NCD-3332.3 for external pressure.

NCD-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

$$A = 0.5\, d t_r$$

where d is as defined in NCD-3332.2 and t_r is the thickness, which meets the requirements of NCD-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 NCD-3325.2(b) eq. (4), by using 2C or 0.75 in place of C, whichever is less;

(2) in NCD-3325.2(b) eq. (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 NCD-3325.1, shall be designed as follows.

Figure NCD-3332.2-1
Chart for Determining Value of *F*

Table NCD-3332.2-1
Values of Spherical Radius Factor K_1

$D/2h$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_1	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius = K_1D; $D/2h$ = axis ratio. Interpolation is permitted for intermediate values.

(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 NCD-3325-1 sketches (a), (b-1), (b-2), (d), or (g), the head shall be designed according to Section III Appendices, Mandatory Appendix XIX and related parts of Section III Appendices, Mandatory Appendix XI. The required head thickness does not have to be calculated according to NCD-3325 since the head thickness that satisfies all the requirements of Section III Appendices, Mandatory Appendix XIX also satisfies the intent of NCD-3325. 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 NCD-1110(c) shall be met.

NCD-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.

NCD-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 of shell or head, t is the nominal vessel wall thickness, in., r is the radius 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.

NCD-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) $2^1/_2$ times the nominal shell thickness less corrosion allowance;

(b) $2^1/_2$ 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.

NCD-3335 Metal Available for Reinforcement

NCD-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, (NCD-3334)

A_2 = area in excess thickness in the nozzle wall available for reinforcement, (NCD-3334)

d = diameter in the plane under consideration of the finished opening in its corroded condition (NCD-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

= for Class 2 only, the joint efficiency obtained from NCD-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 NCD-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 NCD-3335.1(b)-1]

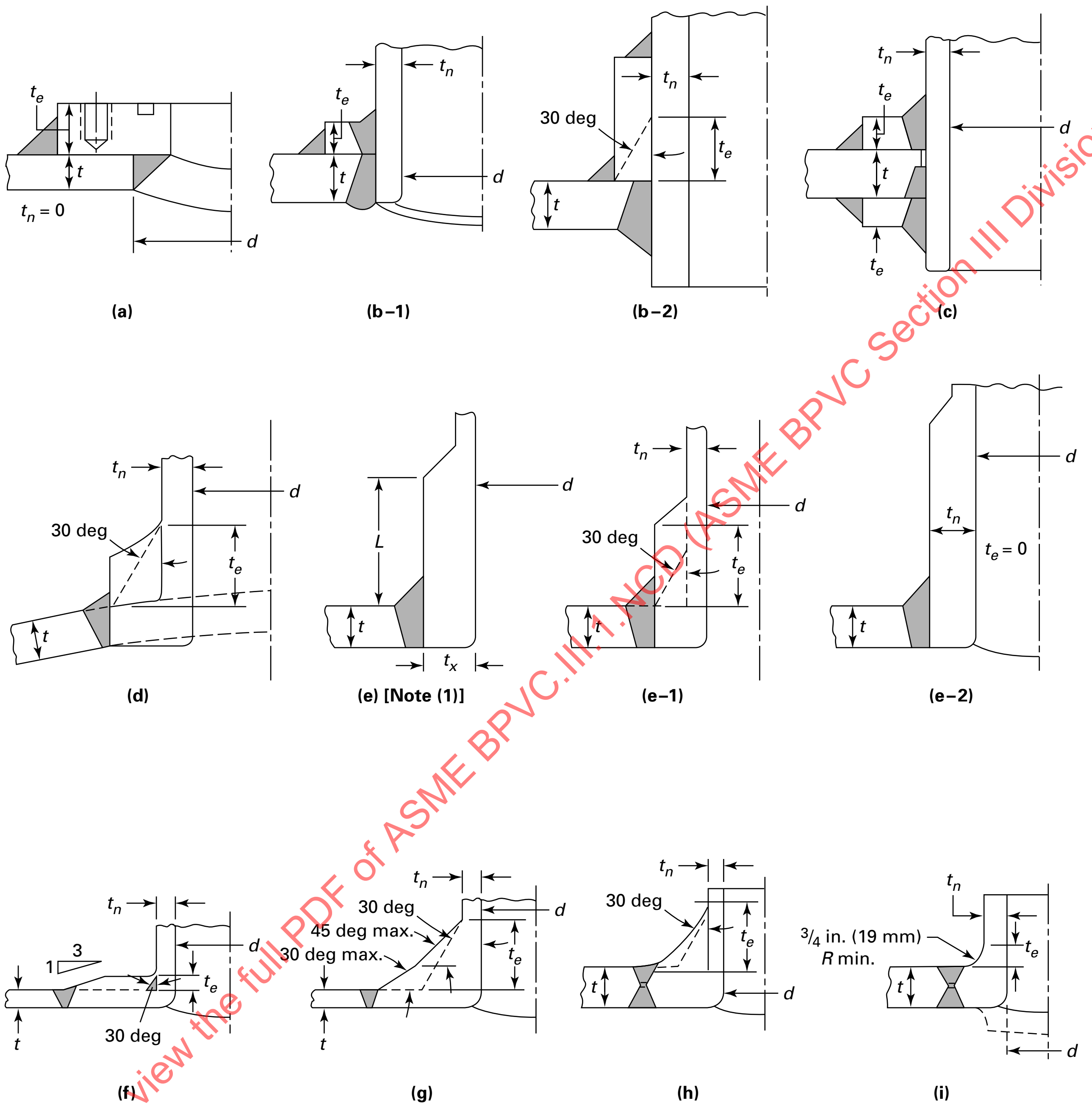
t_n = nominal thickness of nozzle wall, less corrosion allowance

t_r = required thickness of a seamless shell or head as defined in NCD-3332.2

t_{rn} = required thickness of a seamless nozzle wall

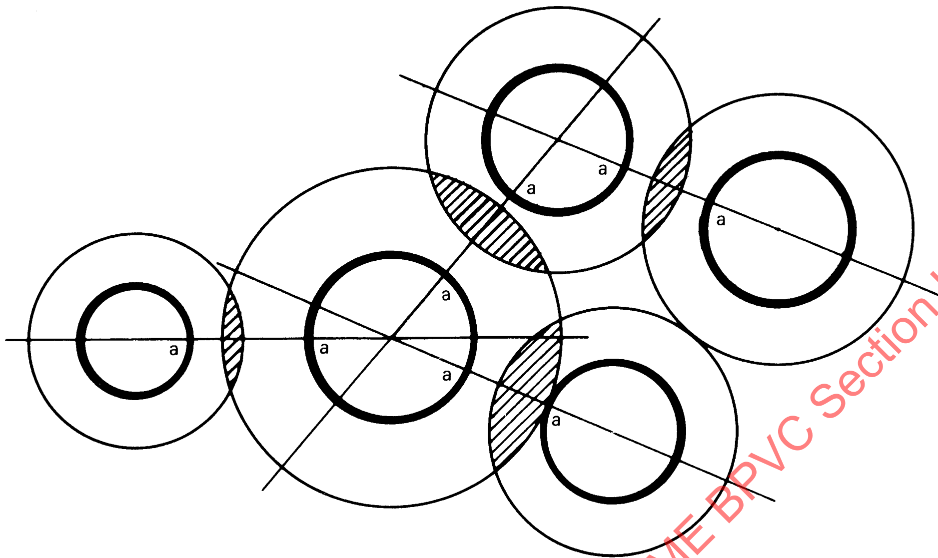
(d) metal added as reinforcement and metal in attachment welds.

Figure NCD-3335.1(b)-1
Some Representative Configurations Describing the t_e Reinforcement Dimension



NOTE: (1) If $L < 2.5t_x$, use sketch (e-1). If $L \geq 2.5t_x$, use sketch (e-2).

Figure NCD-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.

NCD-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 NCD-3335.2-1), in accordance with NCD-3330 through NCD-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 $1^1/_3$ 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 $1^1/_3$ 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.

(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 NCD-3361.

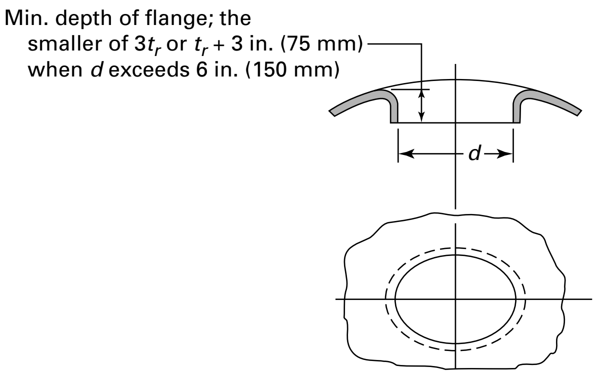
(d) When a series of two or more openings in a pressure vessel are arranged in a regular pattern, reinforcement of the openings may be provided in accordance with the requirements of NCD-3329.1.

NCD-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 NCD-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 in.) (t_r + 75 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 NCD-3335.3(b)-1].

Figure NCD-3335.3(b)-1
Minimum Depth for Flange of Flued Openings



(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with NCD-3363.7.

NCD-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 than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NCD-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.

NCD-3336.1 Strength of Weld. On each side of the plane defined in NCD-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 NCD-3332 less the strength in tension of the reinforcing area that is integral in the vessel wall.

NCD-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 NCD-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.

NCD-3350 DESIGN OF WELDED CONSTRUCTION

NCD-3351 Welded Joint Categories

The term *Category* defines the location of a joint in a vessel but not the type of joint. The categories established are for use in specifying special requirements regarding joint type and degree 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 NCD-3351-1 illustrates typical joint locations included in each category.

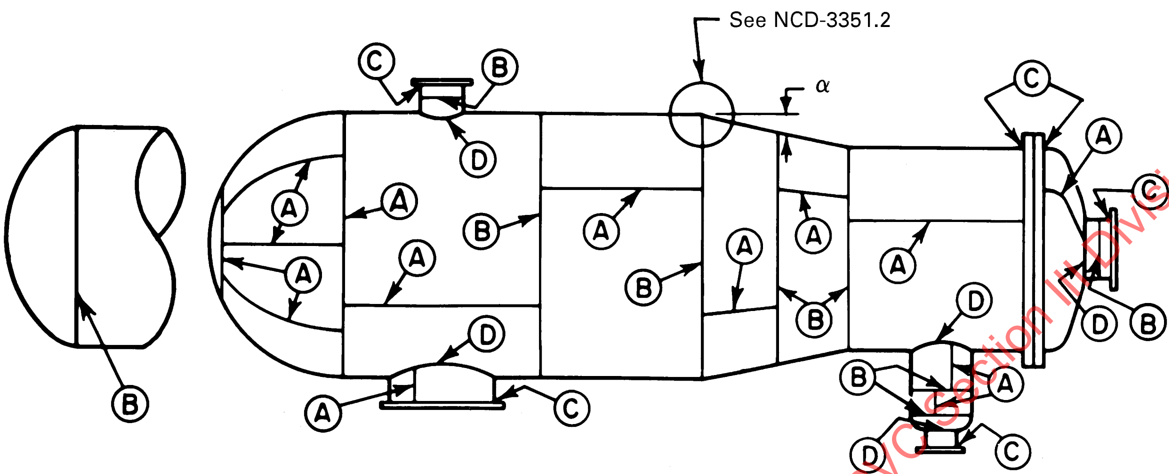
NCD-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,[18] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[19] of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

NCD-3351.2 Category B. Category B comprises circumferential welded joints within the main shell, communicating chambers,[18] 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.

NCD-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;[18] any welded joint connecting one side plate[19] to another side plate of a flat sided vessel.

NCD-3351.4 Category D. Category D comprises welded joints connecting communicating chambers[18] 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.

Figure NCD-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D



NCD-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 NCD-3352-1 shows typical butt welds for each category joint.

NCD-3352.1 Joints of Category A. All welded joints of Category A as defined in NCD-3351 shall meet the fabrication requirements of NCD-4241 and shall be capable of being examined in accordance with NCD-5210. The joint efficiency, E, shall not exceed that given in (a) through (e) below. For Class 2 vessels, the value of E is 1.00.

(a) When the butt weld is fully radiographed in accordance with NCD-5211.2(a)(1), 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 NCD-5211.2(a)(2), 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 NCD-5211.2(a)(3), 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 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 Section III Appendices, Mandatory Appendix XI, Article XI-3000, XI-3130 or for calculating the thickness of braced and stayed surfaces for NCD-3329.2.1(a) eqs. (19) and (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.

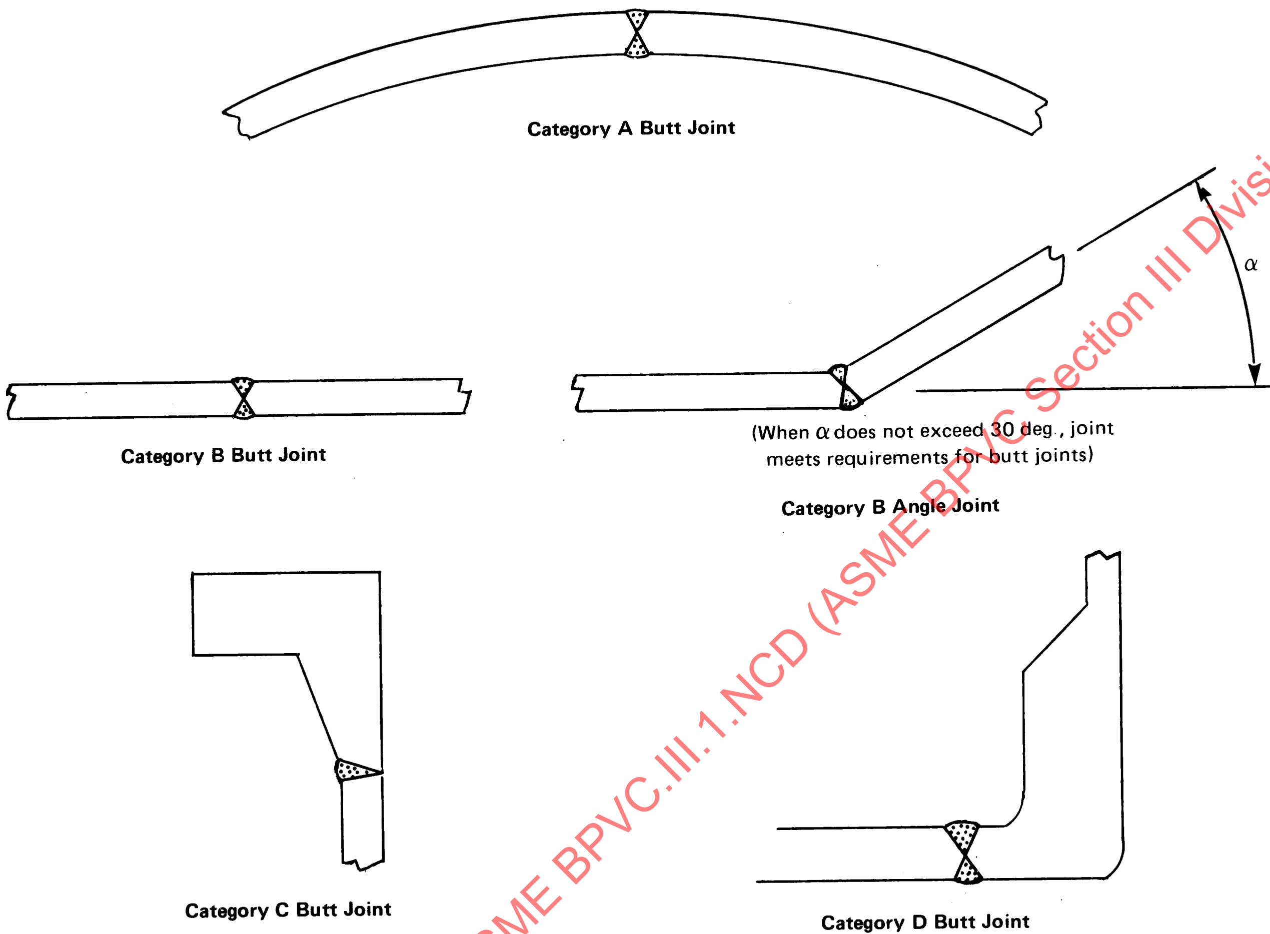
(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category A shall be Type 1 or Type 2.

NCD-3352.2 Joints of Category B. All welded joints of Category B as defined in NCD-3351 shall meet the fabrication requirements of NCD-4242 and shall be capable of being examined in accordance with NCD-5220. The joint efficiency E, shall not exceed that given in (a) through (e) below. For Class 2 vessels, the value of E is 1.00.

(a) When the butt weld is fully radiographed, the design provisions of NCD-3352.1(a) shall apply.

(b) When the butt weld is partially radiographed as allowed by NCD-5221.2(b) or when the vessel section or part is spot radiographed in accordance with NCD-5221.2(c), the value of E used in the longitudinal stress calculations shall be as stated in NCD-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 NCD-3329.2.1(a) eqs. (19) and (20).

Figure NCD-3352-1
Typical Butt Joints



(c) When the vessel section or part is neither fully radiographed, partially radiographed, nor spot radiographed, the design provisions of NCD-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.

NCD-3352.3 Joints of Category C. All welded joints of Category C as defined in NCD-3351 shall meet the fabrication requirements of NCD-4243 and shall be capable of being examined in accordance with NCD-5230. The design for attaching flanged heads shall meet the requirements of NCD-3358. The design requirements of Category C butt welds are given in (a) through (e) below. For Class 2 vessels, the value of *E* is 1.00.

(a) When a Category C butt weld is fully radiographed, the design provisions of NCD-3352.1(a) shall apply.

(b) When a Category C butt weld is spot radiographed, the design provisions of NCD-3352.2(b) shall apply.

(c) When a Category C butt weld is not radiographed, the design provisions of NCD-3352.1(c) shall apply.

(d) When a Category C corner joint is used, the design requirements of NCD-3325 and the dimensional requirements of Figure NCD-4243.1-1 for Class 2 vessels or Figure NCD-4243.2-1 for Class 3 vessels, specified in NCD-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.

NCD-3352.4 Joints of Category D. All welded joints of Category D as defined in NCD-3351 shall be in accordance with the requirements of NCD-3359 and one of (a) through (h) below.

(a) Butt-Welded Attachments. Nozzles shall meet the fabrication requirements of NCD-4244.1(a) for Class 2 vessels or NCD-4244.2(a) for Class 3 vessels and shall be capable of being examined in accordance with

NCD-5241. The minimum dimensions and geometrical requirements of Figure NCD-4244.1-1 shall be met, where

r_1 = $^1/_4 t$ or $^3/_4$ in. (19 mm), whichever is less
r_2 = $^1/_4$ 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 NCD-4244.1(b) for Class 2 vessels or NCD-4244.2(b) for Class 3 vessels and shall be capable of being examined as required in NCD-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 $^1/_2 t_{\min}$. The minimum dimensions of Figure NCD-4244.1-2 shall be met, where

r_1 = $^1/_4 t$ or $^3/_4$ in. (19 mm), whichever is less
r_2 = $^1/_4$ in. (6 mm) minimum
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_e = thickness of reinforcing element
$t_{\min}$ = the lesser of $^3/_4$ 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 NCD-4244.1(c) for Class 2 vessels or NCD-4244.2(c) for Class 3 vessels and shall be capable of being examined in accordance with NCD-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 NCD-4244.1-3 shall be met, where

r_1 = $^1/_4 t$ or $^3/_4$ in. (19 mm), whichever is less
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $^1/_4$ 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 $^3/_4$ in. (19 mm), whichever is less.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds shall meet the requirements of NCD-4244.1(d) for Class 2 vessels or NCD-4244.2(d) for Class 3 vessels. Typical details are shown in Figure NCD-4244.1-4. 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 $^1/_2 t_{\min}$. 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 NCD-4244.1-4].

(-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 NCD-4244.1-4, 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 NCD-4244.1-4, sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of NCD-5241.

(2) The minimum dimensions of Figure NCD-4244.1-4 shall be met, where

c = $^1/_2 t_{\min}$
t = nominal thickness of part penetrated
t_1 *or* t_2 = not less than the lesser of $^1/_4$ in. (6 mm) or $0.7t_{\min}$
$t_1 + t_2$ = $1^1/_4 t_{\min}$
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_e = thickness of reinforcement element
$t_{\min}$ = the lesser of $^3/_4$ 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)

(e) Attachment of Fittings With Internal Threads. (Written for fittings with internal threads but also applicable to externally threaded and socket-welded or butt-welded fittings.) 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 NCD-4244.1(e) for Class 2 vessels or NCD-4244.2(e) for Class 3 vessels shall be met. The minimum weld dimensions shall be as shown in Figure NCD-4244.1-5 where

t_{min} = lesser of $^3/_4$ in. (19 mm) or the thickness of the parts joined
t_c = $^1/_4$ in. (6 mm), minimum

(2) Fittings shown in Figure NCD-4244.1-5 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 NCD-3359.

(3) See below.

(-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 $^3/_8$ in. (10 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Figure NCD-4244.1-6. These openings do not require reinforcement other than that inherent in the construction as permitted in NCD-3332.1.

(-b) If the opening exceeds $5^3/_8$ 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 NCD-6900 or the opening shall be reinforced in accordance with NCD-3332 with the nozzle or other connections attached, using a suitable detail in Figure NCD-4244.1-5.

(f) For Class 3 Only — 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 $^1/_{16}$ 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 $^1/_4$ in. (6 mm). The minimum dimension for t_c shall be $^1/_4$ in. (6 mm) [Figure NCD-4244.2-1, sketches (a) and (b)].

(g) For Class 3 Only — 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 $^1/_2 t_{min}$ [Figure NCD-4244.2-2]. The dimension t_w of the inner weld shall be not less than $0.7t_{min}$, where

c = $^1/_2 t_{min}$
t = nominal thickness of shell
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_e = thickness of reinforcement element
t_{min} = lesser of $^3/_4$ 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 Class 3 Only. 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.

NCD-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NCD-4430.

NCD-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, except as otherwise permitted in NCD-3352.4

NCD-3356 Fillet Welds, Lap Joints, and Plug Welds

NCD-3356.1 Fillet Welds.

(a) Fillet welds may be used as strength welds within the limitations given in NCD-3352 and Figure NCD-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to ensure 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.

NCD-3356.2 For Class 3 Only — 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 NCD-3358 and for tanks in NCD-4246.

NCD-3356.3 For Class 3 Only — Plug Welds.

(a) Plugs 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 $t + {}^1/_4$ in. (6 mm) and not more than $2t + {}^1/_4$ 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 $^5/_{16}$ 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 $^5/_{16}$ of the hole diameter, whichever is larger, but in no case less than $^5/_{16}$ 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 (Section II, Part D, Subpart 1, Tables 1A and 1B)

NCD-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. The requirements of NCD-3356.1(b) apply. For Class 3 vessels, corner joints with fillet welds only shall not be used unless the plates forming the corner are properly supported independently of such welds [NCD-3356.1(b)].

NCD-3358 Design Requirements for Head Attachments

NCD-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 NCD-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 NCD-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 $^1/_8$ 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 NCD-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NCD-3358.2 Unstayed Flat Heads Welded to Shells. The requirements for the attachment of unstayed flat heads welded to shells are given in NCD-3325, NCD-3358.3, and NCD-3358.4.

NCD-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 NCD-4243.1-1, the joint shall meet the requirements of (a) through (h) 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) For Class 2 vessels, other dimensions of the joint shall be in accordance with details shown in Figures NCD-4243.1-1 and NCD-4243.1-2 where:

(1) *Figure NCD-4243.1-1*

Sketches (a), (b), and (c)

(-a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $^1\!/_4$ in. (6 mm), whichever is less
t_w = the lesser of $t_n/2$ or $t/4$

(-b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $^1\!/_4$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$

Sketch (d)

t, t_n = nominal thickness of welded parts, in., either leg of fillet weld = $0.25t_n$ but not less than $^1\!/_4$ in. (6 mm)

Sketches (e) and (f)

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $^1\!/_4$ in. (6 mm), whichever is less

(2) *Figure NCD-4243.1-2*

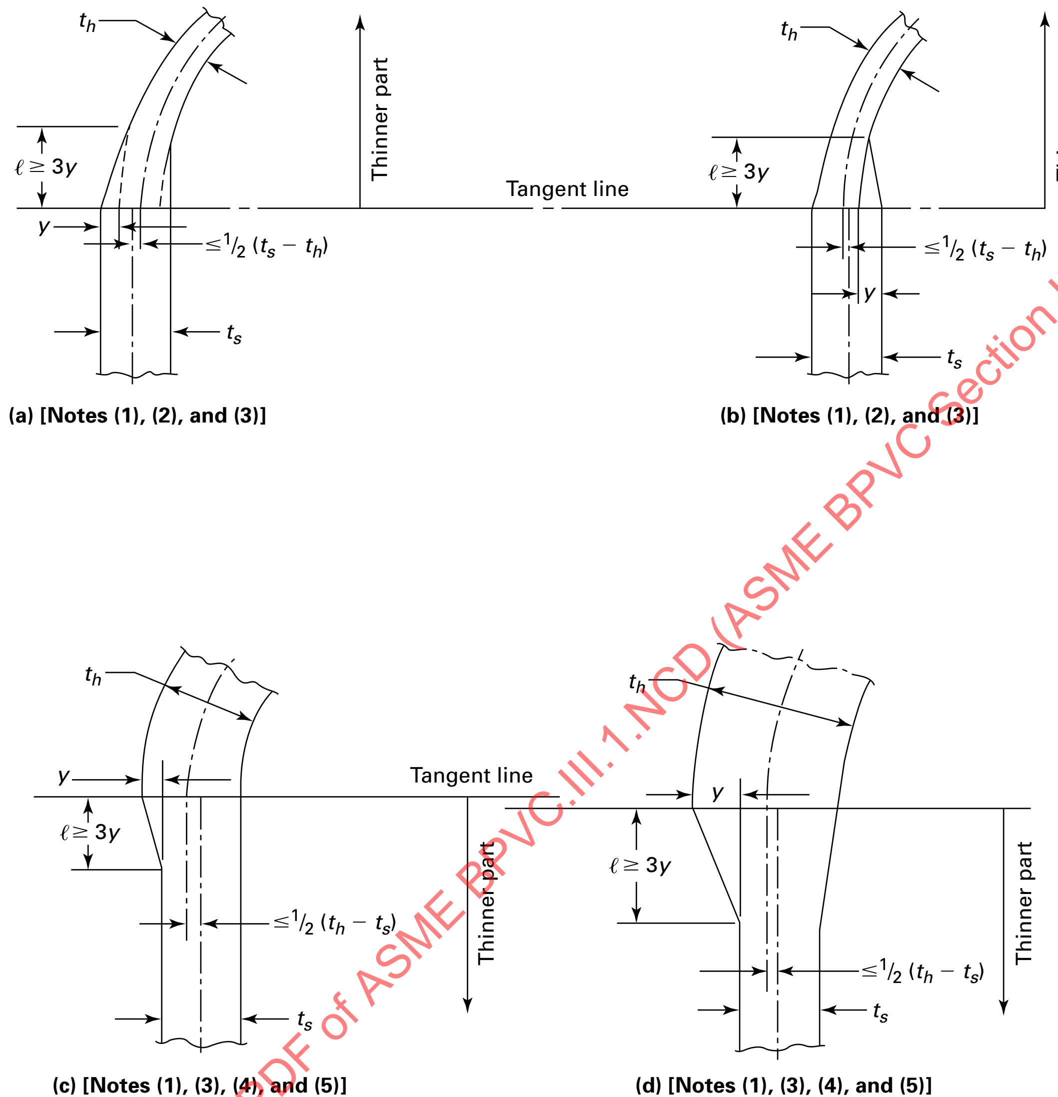
Sketch (a)

$a + b$ not less than $2t_s$
t_w not less than t_s
t_s = actual thickness of shell
t_p not less than t_s

Sketch (b)

$a + b$ not less than $2t_s$

Figure NCD-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_n exceeds $1.25t_s$; minimum length of skirt is $3t_h$, but need not exceed $1^1/_2$ 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.

t_s = actual thickness of shell

Sketch (c)

t_s = actual thickness of shell
t_r = required thickness of shell

for supported tubesheets:

c not less than $0.7t_s$ or $1.4t_r$, whichever is less
$a + b$ not less than $2t_s$

for flange rings, flat heads, and unsupported tubesheets:

c not less than t_s or $2t_r$, whichever is less
$a + b$ not less than $3t_s$

Sketch (d)

t_s = actual thickness of shell
t_r = required thickness of shell
$a + b$ not less than $3t_s$
c not less than t_s

(f) For Class 2 vessels, in Figure NCD-4243.1-1

t, t_n = nominal thicknesses
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$

(g) For Class 3 vessels, other dimensions of the joint shall be in accordance with details as shown in Figure NCD-4243.2-1 where

sketch (a)

$a + b$ not less than $2t_s$, (b = 0)
t_w not less than t_s
t_s = actual thickness of shell

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

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

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

sketch (e)

$a + b$ not less than $2t_s$, (b = 0)
t_s = actual thickness of shell

sketch (f)

$a + b$ not less than $2t_s$
t_s = actual thickness of shell

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

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

sketches (k) through (o)

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
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

sketch (p)

a not less than $3t_n$, (b = 0)
c not less than t_n or t_D, whichever is less (t_n and t_D are defined in Section III Appendices, Mandatory Appendix XI, XI-3130)

sketch (q)

$a + b$ not less than $3t_n$
c not less than t_n or t_D, whichever is less (t_n and t_D are defined in Section III Appendices, Mandatory Appendix XI, XI-3130)

(h) 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 NCD-4243.2-1 sketches (r), (s), and (t)].

NCD-3358.4 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Figure NCD-4243.3-1, 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 NCD-4243.3-1, the minimum dimensions are as follows:

sketch (a)

r not less than $1.5t_s$

sketch (b)

r not less than $1.5t_s$
e not less than t_s

sketch (c)

h not less than $1.5t_s$

sketch (d)

t_f not less than $2t_s$
r not less than $3t_f$

sketch (e)

t_f not less than $2t_s$
r not less than $3t_f$
e not less than t_f

NCD-3358.5 For Class 3 Only.

NCD-3358.5.1 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 NCD-4245.2-1 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.

NCD-3358.5.2 Intermediate Heads.

(a) Intermediate heads of the type shown in Figure NCD-4245.2-1 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 $^5/_8$ in. (16 mm).

NCD-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of NCD-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 NCD-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%

NCD-3360 SPECIAL VESSEL REQUIREMENTS

NCD-3361 Tapered Transitions, Threaded Connections, and Staggered Welds

NCD-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 NCD-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 $^1/_8$ 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 NCD-3358.1(b).

NCD-3361.2 Threaded Connections.

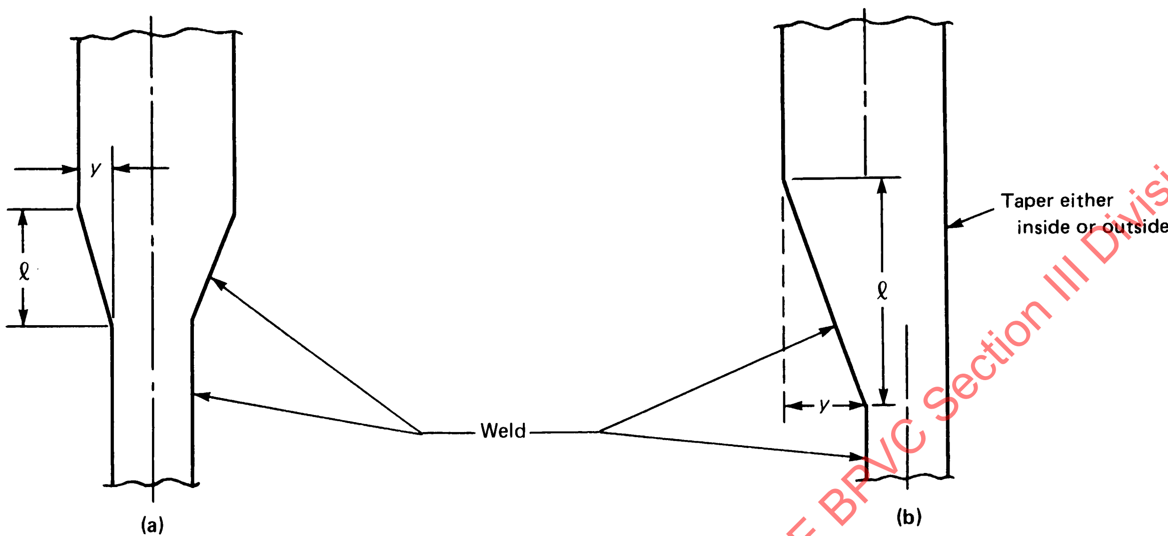
NCD-3361.2.1 For Class 2 Only. Threaded connections for Class 2 vessels shall be in accordance with NCD-3266.

NCD-3361.2.2 For Class 3 Only.

(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 NCD-3361.2.2-1 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 NCD-3361.2.2-1, 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)

Figure NCD-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 ≥ 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.

Table NCD-3361.2.2-1
Minimum Number of Pipe Threads for Connections

Size of Pipe Connections, in. (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
1/2, 3/4 (15, 20)	6	0.43 (11)
1, 1 1/4, 1 1/2 (25, 32, 40)	7	0.61 (16)
2 (50)	8	0.70 (18)
2 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)

restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes.

NCD-3361.3 For Class 3 Only — 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.

NCD-3362 Bolted Flange and Studded Connections

(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 designed in accordance with the rules of Section III Appendices, Mandatory 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 $1^1/_2 d_s$.

NCD-3363 Access or Inspection Openings

All dimensions given are nominal.

NCD-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 (NCD-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 NCD-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 NCD-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 $^3/_{16}$ 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.

NCD-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 $^3/_4$ (DN 20).

NCD-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 $1^1/_2$ (DN 40).

NCD-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 $1^1/_2$ (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. × 6 in. (100 mm × 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.

NCD-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. × 15 in. (275 mm × 375 mm) or 10 in. × 16 in. (250 mm × 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. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

NCD-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.

NCD-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 $^{11}/_{16}$ in. (17 mm).

NCD-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.

NCD-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NCD-3135.

NCD-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 loadings (NCD-3111 and Subsection NF).

NCD-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 NCD-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 Article NCD-2000.

(h) All welded joints shall comply with the requirements of NCD-4400.

(i) Design of bellows-type expansion joints shall comply with the requirements of NCD-3649.4.

NCD-3400 PUMP DESIGN

NCD-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NCD-3411 Scope

NCD-3411.1 Applicability. The rules of NCD-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.

NCD-3411.2 Exemptions. The rules of NCD-3400 do not apply to (a) through (c) below:

(a) pump shafts and impellers (shafts may be designed in accordance with Section III Appendices, Nonmandatory Appendix S)

(b) nonstructural internals

(c) seal packages

NCD-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 NCD-3100 are satisfied.

(b) The rules of this subarticle are met.

NCD-3413 Design Specification (21)

Design and Service Loadings (NCA-2142) shall be stipulated in the Design Specification [NCA-3211.19(b)]. Loads from thermal expansion, deadweight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

Table NCD-3416-1
Stress and Pressure Limits for Design and Service Loadings

Service Limit	Stress Limits Note (1)	P_{max} Note (2)
Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:
(1) These requirements for acceptability of pump design are not intended to ensure the operability of the pump.
(2) The maximum pressure shall not exceed the tabulated factors listed under P_{max} times the Design Pressure.

NCD-3414 Design and Service Loadings

The general design considerations, including definitions, of NCD-3100 plus the requirements of NCD-3320, NCD-3330, NCD-3361, and NCD-3362 are applicable to pumps. The pump shall conform to the requirements of NCD-3400. The stress limits listed in NCD-3416 shall be used for the specified Design and Service Loadings. 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.

NCD-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

NCD-3416 Stress and Pressure Limits for Design and Service Loadings

Stress limits for maximum normal stress for Design and Service Loadings are specified in Table NCD-3416-1. The symbols used in Table NCD-3416-1 are defined as follows:

S = allowable stress value, given in Section II, Part D, Subpart 1, Tables 1A and 1B. 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.

NCD-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.

NCD-3418 Corrosion

The requirements of NCD-3121 apply.

NCD-3419 Cladding

Cladding design dimensions used in the design of pumps shall be as required in NCD-3122.

NCD-3420 DEFINITIONS

NCD-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.

NCD-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.

NCD-3423 Single and Double Volute Casings

Figures NCD-3423-1 and NCD-3423-2 show typical single and double volute casings, respectively.

NCD-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.

Figure NCD-3423-1
Typical Single Volute Casing

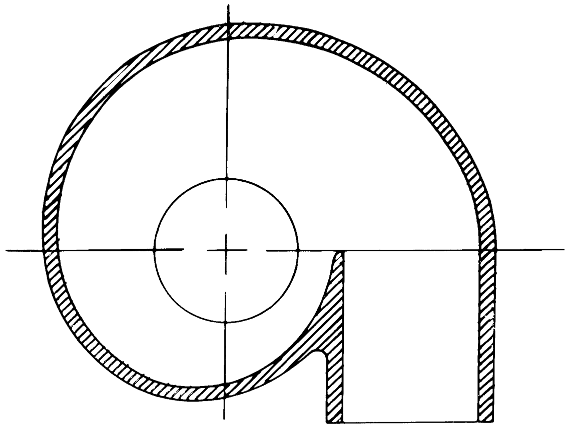
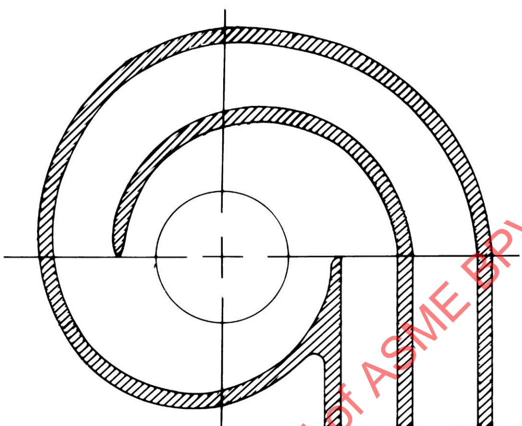


Figure NCD-3423-2
Typical Double Volute Casing



NCD-3425 Typical Examples of Pump Types

Figures NCD-3441.1-1 through NCD-3441.11-1 are intended to be typical examples to aid in the determination of a pump type and are not considered as limiting.

NCD-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

NCD-3431 Design of Welded Construction

(a) The design of welded construction shall be in accordance with NCD-3350.

(b) Partial penetration welds, as shown in Figure NCD-4244.1-5 sketch (c-3) and Figure NCD-4266(d)-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.

NCD-3432 Flanged Connections

NCD-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 Section III Appendices, Mandatory Appendix I for the material utilized.

(b) Flanged connections not meeting the requirements of (a) shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000 or Section III Appendices, Nonmandatory Appendix L, Article L-3000.

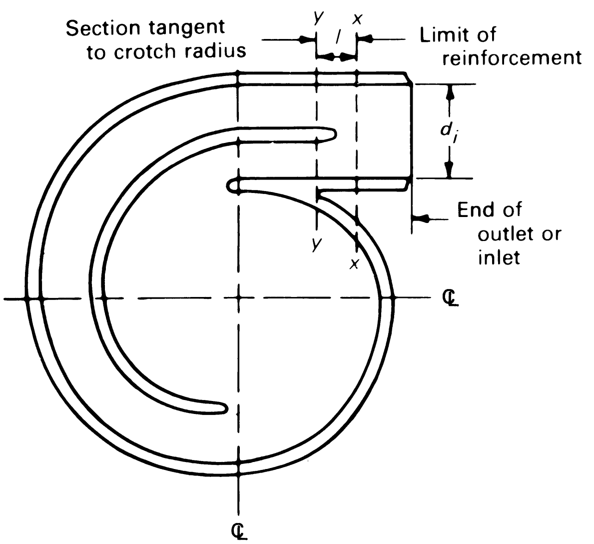
(c) Pump flanges meeting all requirements of Table NCA-7100-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle, provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of NCD-1130.

NCD-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 accomodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

(a) Flanged connections meeting the requirements of NCD-3432.1 do not require futher analysis when all requirements of NCD-3658.2 or NCD-3658.3 are met. All other flanged connections shall all meet the requirements of (b) below.

(b) Flanged connections shall meet the requirements of NCD-3658.1.

Figure NCD-3433.4-1
Minimum Tangential Inlet and Outlet Wall Thickness



NCD-3433 Reinforcement of Pump Casing Inlets and Outlets

NCD-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 NCD-3330.

(b) To avoid stress concentrations, the outside radius r_2 of Figures NCD-3441.1(a)-1 and NCD-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NCD-3433.2 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets is required. The applicable portions of NCD-3330 shall apply.

NCD-3433.3 Tangential Inlets and Outlets. Except as modified in NCD-3433.4, any design method that has been demonstrated to be satisfactory for the specified Design Loadings may be used.

NCD-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses. In Figure NCD-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 NCD-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 NCD-4250-1.

NCD-3434 Bolting

NCD-3434.1 Radially Split Configurations. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.

NCD-3434.2 Axially Split Configurations. Bolting in axially split configurations shall be designed in accordance with the procedure given in NCD-3441.7 for Type G pumps.

NCD-3435 Piping

NCD-3435.1 Piping Under External Pressure. Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with NCD-3640.

NCD-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 NCD-3640.

NCD-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. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of NCD-3135.

NCD-3437 Pump Covers

Pump covers shall be designed in accordance with NCD-3325 or NCD-3326. Covers for which specific design rules are not given in NCD-3325 or NCD-3326 shall be designed by any method shown by analysis or experience to be satisfactory.

NCD-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of NCD-3411.1(j).

NCD-3440 DESIGN OF SPECIFIC PUMP TYPES

NCD-3441 Standard Pump Types

(21) **NCD-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 Figures NCD-3441.1-1 and NCD-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, 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 NCD-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) (NCD-2571 and Section II, Part D, Subpart 1, Tables 1A and 1B)
t = minimum allowable wall thickness, in. (mm)

(b) Cutwater Tip. The cutwater tip radius shall not be less than 0.05t.

(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 NCD-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 NCD-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.

(1) For Class 2 pumps, the value of t_b shall be determined by the methods of NCD-3300 or Section III Appendices, Nonmandatory Appendix A, using the appropriate equations for the casing shape, or by the methods permitted in Section III Appendices, Mandatory Appendix XIII.

(2) For Class 3 pumps, the value of t_b shall be determined by the methods of NCD-3300 or Section III Appendices, Nonmandatory 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.

(1) Class 2 pumps of this larger size shall be designed in accordance with Section III Appendices, Mandatory Appendix II or Mandatory Appendix XIII. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3211.40(b).

(2) Class 3 pumps of this larger size shall be designed in accordance with Section III Appendices, Mandatory Appendix II, or NCD-3414. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3211.40(b).

NCD-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 NCD-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified design conditions may be used.

NCD-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 NCD-3441.3-1 and NCD-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 inside casing as shown in Figure NCD-3441.3-2, in. (mm)
P = Design Pressure, psig (MPa gage)
S = allowable stress, including casting factor, psi (MPa) (NCD-2571 and Section II, Part D, Subpart 1, Tables 1A and 1B)
t = minimum allowable wall thickness, in. (mm)

Figure NCD-3441.1-1
Type A Pump

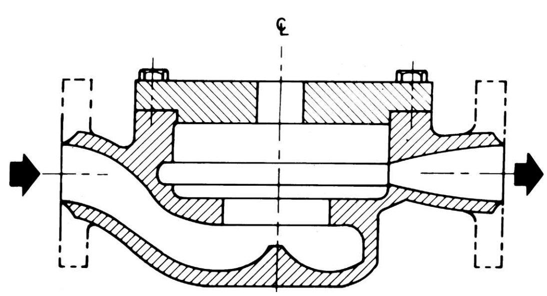


Figure NCD-3441.1-2
Type A Pump

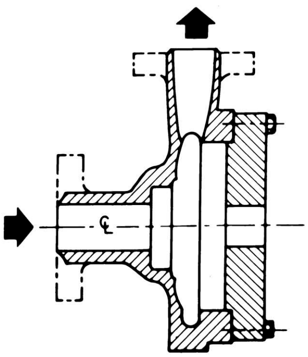


Figure NCD-3441.1(a)-1
Type A Pump

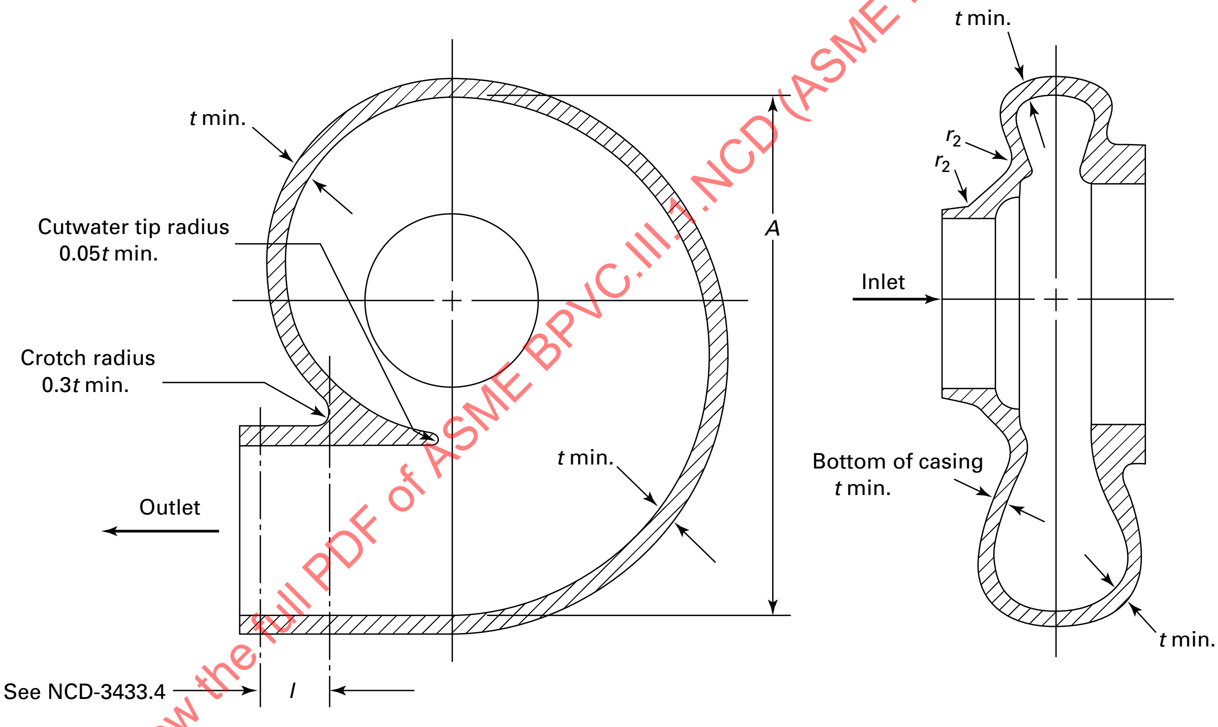


Figure NCD-3441.2-1
Type B Pump

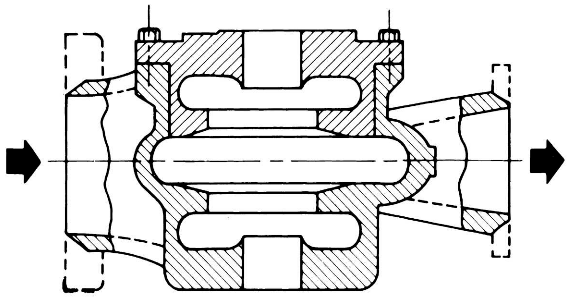


Figure NCD-3441.3-1
Type C Pump

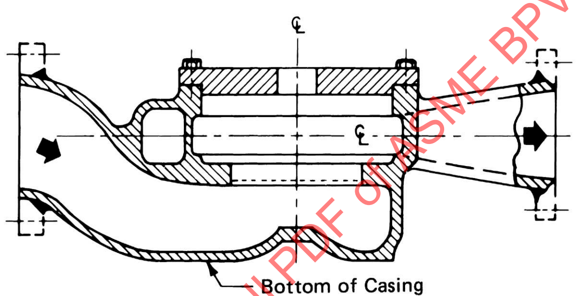
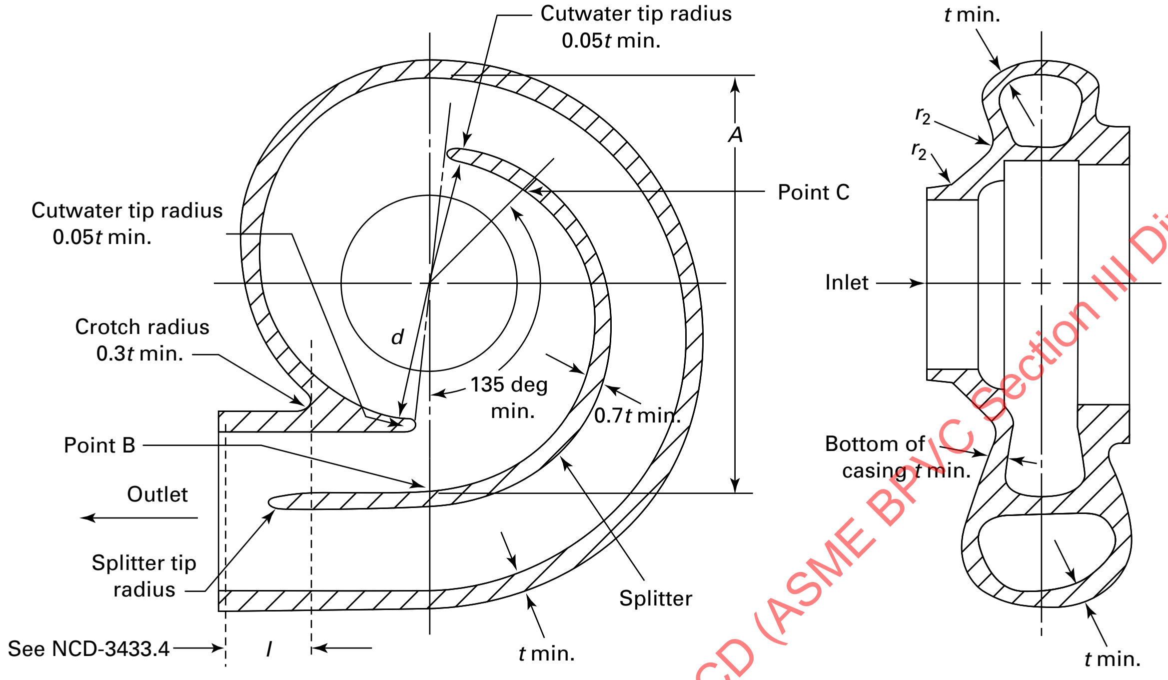
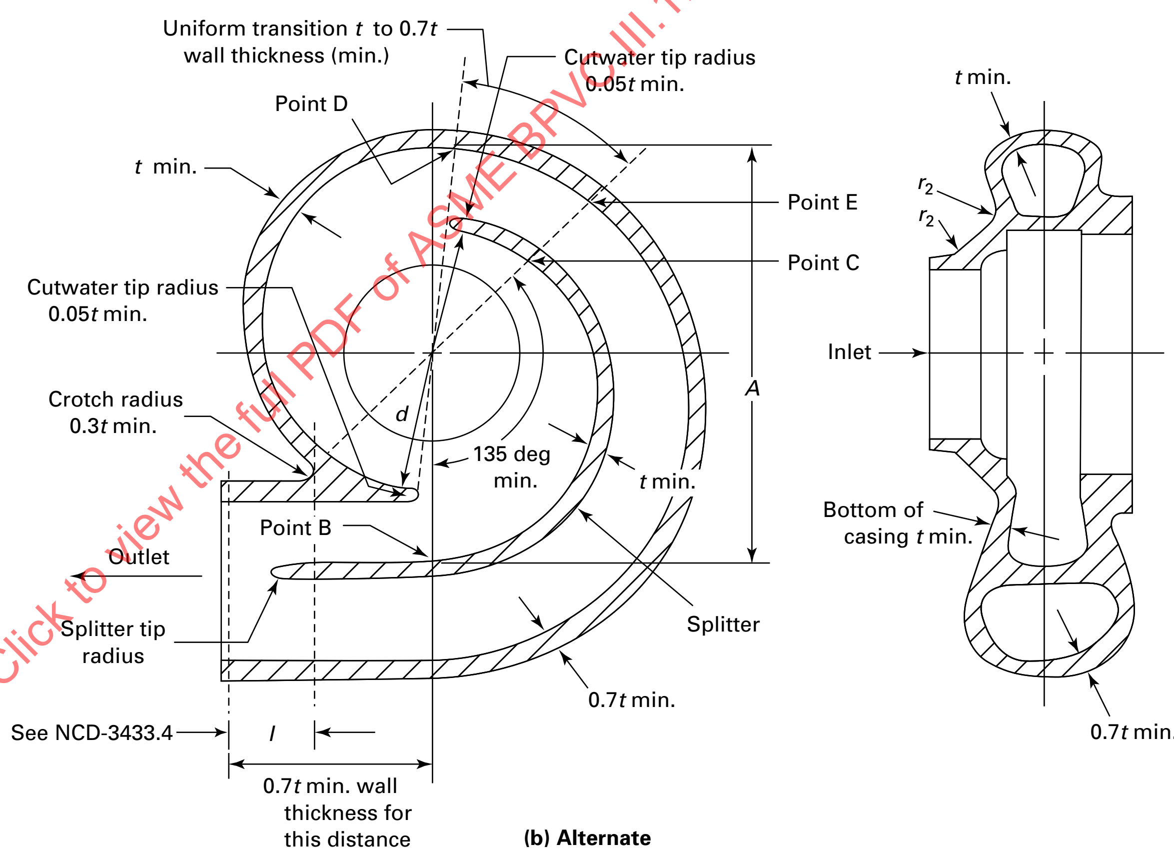


Figure NCD-3441.3-2
Type C Pump

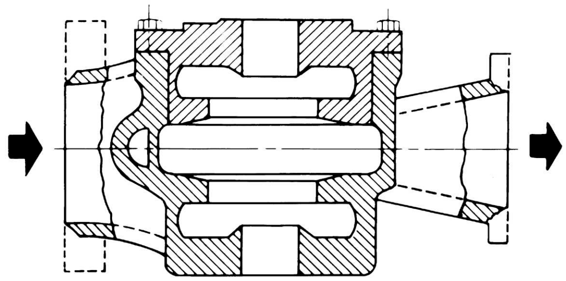


(a) Standard



(b) Alternate

Figure NCD-3441.4(a)-1
Type D Pump



(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 NCD-3441.3-2 sketch (a) through a minimum angle of 135 deg 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 NCD-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 NCD-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 between the tangent point of the crotch radius to a point D radially opposite the splitter tip [Figure NCD-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 from the crotch, where l is defined in Figure NCD-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness t instead of $0.7t$.

(3) The requirements of (b)(2) and (b)(3) above shall apply.

NCD-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 NCD-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of NCD-3400.

(b) The requirements of NCD-3441.3(a), NCD-3441.3(b), and NCD-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.

NCD-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 NCD-3441.5-1. The design shall be in accordance with the applicable requirements of NCD-3400.

NCD-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 NCD-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 NCD-3400.

Figure NCD-3441.5-1
Type E Pump

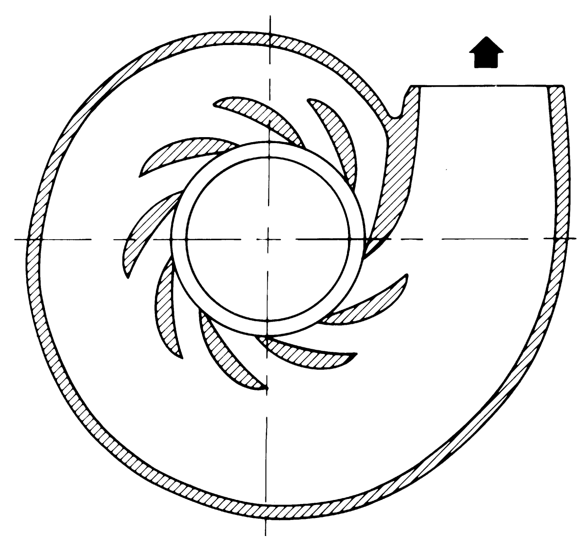
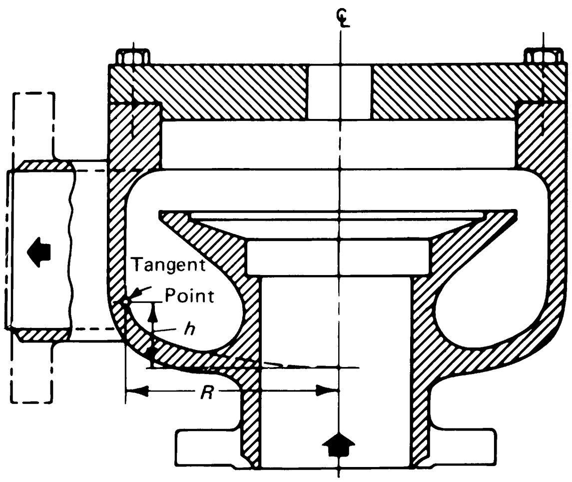


Figure NCD-3441.6(a)-1
Type F Pump



NCD-3441.7 Design of Type G Pumps.

(a) Type G pumps are those having axially split, single- or double-volute casings [Figures NCD-3441.7(a)-1 and NCD-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 NCD-3441.7(c)-1 Section B–B]. 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.

(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 NCD-3441.7(c)(2)-1, NCD-3441.7(c)(2)-2, and NCD-3441.7(c)(2)-3. The procedure for the calculation is given in (-a) through (-o) below.

(-a) Establish the Design Pressure *P*, psi (MPa). Establish dimensions *A*, *B*, *C*, *F*, *R*, t_c, t_f, *w*, and *b* from Figures NCD-3441.7(c)(2)-1, NCD-3441.7(c)(2)-2, and NCD-3441.7(c)(2)-3 and determine the following:

A_b = bolt root area, in.^{2} (mm^2)
A_G = effective gasket area, in.^{2} (mm^2)
D = diameter of bolt hole, in. (mm)
d = bolt root diameter, in. (mm)
DTF = Design Temperature, °F (°C)
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 (Section III Appendices, Mandatory Appendix XI, 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) (Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-1)

(-b) Determine the effective gasket area A_G, in.^{2} (mm^2), for Sections *X* and *Y*:

$$A_G = \left[(A - F)w - \frac{\pi D^2}{4}\right] \times K$$

For the factor *K*, use 0.20 if case face is crowned for greatest contact pressure at inner edge and use 0.50 for flat surfaces.

Figure NCD-3441.7(a)-1
Axially Split Casing, Volute Pump, Type G

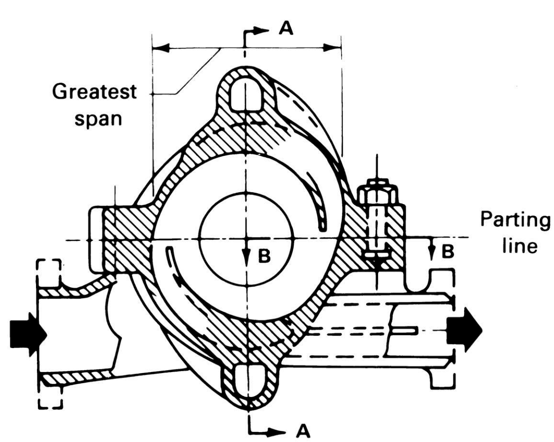


Figure NCD-3441.7(a)-2
Axially Split Casing, Volute Pump, Type G

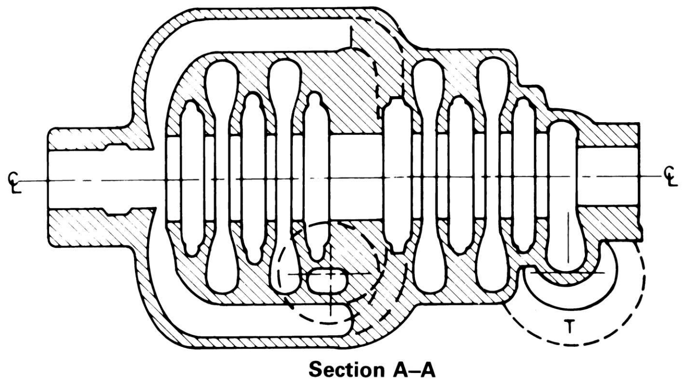


Figure NCD-3441.7(c)-1
Axially Split Casing, Volute Pump, Type G
Section B–B Typical Highly Stressed Sections of Pump Case

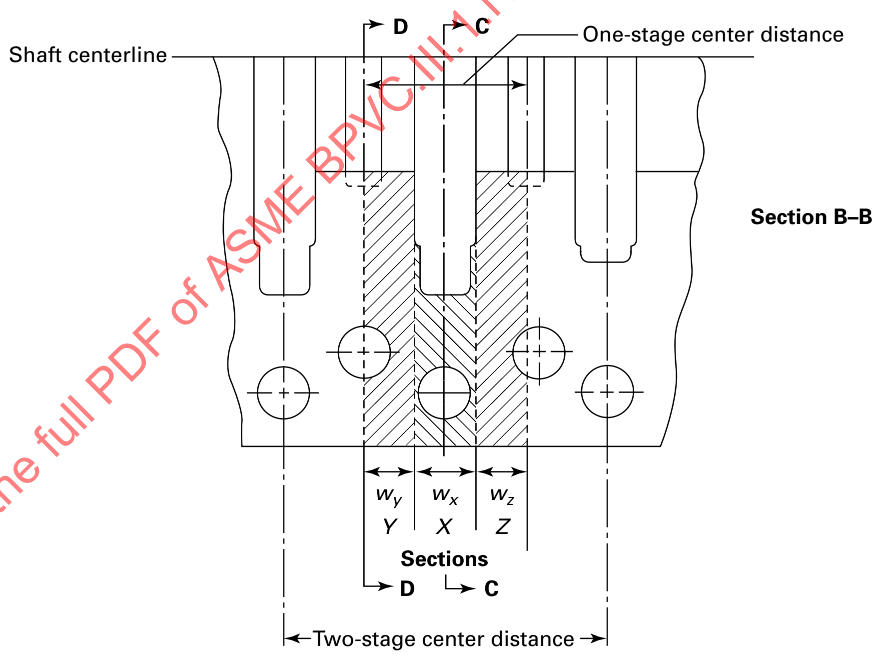
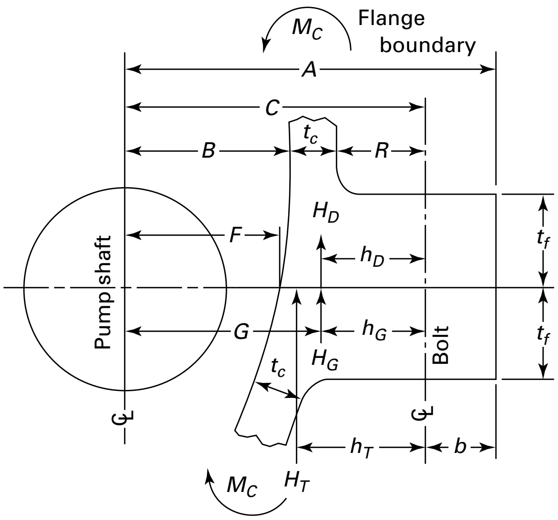
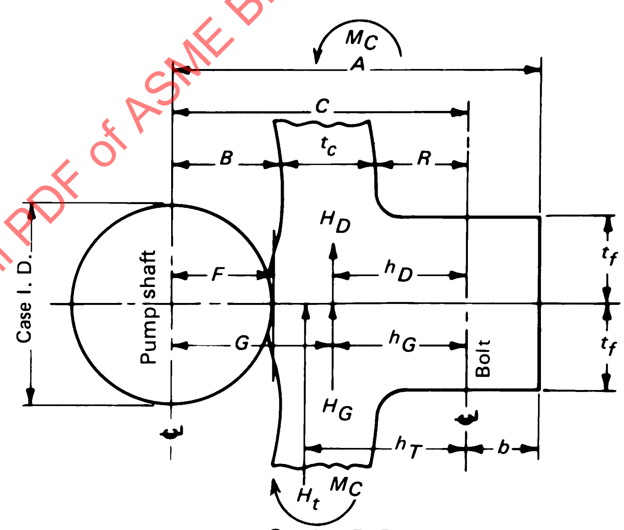


Figure NCD-3441.7(c)(2)-1
Typical Section of Type G Pumps



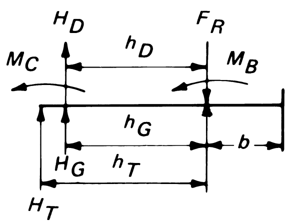
Section C–C

Figure NCD-3441.7(c)(2)-2
Typical Section of Type G Pumps



Section D–D

Figure NCD-3441.7(c)(2)-3
Typical Loads on Type G Pumps



Equivalent Beam

(-c) Determine bolt load, lb (N), and preliminary bolt stress σ_{PRE}, psi (MPa):

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5 A_G y$$

$$W = \text{greator of } W_{m1} \text{ or } W_{m2}$$

$$\sigma_{PRE} = W / A_b$$

(-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):

$$h_D = R + 0.5 t_c$$

$$h_G = h_D$$

$$h_T = 0.5(R + t_c + h_G)$$

(-f) Determine the total moment M_o, in.-lb (N·mm):

$$M_D = H_D h_D$$

$$M_G = H_G h_G$$

$$M_T = H_T h_T$$

$$M_o = M_D + M_G + M_T$$

(-g) Determine the moments of inertia, in.^{4} (mm^4), I_F (flange) I_B (bolt), I_C (case), and I_T (total):

$$I_F = \left[w\left(t_f\right)^3 / 12 \right] - \left[D\left(t_f\right)^3 / 12 \right]$$

$$I_B = 0.049 d^4$$

$$I_C = w(t_c)^3 / 12$$

$$I_T = I_F + I_B + I_C$$

(-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):

$$F_R = [H_D(b + h_D) + H_G(b + h_G) + H_T(b + h_T) - M_C - M_B]/b$$

or

$$F_R = H_o + [(M_o - M_C - M_B)/b]$$

(-j) Determine the 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 $\sigma_s{}'$, psi (MPa), and $\sigma_b{}'$, 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 $\sigma_t{}''$, psi (MPa), and $\sigma_b{}''$, psi (MPa), respectively

$$\sigma_t{}'' = H_D/wt_c$$

$$\sigma_b{}'' = M_C t_C/2I_C$$

(-m) Use the following method for combining stress in combined sections:

F_X = load on Section X, lb (N)
F_Y = load on Section Y, etc., lb (N)
S_X = stress on Section X, psi (MPa)
S_Y = stress on 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 the stress σ_{PRE} for Section X and for Section $(Y + Z)$

$$\sigma_{\text{PRE}_{\text{COMB}}} = \frac{W_X + W_{(Y+Z)}}{\frac{W_X}{\sigma_{\text{PRE}_X}} + \frac{W_{(Y+Z)}}{\sigma_{\text{PRE}_{(Y+Z)}}}}$$

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 $(Y + Z)$

$$\sigma_{b_{\text{COMB}}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{t_X}} + \frac{F_{R_{(Y+Z)}}}{\sigma_{t_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{t_{\text{COMB}}}$ is $2S_b$.

$$\sigma_{b_{\text{COMB}}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{b_X}} + \frac{F_{R_{(Y+Z)}}}{\sigma_{b_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{t_{\text{COMB}}} + \sigma_{b_{\text{COMB}}}$ 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 $(Y + Z)$

$$\sigma'_{s_{\text{COMB}}} = \frac{H_{o_X} + H_{o_{(Y+Z)}}}{\frac{H_{o_X}}{\sigma'_{s_X}} + \frac{H_{o_{(Y+Z)}}}{\sigma'_{s_{(Y+Z)}}}}$$

$$\sigma'_{b_{\text{COMB}}} = \frac{H_{o_X} + H_{o_{(Y+Z)}}}{\frac{H_{o_X}}{\sigma'_{b_X}} + \frac{H_{o_{(Y+Z)}}}{\sigma'_{b_{(Y+Z)}}}}$$

$$\sigma'_{s_{\max}} = \left[\left(\sigma'_{s_{\text{COMB}}}\right)^2 + \left(\sigma'_{b_{\text{COMB}}}/2\right)^2\right]^{1/2}$$

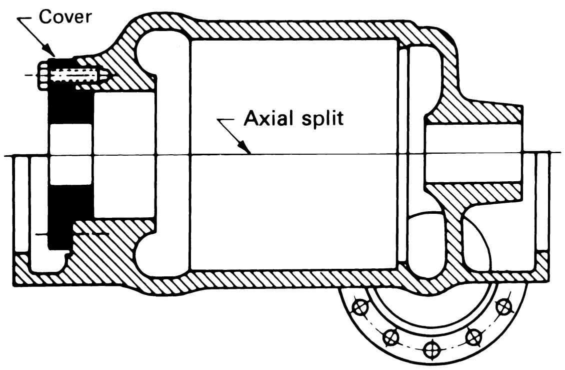
$$\sigma'_{n_{\max}} = \sigma'_{s_{\max}} + \left(\sigma'_{b_{\text{COMB}}}/2\right)$$

where $\sigma'_{n_{\max}}$ is the maximum normal stress. The allowable limit for $\sigma'_{s_{\max}}$ is S_c and the allowable limit for $\sigma'_{n_{\max}}$ is $1.5S_c$.

(-4) To determine the case stresses, establish the load H_D, the tensile stress $\sigma_t{}''$, and the bending stress $\sigma_b{}''$ for Section X and for Section $(Y + Z)$

$$\sigma''_{t_{\text{COMB}}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma''_{t_X}} + \frac{H_{D_{(Y+Z)}}}{\sigma''_{t_{(Y+Z)}}}}$$

Figure NCD-3441.8-1
Longitudinal Section Through Type H Pump



$$\sigma''_{b\text{COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma''_{b_X}} + \frac{H_{D_{(Y+Z)}}}{\sigma''_{b_{(Y+Z)}}}}$$

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.

NCD-3441.8 Design of Type H Pumps. Type H pumps are those having axially split, barrel-type casings (Figures NCD-3441.8-1 and NCD-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of NCD-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of NCD-3437.

(21) **NCD-3441.9 Design of Type K Pumps.** Type K pumps are vertical pumps of one or more stages having a radially split casing, as illustrated in Figures NCD-3441.9-1 and NCD-3441.9-2. The basic configuration is a casing consisting of 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) Casing. The flanged joints, barrel, and head of the casing shall be designed in accordance with the requirements of NCD-3400 and those given in (1) through (3).

(1) Flanged Joints. Flanged joints may be analyzed and the stresses evaluated by using methods given in Section III Appendices, Mandatory Appendix XI if of the "RF" type, and in accordance with Section III Appendices, Nonmandatory Appendix L if of the "FF" type, as modified by (-a) through (-d) below or by (-e) below.

(-a) The Design Pressure to be used for the calculation of H in Section III Appendices, Mandatory Appendix XI or Section III Appendices, Nonmandatory Appendix L shall be replaced by the flange design pressure

$$P_{FD} = P + P_{eq} \tag{1}$$

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

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{4F}{\pi G^2} \tag{2}$$

Figure NCD-3441.8-2
Transverse Section Through Type H Pump

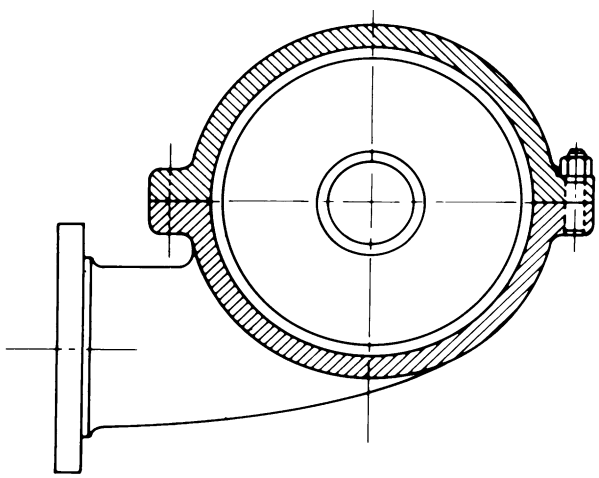


Figure NCD-3441.9-1
Type K Pump

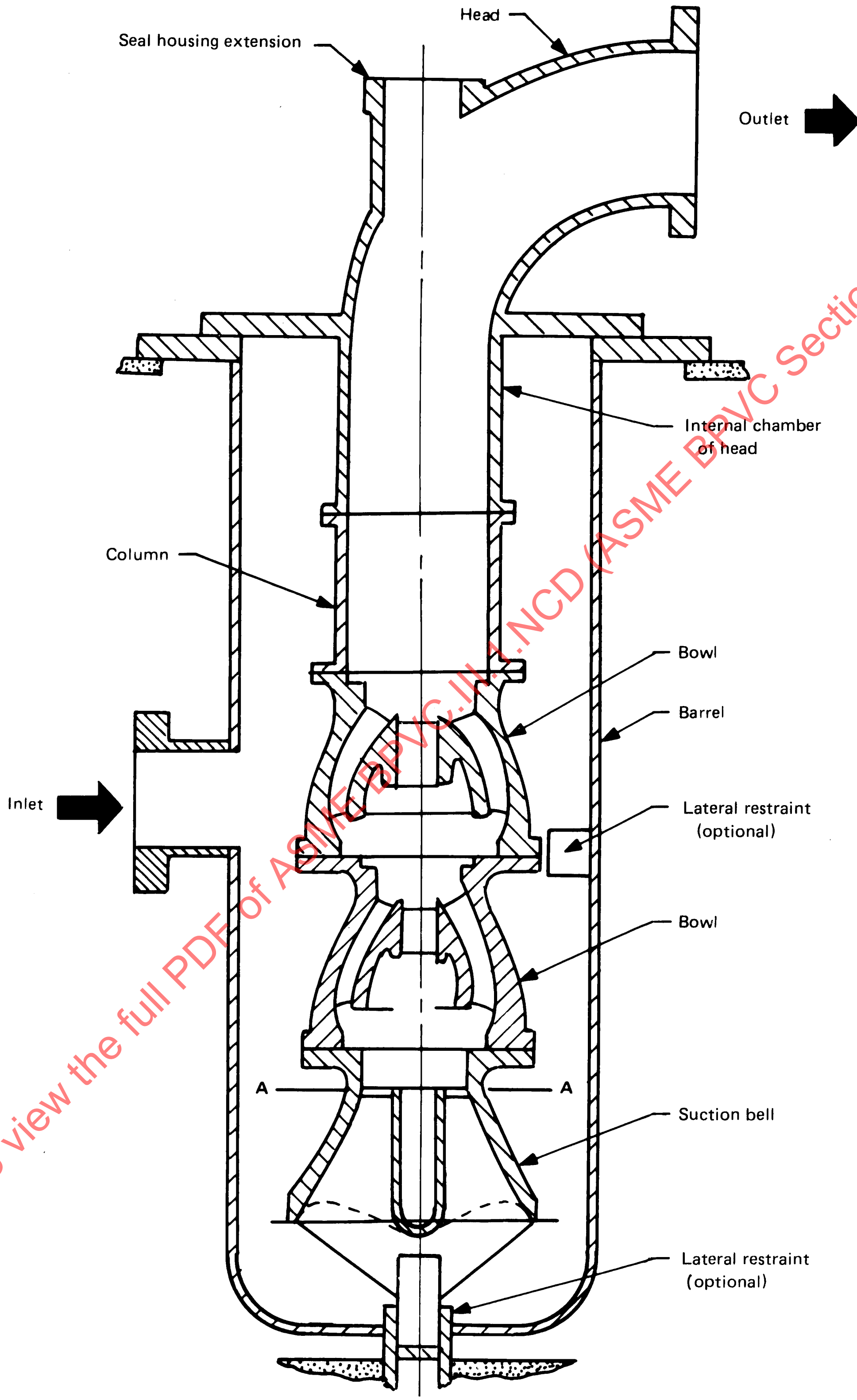
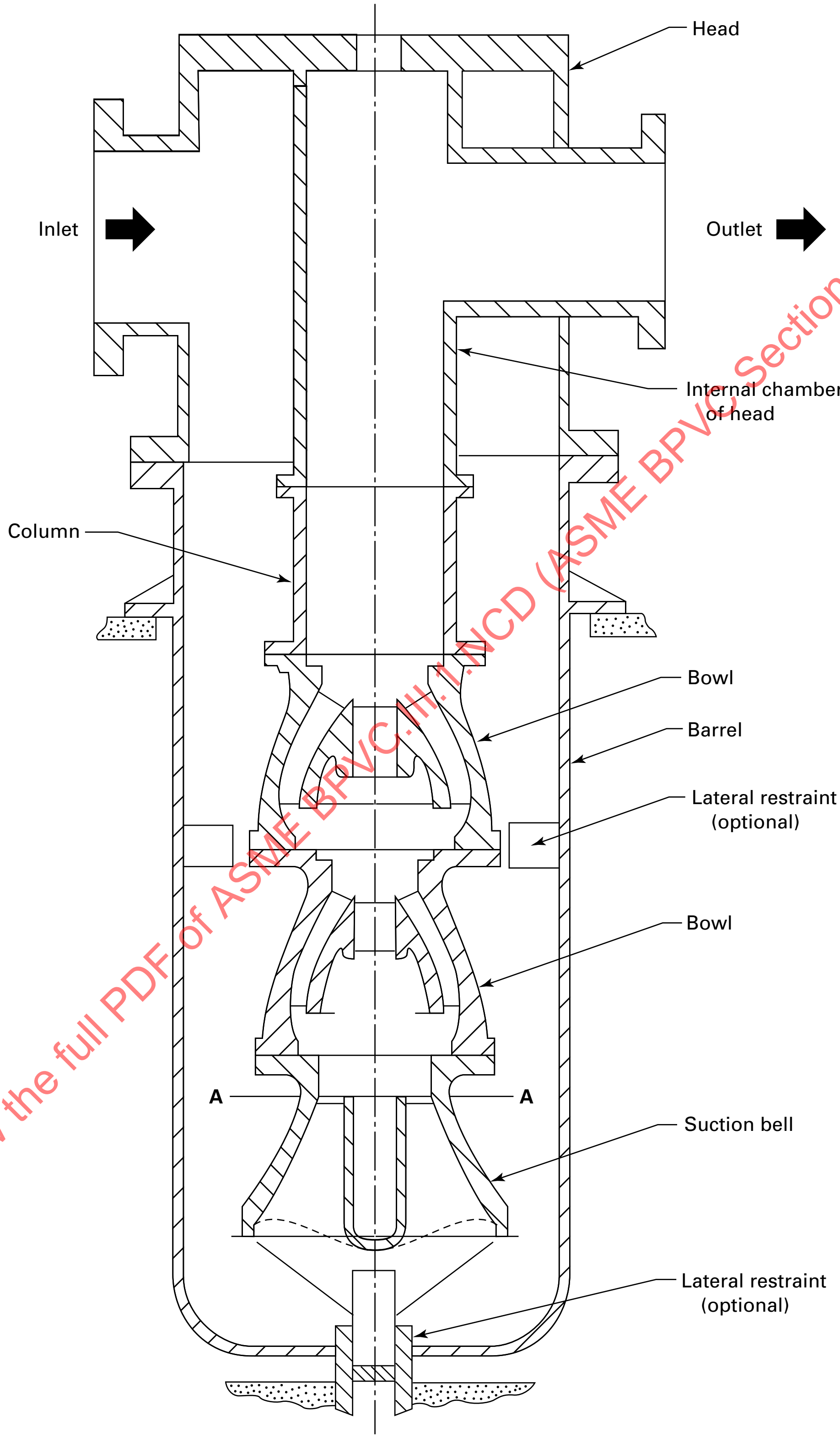


Figure NCD-3441.9-2
Type K Pump



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 NCD-3658, in.-lbf (N·mm)

(-b) Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4) or Section III Appendices, Nonmandatory Appendix L, L-3221 shall be used to establish minimum bolt area required using allowable stress values given in Section II, Part D, Subpart 1, Table 3.

(-c) 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:

$$S_H = \frac{fM_o}{Lg_1^{\,2}B} + \frac{PB}{4g_o} \tag{3}$$

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.

(-d) The allowable stress limits S_H, S_R, and S_T shall not be greater than $1.5S$.

(-e) 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. (-a)(1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(2) Barrel. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3211.19), 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. (1)(-a)(1), with F = 0 in eq. (1)(-a)(2), as applied to the inlet geometry.

The barrel shall be designed in accordance with the requirements of NCD-3320 for pressure vessels.

(3) 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 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 Section II, Part D, Subpart 1, Tables 1A and 1B shall be not less than that determined by the equation

$$t_m = \frac{P\,D_o}{2(SE + Py)} + A \tag{4}$$

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 NCD-3350 or casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B.
S = the allowable stress for the material at the design temperature (Section II, Part D, Subpart 1, Tables 1A and 1B), 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
= $\dfrac{d}{d + D_o}$ 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. (1)(-a)(1), with F = 0 in eq. (1)(-a)(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 NCD-3320 for pressure vessels.

(b) Inner Assembly. The inner assembly consists of those elements of the pump subjected to differential pressure within the pump and those that do not form part of the pressure boundary to the atmosphere. 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 NCD-3400 and with those given in (1) through (5) below. Alternatively, the configuration may be designed in accordance with Section III Appendices, Mandatory Appendix II, Design by Experimental Stress Analysis, or Section III Appendices, Mandatory Appendix XIII, Design Based on 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)(-a)(1) and (a)(1)(-a)(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

$$t_m = \frac{P_c D_o}{2(SE + Py)} + A \tag{5}$$

where the terms are as defined in (a)(3)(-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)(1) except that the design pressure shall be P_c. The equivalent pressure shall be determined using eq. (a)(1)(-a)(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)(-a)(1), with F = 0 in eq. (a)(1)(-a)(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 ensure 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

$$t_m = \frac{P_b D_o}{2(SE + P_b y)} + A \tag{6}$$

where the terms are as defined in (a)(3)(-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 NCD-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

$$F_D = \frac{2(2-\mu) P_b {A_D}^2}{\dfrac{16 l_D t_D}{t_v} + \dfrac{t_D (\pi A_D)^3}{(n_v t_D)^3}} \tag{7}$$

where

A_D = the mean diameter of the vaned portion of the bowl as defined in Figure NCD-3441.10-2, in. (mm)
F_D = vane load/unit length, lbf/in. (N/m)
l_D = the radial mean vane length as defined in Figure NCD-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 NCD-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

$$\sigma_B = \frac{3 F_D \pi A_D}{n_v {t_D}^2} \tag{8}$$

The vane membrane stress, σ_v, shall be less than SE as determined by the equation

$$\sigma_v = \frac{F_D}{t_v} \tag{9}$$

(-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 Section III Appendices, Mandatory 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 a Section III Appendices, Nonmandatory Appendix L flange. The analysis shall be in accordance with (a)(1) using eq. (a)(1)(-a)(1), with $F = 0$ in eq. (a)(1)(-a)(2). The definition of the outlet flange geometry for the analysis is shown in Figure NCD-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 maximum 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)(-a)(1), with $F = 0$ in eq. (a)(1)(-a)(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 NCD-3441.9-1 and NCD-3441.9-2), the remaining portions of the bell are not considered subject to a differential pressure.

(5) Materials and Design. Each bowl and suction bell shall be manufactured of material meeting the rules of NCD-2190 and designed using the casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B.

(21) **NCD-3441.10 For Class 3 Only — 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 NCD-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 columns. 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 affect the integrity of the overall pressure boundary.

Type L pumps shall be designed in accordance with the requirements of NCD-3400 and with those given in (a) through (e) below. Alternatively, the configuration may be designed in accordance with Section III Appendices, Mandatory Appendix II, Design by Experimental Stress Analysis, or Section III Appendices, Mandatory Appendix XIII, Design Based on 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 Section III Appendices, Mandatory Appendix XI if of the "RF" type and in accordance with Section III Appendices, Nonmandatory 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 Section III Appendices, Mandatory Appendix XI or Section III Appendices, Nonmandatory Appendix L shall be replaced by the flange design pressure

$$P_{FD} = P + P_{\mathrm{eq}} \tag{1}$$

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

$$P_{\mathrm{eq}} = \frac{KM_f}{\pi G^3} + \frac{4F}{\pi G^2} \tag{2}$$

where

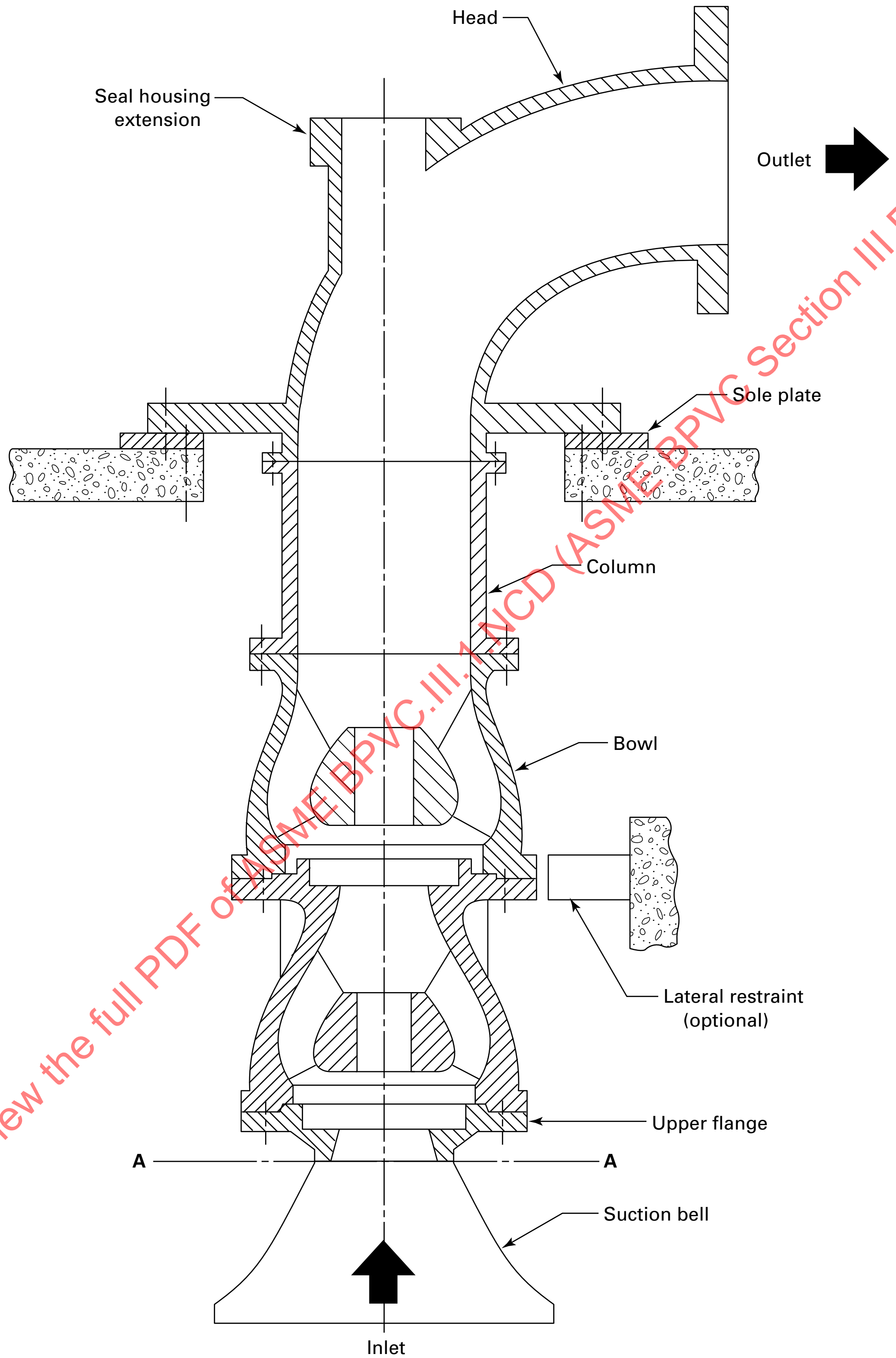
F = the axial load at the flange, lb (N)
G = the diameter at the location of the gasket load reaction, in. (mm)
K = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.
M_f = the resultant bending moment on the flange as taken from NCD-3658, in.-lbf (N·mm)

(2) Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4) or Section III Appendices, Nonmandatory Appendix L shall be used to establish minimum bolt area required using allowable stress values given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(3) Section III Appendices, Mandatory Appendix XI, XI-3240, eq. (6) for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1{}^2B} + \frac{PB}{4g_o} \tag{3}$$

Figure NCD-3441.10-1
Type L Pump



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. NCD-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 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 Section II, Part D, Subpart 1, Tables 1A and 1B shall be not less than that determined by the equation

$$t_m = \frac{PD_o}{2(SE + Py)} + A \qquad (4)$$

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 NCD-3350 or casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B

S = the allowable stress for the material at the design temperature (Section II, Part D, Subpart 1, Tables 1A and 1B), 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

$$t_m = \frac{P_c D_o}{2(SE + Py)} + A \qquad (5)$$

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 ensure 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

$$t_m = \frac{P_b D_o}{2(SE + Py)} + A \qquad (6)$$

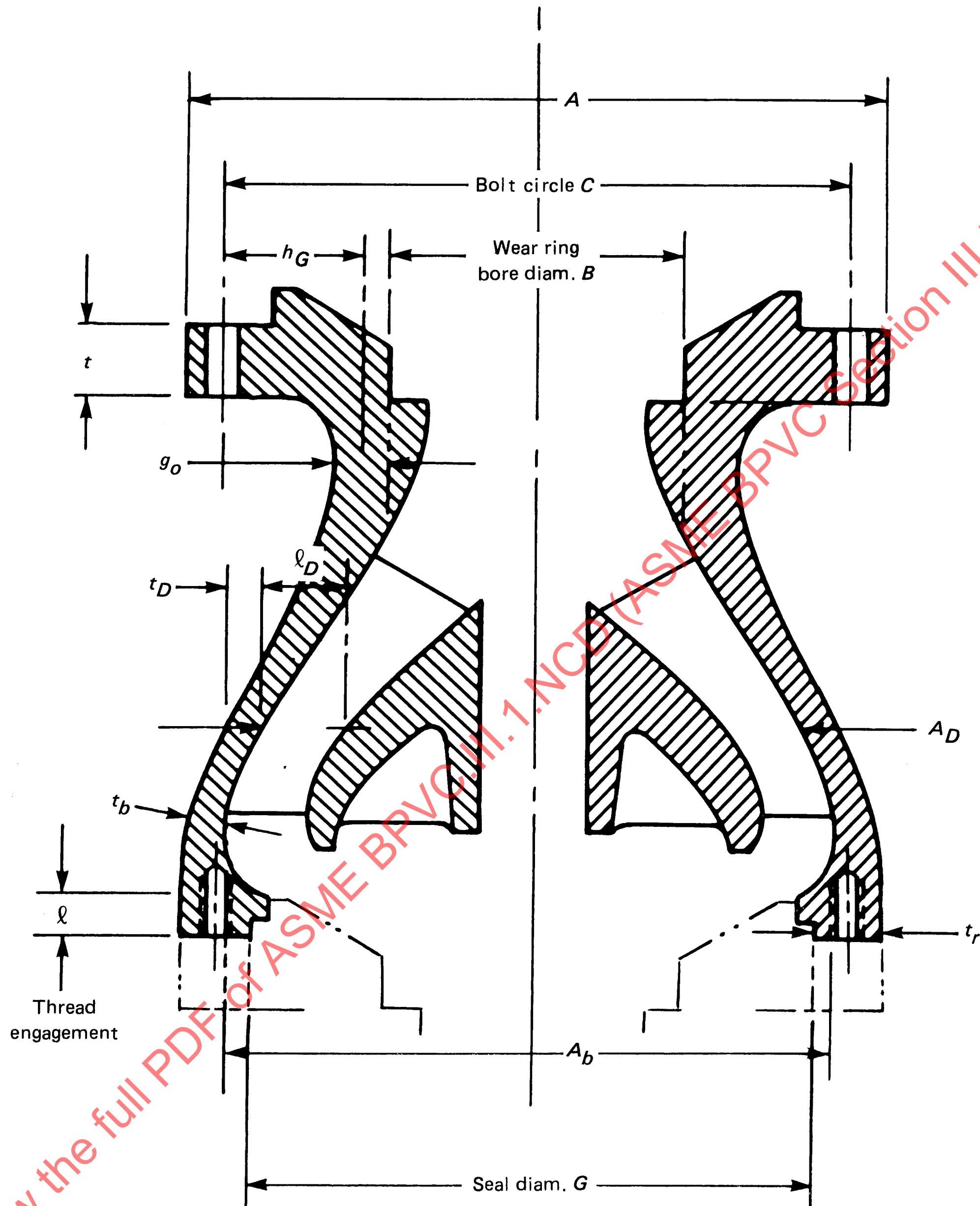
where

D_o = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly (Figure NCD-3441.10-2), in. (mm)

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.

Figure NCD-3441.10-2
Type L Pump Bowl



$$F_D = \frac{2(2 - \mu)\, P_b A_D^{\,2}}{\dfrac{16 l_D t_D}{t_v} + \dfrac{t_D(\pi A_D)^3}{(n_v t_d)^3}} \qquad (7)$$

where

A_D = the mean diameter of the vaned portion of the bowl as defined in Figure NCD-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)
l_D = the radial mean vane length as defined in Figure NCD-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 NCD-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 1.5*SE*. Its value is determined by the equation

$$\sigma_v = \frac{F_D}{t_v} \qquad (8)$$

(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 Section III Appendices, Mandatory 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 NCD-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 NCD-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.

NCD-3441.11 For Class 2 Only — Type N Pumps.

(a) Type N pumps have radially split, multistage barrel type casings with single nozzles each for suction and discharge, radially disposed with respect to the shaft axis [Figure NCD-3441.11-1, sketch (a)].

The design shall be in accordance with the applicable requirements of NCD-3400.

(b) Minimum transition radii at critical sections of the barrel shall be limited to 0.2 in.

(c) The circumferential pitch between drilled and tapped holes shall be a minimum of 2*d* where *d* is the nominal diameter of the bolt or stud [Figure NCD-3441.11-1, sketch (b)].

(d) The minimum distance, *X*, between the bottom of the hole and the nozzle opening shall be greater than or equal to the greater of the minimum, nozzle, wall thickness or 50% of the hole diameter as shown [Figure NCD-3441.11-1, sketch (c)].

NCD-3442 Special Pump Types

NCD-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. Any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

NCD-3442.2 Design of Reciprocating Pumps. See NCD-3450.

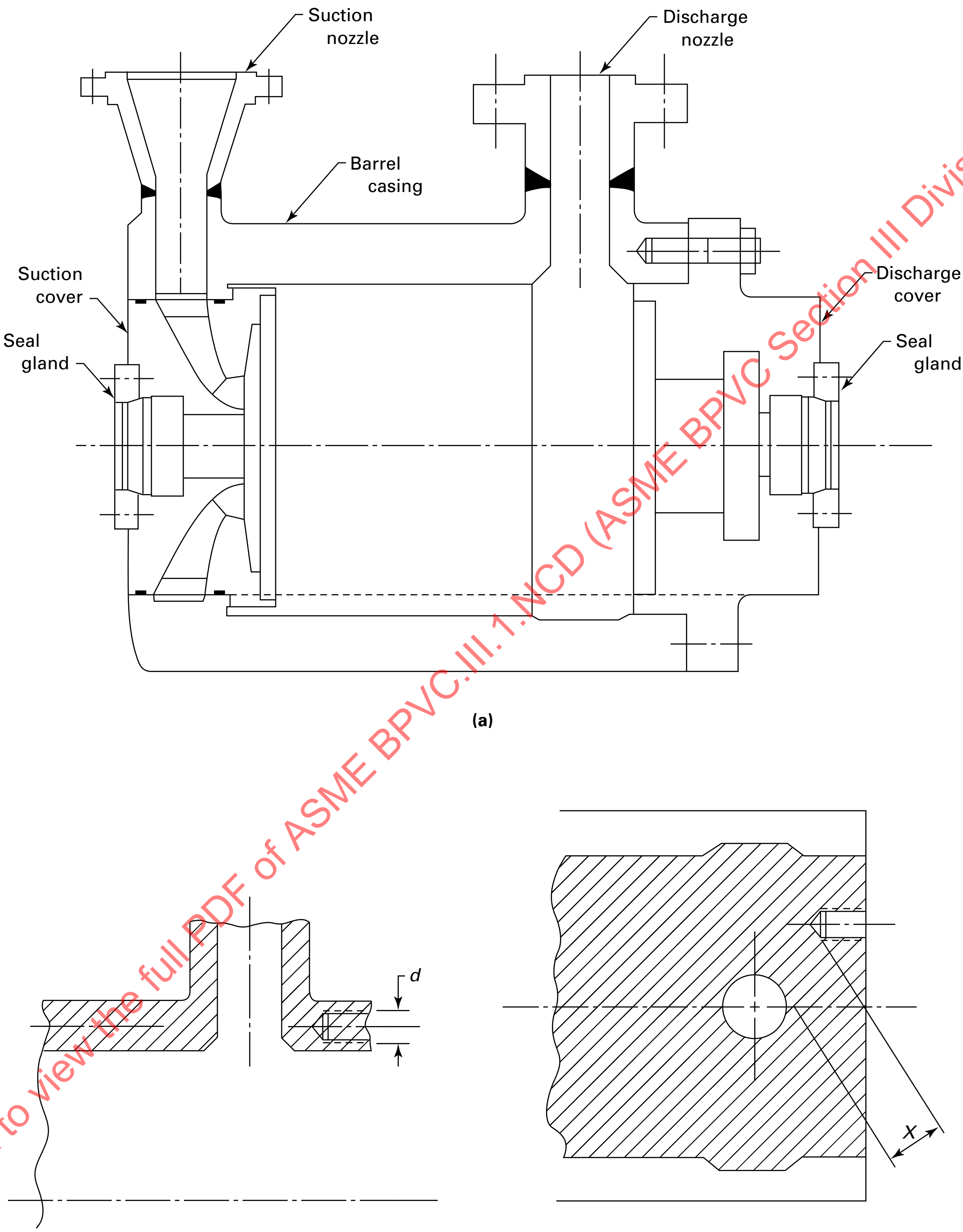
NCD-3450 DESIGN OF CLASS 2 RECIPROCATING PUMPS

NCD-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Figure NCD-3451(a)-1], whose failure would violate the pressure boundary. Such parts include

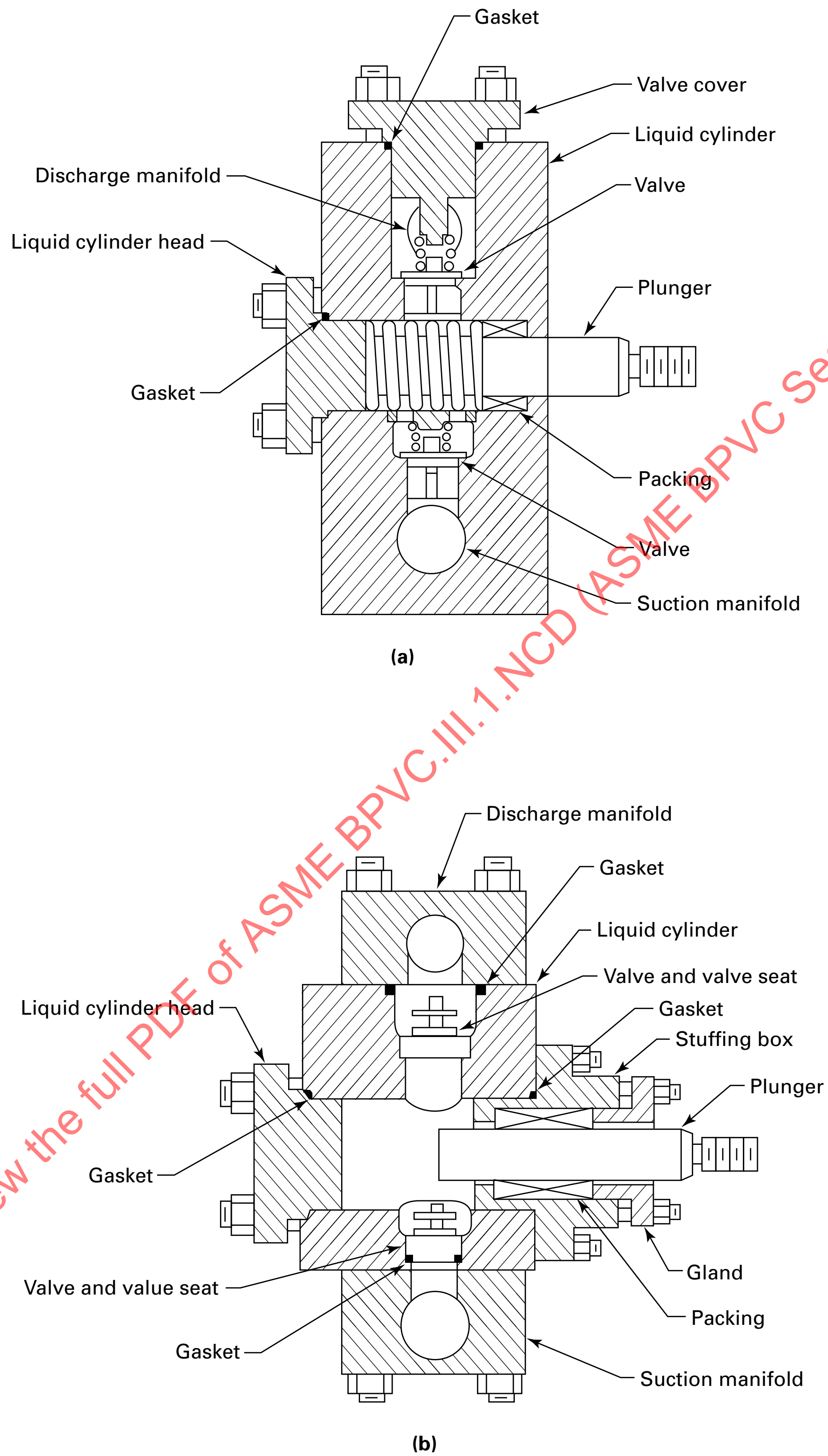
(1) liquid cylinder and valve chambers
(2) valve covers
(3) liquid cylinder heads
(4) stuffing boxes
(5) packing glands
(6) manifolds
(7) piping and nozzles normally identified with the pump and furnished by the pump supplier
(8) related bolting
(9) external and internal integral attachments to the pressure-retaining boundary

Figure NCD-3441.11-1
Type N Pump



(a) (b) (c)

Figure NCD-3451(a)-1
Horizontal Single-Acting Power Pump Liquid Ends



(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.

NCD-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 NCD-3100 are satisfied in addition to these rules.

NCD-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of Article NCD-2000.

NCD-3454 Design Requirements

NCD-3454.1 Design of Welded Construction.

(a) Design of welded construction shall be in accordance with NCD-3350.

(b) Partial penetration welds, as shown in Figure NCD-4244.1-5 sketch (c-3) and Figure NCD-4266(d)-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.

NCD-3454.2 Piping. Piping located within the pressure-retaining boundary of the pump, and identified with the pump, shall be designed in accordance with NCD-3600.

NCD-3454.3 Liquid End. Any design method that has been demonstrated to be satisfactory for the specified design may be used.

NCD-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.

NCD-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.

NCD-3454.6 Corrosion. In designs where corrosion of material is a factor, allowances shall be made.

NCD-3454.7 Bolting. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.

NCD-3500 VALVE DESIGN

NCD-3510 GENERAL REQUIREMENTS

NCD-3511 Design Specification (21)

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification [NCA-3211.19(b)]. The requirements of NCA-3211.19(c)(1)(-a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of NCD-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3211.19(c)(1)(-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.

NCD-3512 Standard Design Rules

NCD-3512.1 Flanged and Butt Welding End Valves. The design of valves with flanged and butt welding 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:

$$t_m = 0.4t_o + 0.2 \text{ for } d \leq 50 \text{ in. } (1{,}250 \text{ mm})$$

or

$$t_m = 0.008d + 0.2 \text{ for } d > 50 \text{ in. } (1{,}250 \text{ mm})$$

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, 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.

NCD-3512.2 Socket Welding End and Nonwelding End Valves. The design of valves with socket welding end connections and nonwelding piping end connections other than ASME B16.5 flanges shall conform to the applicable requirements for Standard Class category butt welding end valves of ASME B16.34, except that the end connections shall conform to the applicable requirements of NCD-3661 or NCD-3671.

Instrument, control, and sampling line valves, NPS 1 (DN 25) and smaller, with welding or nonwelding piping or tubing end connections other than flanges, and with body wall thickness not meeting Standard Class category valves of ASME B16.34, are acceptable, provided that the following additional requirements of (a) through (g) are met:

(a) The valve design shall meet one or more of the following:

(1) the pressure design rules of NCD-3324

(2) an experimental stress analysis (Section III Appendices, Mandatory Appendix II)

(3) design based on stress analysis (Section III Appendices, Mandatory Appendix XIII) and meeting the limits of Section III Appendices, Mandatory Appendix XIII

(b) The end connections shall meet the requirements of NCD-3661, NCD-3671.3, or NCD-3671.4 for welded, threaded, flared, flareless, and compression-type fitting tube ends.

(c) Valve loadings, including but not limited to operation, closure, and assembly, shall be accounted for by one of the following methods:

(1) experimental stress analysis (Section III Appendices, Mandatory Appendix II), or

(2) design based on stress analysis (Section III Appendices, Mandatory Appendix XIII).

(d) All valves shall meet the requirements of NCD-3521.

(e) Valve bonnets threaded directly into valve bodies shall have a lock weld or locking device to ensure that the assembly does not disengage through either stem operation or vibration.

(f) The valve's design shall be qualified and a maximum pressure–temperature rating shall be determined in accordance with the requirements of MSS SP-105, Section 5. A lesser pressure–temperature rating may be applied to the valve.

(g) Valves shall be hydrostatic tested per the requirements of NCD-3531 at pressures appropriate for the valve's applied pressure rating.

NCD-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.

NCD-3512.4 Design and Service Loadings. The design requirements of NCD-3512.1 and NCD-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 NCD-3520 shall be met.

NCD-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 NCD-3330.

NCD-3513 Alternative Design Rules

For butt welding end valves and for socket welding end valves whose end connections conform to the requirements of NCD-3661, the design requirements for Special Class category valves of ASME B16.34 may be used in place of NCD-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 NCD-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 NCD-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 NCD-3330.

NCD-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.

NCD-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 NCD-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 additional requirements below.

(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.

NCD-3520 SERVICE LOADING LIMITS

NCD-3521 General Requirements

(a) When the piping system in which the valve is located is designed to the requirements of NCD-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 NCD-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.

(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_{pipe}/S_{valve}.

(b) The maximum internal pressure resulting from Service Loadings for which Level A, Level B, Level C, or Level D limits are designated shall not exceed the tabulated factors in Table NCD-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 NCD-3521-1 are considered to be satisfied. Conversely, if the stress limits in Table NCD-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 NCD-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.

NCD-3522 Stress and Pressure Limits

Stress and pressure limits for service loadings are specified in Table NCD-3521-1. The symbols used in Table NCD-3521-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, 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.

Figure NCD-3521-1
Typical Sections of Valve Bodies

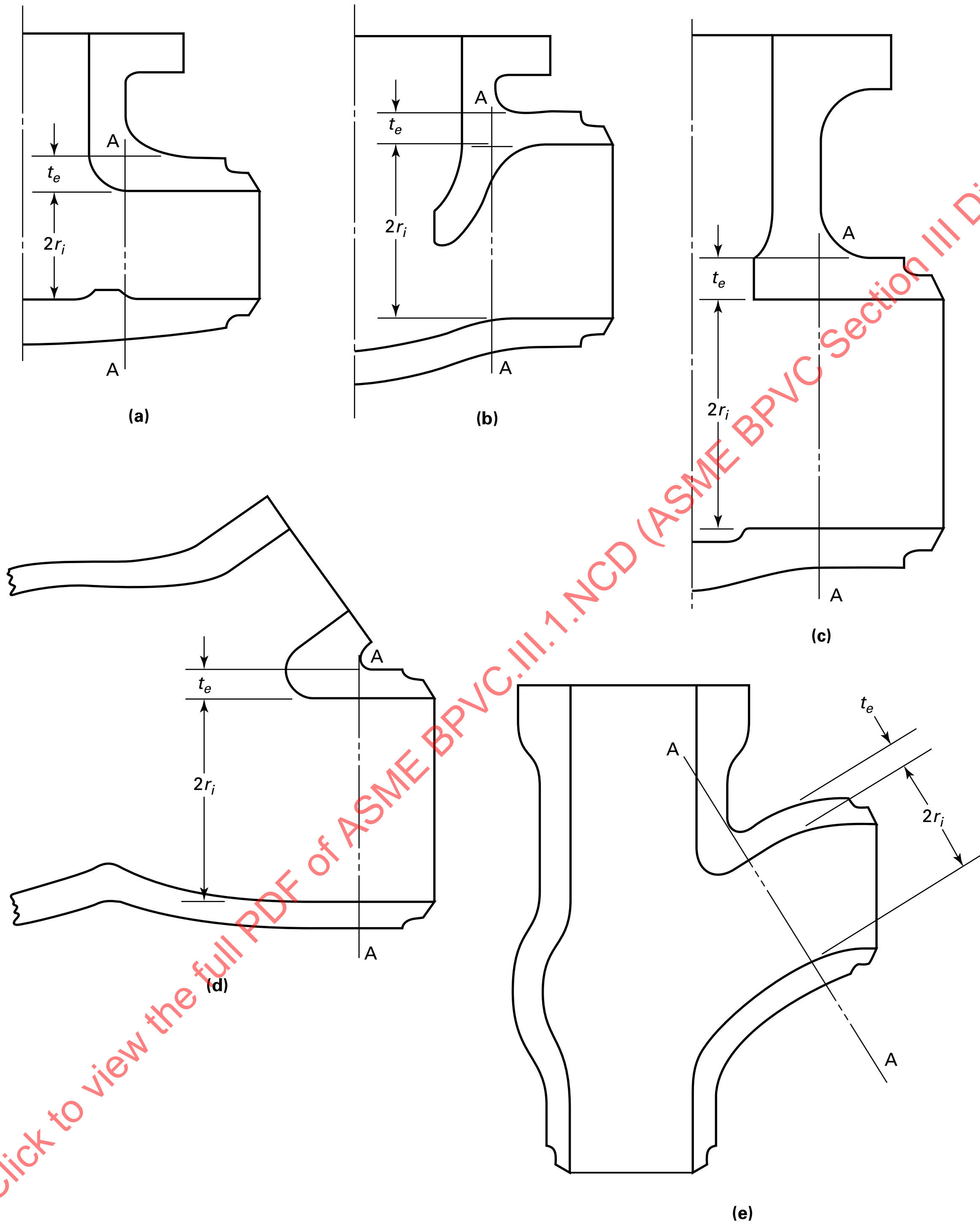


Table NCD-3521-1
Service Loading Limits

Service Loading	Stress Limits [Notes (1)–(4)]	P_{max} Note (5)
Level A	$\sigma_m \leq S$	1.0
	$(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.5S$	
Level B	$\sigma_m \leq 1.1S$	1.1
	$(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.65S$	
Level C	$\sigma_m \leq 1.5S$	1.2
	$(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.8S$	
Level D	$\sigma_m \leq 2.0S$	1.5
	$(\sigma_m$ or $\sigma_L) + \sigma_b \leq 2.4S$	

NOTES:
(1) A casting quality factor of 1 shall be assumed in satisfying these stress limits.
(2) The above limits are not intended to ensure the functional adequacy of the valve.
(3) The above limits are not applicable to valve disks, stems, seat rings, or other parts of the valves that are contained within the confines of the body and bonnet.
(4) The above limits do not apply to safety relief valves.
(5) 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.

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.

NCD-3530 GENERAL RULES

NCD-3531 Hydrostatic Tests

The following requirements apply to valves designated to either NCD-3512 or NCD-3513.

(21) **NCD-3531.1 Shell Hydrostatic Test.** For valves other than pilot-operated pressure relief valves and power-actuated pressure relief valves, 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.

For pilot-operated pressure relief valves and power-actuated pressure relief valves, the hydrostatic tests shall be performed in accordance with NCD-3593.1 and in accordance with the appropriate rules of Article NCD-6000.

NCD-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.

NCD-3531.3 Time at Pressure. The duration of the shell hydrostatic test shall meet the requirements of NCD-6223. The duration of the valve closure test shall be 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.

NCD-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 (38 °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 NCD-3531.2 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.

NCD-3590 PRESSURE RELIEF VALVE DESIGN

NCD-3591 Acceptability (21)

NCD-3591.1 General Requirements. The rules of this subsubarticle constitute the requirements for the design acceptability of direct spring-loaded pressure relief valves. The design rules for pilot-operated and power-actuated pressure relief valves are covered by NCD-3510 through NCD-3522.

NCD-3591.2 Applicable Items. 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 non-pressure-retaining items. Figures NCD-3591.2-1 and NCD-3591.2-2 are illustrations of typical direct spring-loaded pressure relief valves.

NCD-3591.3 Definitions. The definitions for pressure relief valve terms used in this subsubarticle are given in ASME PTC 25 and also in Article NCD-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 NCD-3591.2-1 and NCD-3591.2-2.

NCD-3591.4 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 NCD-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.

NCD-3591.5 Acceptability of Large Pressure Relief Valves. The design shall be such that the requirements of this subsubarticle are met.

NCD-3592 Design Considerations

NCD-3592.1 Design Conditions. The general design requirements of NCD-3100 are applicable, with consideration for the design conditions of the primary and secondary pressure zones. In case of conflict between NCD-3100 and NCD-3590 the requirements of NCD-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 Article NCD-7000 shall be met.

NCD-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 1.5*S*.

(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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

(b) Levels B, C, and D Service Loadings. Stress limits for Levels B, C, and D service loadings are specified in Table NCD-3592.2(b)-1. The symbols used in Table NCD-3592.2(b)-1 are defined in NCD-3522.

NCD-3593 Special Rules

NCD-3593.1 Hydrostatic Test. Pressure relief valve shell hydrostatic tests shall be made in accordance with NCD-3531.1 and NCD-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 (NCD-7111).

NCD-3593.2 Marking. In addition to marking required by NCA-8220 and Article NCD-7000, the secondary Design Pressure shall be marked on the valve or valve nameplate.

NCD-3594 Service Loading Limits

(a) When the piping system in which the valve is located is designed to the requirements of NCD-3600, the valve body may be considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied.

(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 NCD-3591.2-1 and NCD-3591.2-2) 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_{pipe}/S_{valve}.

(b) The pressure-retaining portions of pressure relief valves shall conform to the stress limits listed in Table NCD-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.

NCD-3595 Design of Pressure Relief Valve Parts

NCD-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

Figure NCD-3591.2-1
Typical Pressure Relief Devices

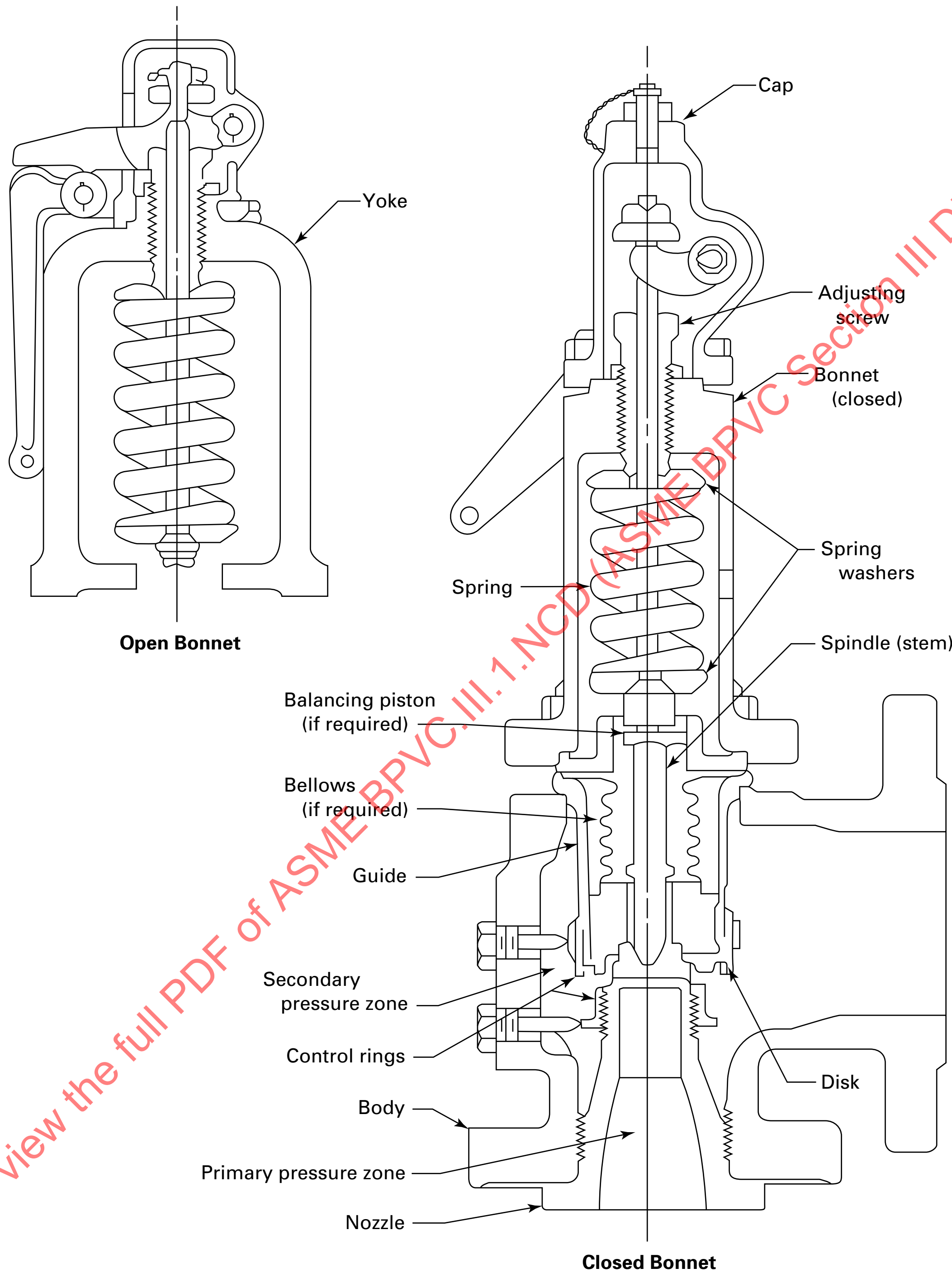
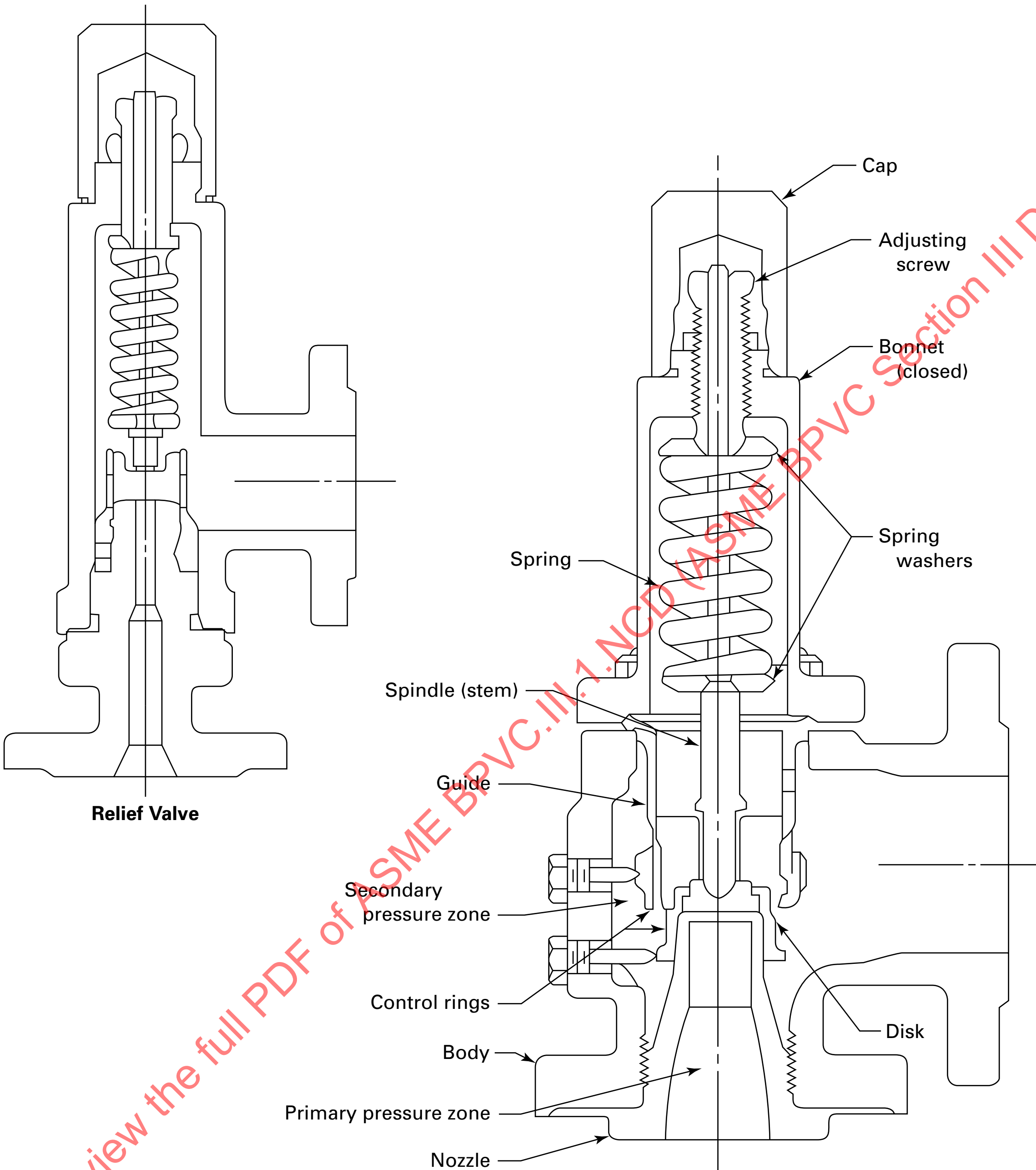


Figure NCD-3591.2-2
Typical Pressure Relief Devices



Relief Valve

Safety Relief Valve

Table NCD-3592.2(b)-1
Pressure Relief Devices Service Loading Limits

Service Loading	Stress Limits
Level B	$\sigma_m \le 1.1S$
	$(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.65S$
Level C	$\sigma_m \le 1.5S$
	$(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.8S$
Level D	$\sigma_m \le 2.0S$
	$(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 2.4S$

GENERAL NOTES:
(a) A casting quality factor is not required to satisfy these limits.
(b) The above limits are not intended to ensure the functional adequacy of the valve. However, the designer is cautioned that the requirements of Article NCD-7000 relative to set pressure, lift, blowdown, and closure shall be met.
(c) The above limits are applicable to those portions of the valves that are pressure retaining or affect pressure-retaining items of these valves.

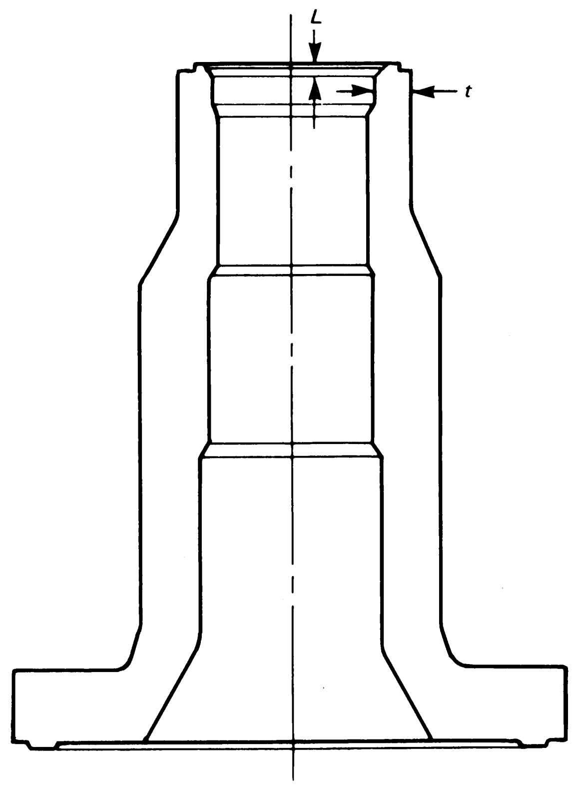
thickness adjacent to the inlet nozzle and for a distance equal to that minimum wall thickness from the plane of the back face of the inlet flange shall be that required for Standard Class category valves of ASME B16.34 for the inlet flange size and pressure class. Minimum wall thicknesses elsewhere 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 NCD-3658. Additional metal thickness needed for operating stresses, shapes other than circular, stress concentrations, and adequate structural strength of valve body crotch areas for bending stresses and installation stress that may be imposed on the valve must be determined by the manufacturer.

NCD-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 NCD-3592.2.

(21) **NCD-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 NCD-3595.3-1, provided the dimension L is less than the nominal wall thickness t. In accordance with NCD-2121(c), for materials not listed in Section II, Part D, Subpart 1, Tables 1A and 1B, the S value shall be determined in accordance with the rules of Section II, Part D, Mandatory Appendix 1.

NCD-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 Section II, Part D, Subpart 1, Table 3.

Figure NCD-3595.3-1
Valve Nozzle



GENERAL NOTE: $L < t$ where
L = length of seal transition region, in. (mm)
t = nozzle wall thickness, in. (mm)

(21) **NCD-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 NCD-3592.2. In accordance with NCD-2121(c), for materials not listed in Section II, Part D, Subpart 1, Tables 1A and 1B, the *S* value shall be determined in accordance with the rules of Section II, Part D, Mandatory Appendix 1.

NCD-3595.6 Spring Washer. The shear stress shall not exceed 0.6*S*. The bending stress shall not exceed the stress limits of NCD-3592.2.

NCD-3595.7 Spindle (Stem). The general membrane stress shall not exceed the stress limits of NCD-3592.2.

NCD-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 0.6*S*. The general membrane stress of the adjusting screw shall not exceed the stress limits of NCD-3592.2, based on the root diameter of the thread.

NCD-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.

NCD-3596 Design Reports

(21) **NCD-3596.1 General Requirements.** The manufacturer shall certify compliance with the requirements of this subarticle in accordance with the provisions of NCA-3211.10.

NCD-3600 PIPING DESIGN

NCD-3610 GENERAL REQUIREMENTS

NCD-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NCD-3611.1 Allowable Stress Values. Allowable stress values to be used for the design of piping systems are given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NCD-3611.2 Stress Limits.

(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. NCD-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 NCD-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. NCD-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 NCD-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 shall meet the requirements of NCD-3655.

(4) Test Conditions. Testing shall be in accordance with Article NCD-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 NCD-3641.2.

(e) Allowable Stress Range for Expansion Stresses. The allowable stress range S_A is given by eq. (1)

$$S_A = f(1.25\, S_c + 0.25\, S_h) \tag{1}$$

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 NCD-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.

Table NCD-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

(2) Stress reduction factors apply essentially to noncorrosive 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:

$$N = N_E + r_1{}^5 N_1 + r_2{}^5 N_2 + \ldots, + r_n{}^5 N_n \qquad (2)$$

where

N_E = number of cycles at full temperature change ΔT_E for which expansion stress S_E has been calculated

$N_1, N_2, \ldots, N_n$ = number of cycles at lesser temperature changes, ΔT_1, ΔT_2, ..., ΔT_n

$r_1, r_2, \ldots, r_n$ = $(\Delta T_1)/(\Delta T_E)$, $(\Delta T_2)/(\Delta T_E)$, ..., $(\Delta T_n)/(\Delta T_E)$
= 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. NCD-3653.2(b)(10b) shall be $3.0S_c$.

NCD-3611.3 Alternative Analysis Methods. The specific design requirements of NCD-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. 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.

NCD-3612 Pressure–Temperature Ratings for Piping Products

NCD-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 Section II, Part D, Subpart 1, Tables 1A and 1B 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.

NCD-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 NCD-3640 and NCD-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.

NCD-3612.4 Considerations for Local Conditions and Transients. (21)

(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 NCD-7311 and NCD-7321.

(3) Ensure 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 ensure 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 NCD-7311 and NCD-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 Article NCD-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)
Above 600 (4.0) to 900 (6.0)	400 (3.0)	450 (230)
Above 900 (6.0) to 1,500 (10.0)	600 (4.0)	490 (255)
Above 1,500 (10.0)	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.

NCD-3613 Allowances

NCD-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.

NCD-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.

NCD-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.

NCD-3613.4 Pressure Design Weld Joint Efficiency for Butt Welds. For Class 2 piping, the joint efficiency factor, E, equals 1.0. For Class 3 piping, longitudinal weld joint efficiency factors for pressure design for butt welds as listed in Table NCD-3613.4-1 shall be applied to the allowable stress values given in Section II, Part D, Subpart 1, Tables 1A and 1B.

Table NCD-3613.4-1
For Class 3 Only — Weld Joint Efficiency Factor

Type of Longitudinal Joint	Weld Joint Efficiency Factor, E
Arc weld	
Single butt weld	0.80
Double butt weld	0.90
Single or double butt weld with 100% radiography per NCD-2560 for joints welded with filler metal or otherwise examined by ultrasonic methods per NCD-2550 for joints welded without filler metal, as applicable	1.00
Electric resistance weld	0.85

NCD-3613.5 Steel Casting Quality Factors. The quality factors for castings required in Section II, Part D, Subpart 1, Tables 1A and 1B 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 NCD-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

NCD-3620 DESIGN CONSIDERATIONS

NCD-3621 Design and Service Loadings

The provisions of NCD-3110 shall apply, except as modified in this subarticle.

NCD-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.

NCD-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.

NCD-3622 Dynamic Effects

NCD-3622.1 Impact. Impact forces caused by either external or internal loads shall be considered in the piping design.

NCD-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 NCD-3600 when the number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

NCD-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.

NCD-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.

NCD-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 NCD-3622-1). Reflected waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

NCD-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.

NCD-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.

NCD-3623.2 Dead Weight. The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

NCD-3624 Thermal Expansion and Contraction Loads

NCD-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.

NCD-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 NCD-3649.1 through NCD-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.

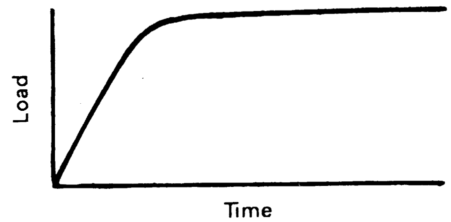
NCD-3640 PRESSURE DESIGN OF PIPING PRODUCTS

NCD-3641 Straight Pipe

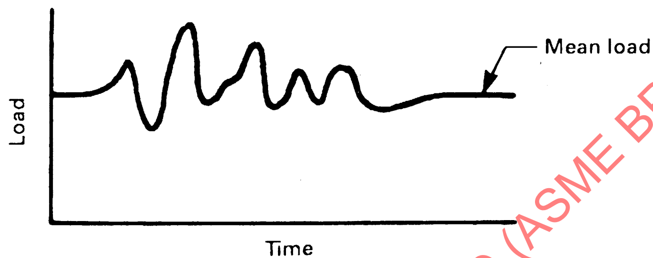
NCD-3641.1 Straight Pipe Under Internal Pressure. The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Section II, Part D, Subpart 1, Tables 1A and 1B, including allowances for mechanical strength, shall not be less than that determined by eq. (3) as follows:

$$t_m = \frac{PD_o}{2(SE + Py)} + A \tag{3}$$

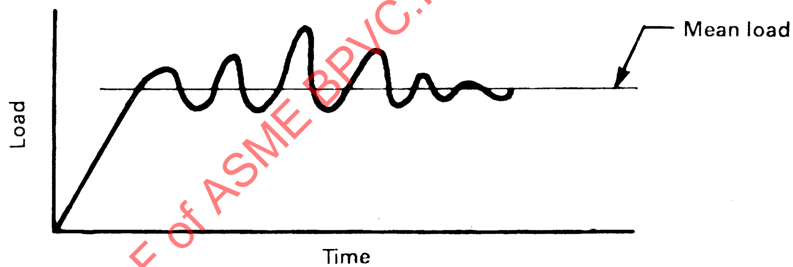
Figure NCD-3622-1
Examples of Reversing and Nonreversing Dynamic Loads



(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)

Table NCD-3641.1(a)-1
Values of *A*

Type of Pipe	*A*, in. (mm)
Threaded steel and nonferrous pipe:	
$^3/_4$ 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 $^1/_{64}$ in. (0.4)

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)} \quad (4)$$

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 NCD-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 NCD-3613.4-1, or casting quality factor determined in accordance with NCD-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.

(c) For reinforced branch connections (NCD-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 Section III Appendices, 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 (NCD-3642.1), and 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

$$y = \frac{d}{d + D_o} \quad (6)$$

NCD-3641.2 Straight Pipe Under External Pressure. For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in NCD-3133 shall be followed.

NCD-3642 Curved Segments of Pipe

NCD-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 NCD-4223.2.

(c) The information in Section III Appendices, Nonmandatory Appendix GG is given to guide the designer when ordering pipe.

NCD-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.

NCD-3643 Intersections

NCD-3643.1 General Requirements.

(a) NCD-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 NCD-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 NCD-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 $1^1/_4$ 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 NCD-3643.3 shall be met.

(3) extruded outlets at right angles to the run pipe, in accordance with NCD-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 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 $^1/_{16}$ 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 $^1/_{16}$ 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 $1^1/_4$ times the nominal branch wall thickness;

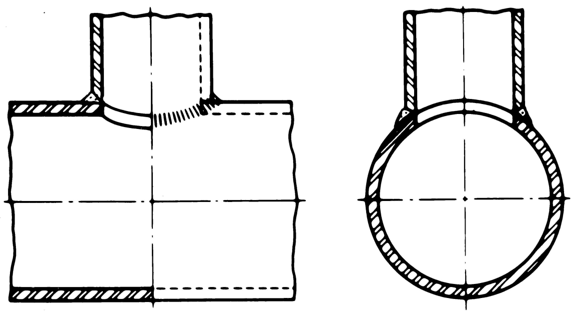
(-5) the requirements of NCD-3643.3 shall be met.

(-b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of NCD-3671.3 and provided the requirements of (-1) and (-2) below are met:

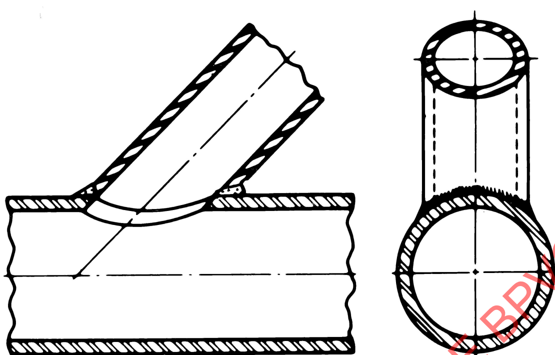
(-1) the nominal size of the branch does not exceed NPS 2 (DN 50) or one-fourth the nominal size of the run, whichever is less;

(-2) minimum thread engagement shall be six full threads for $^1/_2$ in., and $^3/_4$ in. (DN 15 and DN 20) branches; seven for 1 in., $1^1/_4$ in., and $1^1/_2$ 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;

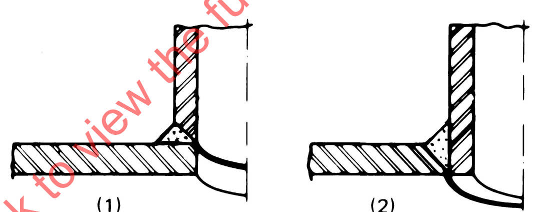
Figure NCD-3643.2(b)-1
Typical Welded Branch Connections



(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

(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 NCD-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Figure NCD-3643.3(c)(1)-1 or Figure NCD-3643.3(c)(1)-2, provided the requirements of NCD-3643.3 are met; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure NCD-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 $1^1/_4$ times the nominal branch wall thickness;

(-3) the groove angle, θ, shall be equal to or greater than 45 deg;

(-4) the requirements of NCD-3643.3 shall be met.

NCD-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;

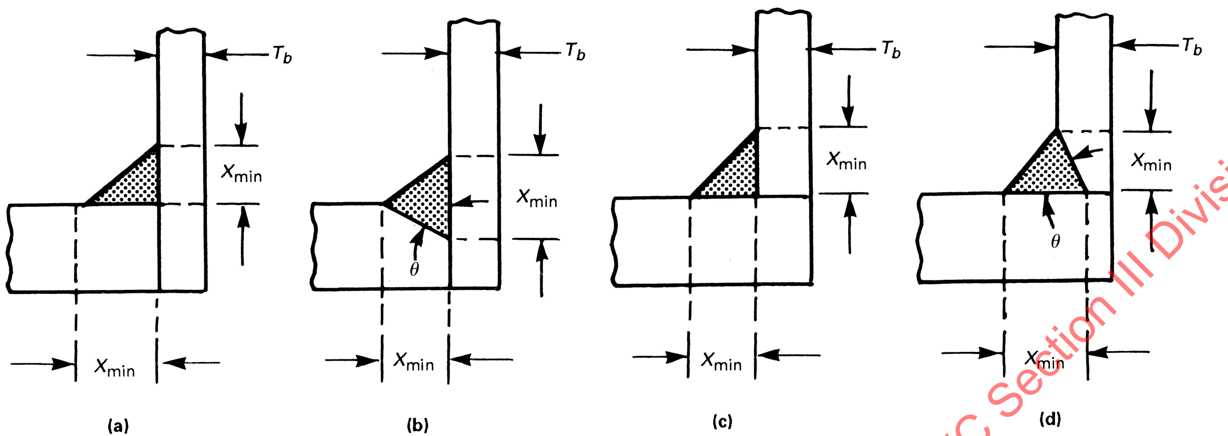
(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Figure NCD-3643.2(b)-1 sketch (c)(1) or Figure NCD-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.

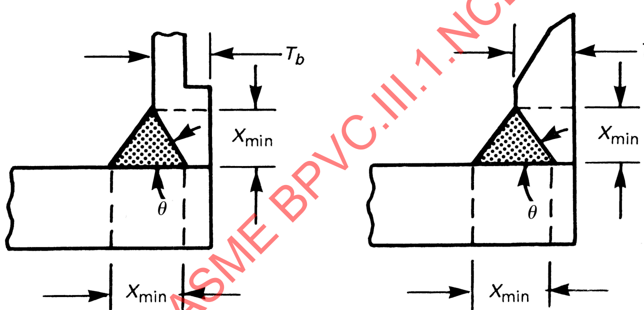
NCD-3643.3 Branch Connections Requiring Reinforcement.

(a) Calculations shall be made to determine the adequacy of reinforcement in branch connections except as exempted in NCD-3643.2.

Figure NCD-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



(e) ANSI B16.11 Coupling   (f) 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

(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 NCD-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. NCD-3643.5 gives rules governing the design of connections to sustain external pressure.

(1) Nomenclature. Figures NCD-3643.3(c)(1)-1 and NCD-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)
= 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 NCD-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. NCD-3641.1(3) or eq. NCD-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), NCD-3643.4, or NCD-3643.5.

(3) Reinforcement Area. The required reinforcement area in in.^{2} (mm^2) 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} (mm^2)
= $(2d_2 - d_1)\,[(T_h - \text{mill tolerance on } T_h) - t_{mh}]$
A_2 = area provided by excess pipe wall in the branch for a distance L above the run, in.^{2} (mm^2)
= $2L/\sin\alpha\,[(T_b - \text{mill tolerance on } T_b) - t_{mb}]$. 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} (mm^2)
A_4 = area provided by reinforcement, in.^{2} (mm^2)

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 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.

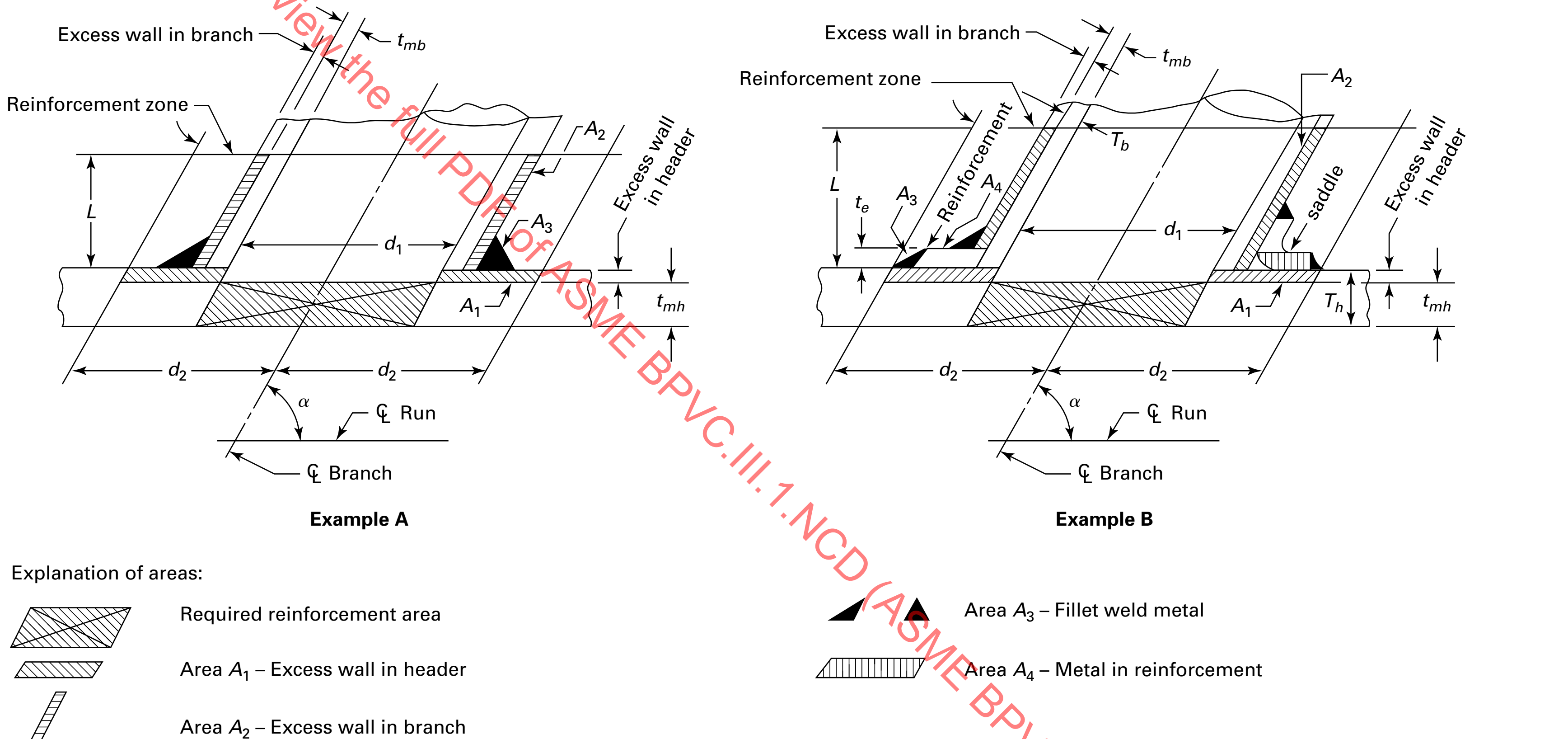
(6) Reinforcement of Multiple Openings

(-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 $1^1/_2$ 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.

Figure NCD-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:

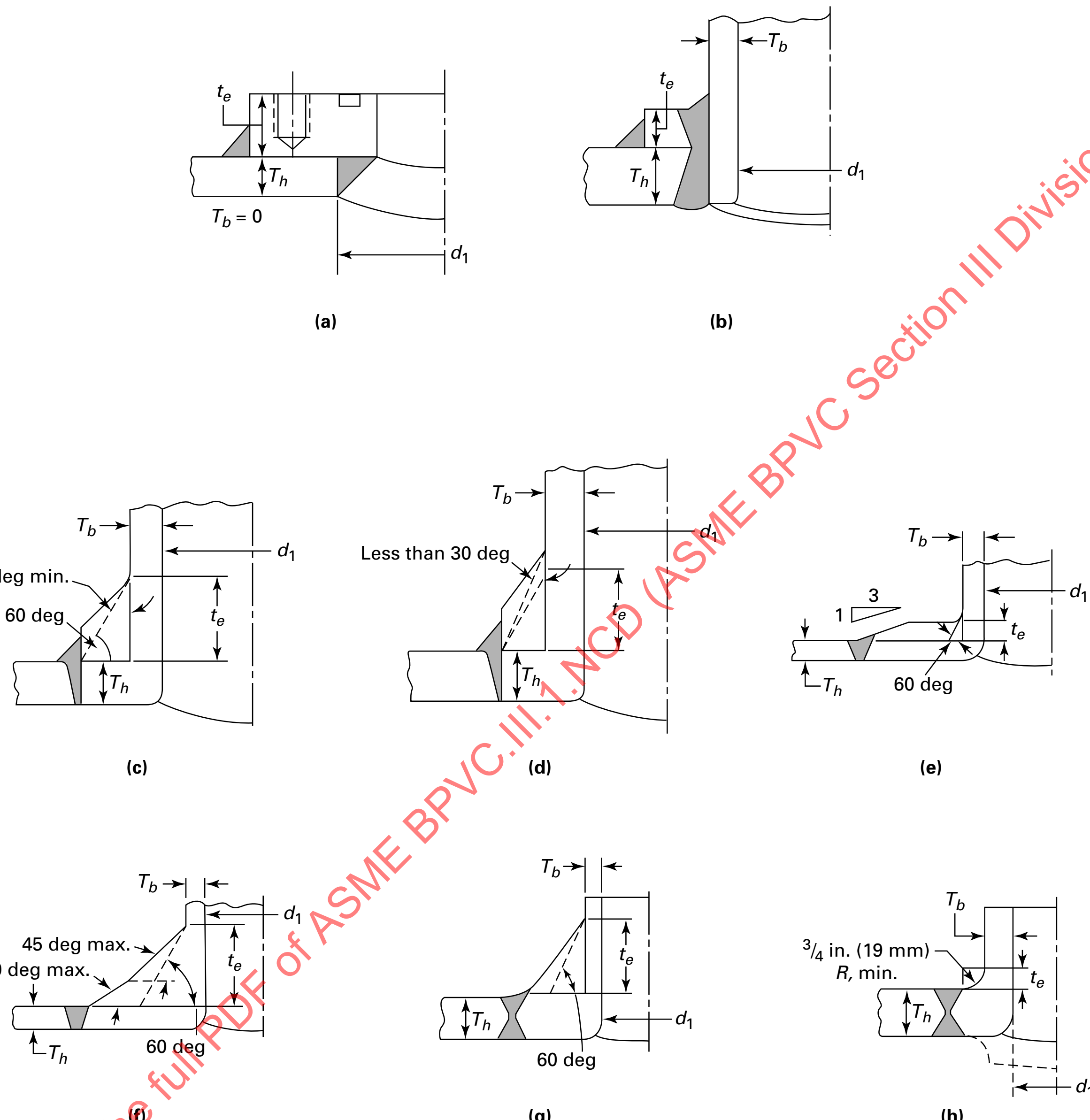
(a) When metal is added as reinforcement (Example B), the value of reinforcing area may be taken in the same manner in which excess header metal is considered. Typical acceptable methods of meeting the above requirement are shown in Figure NCD-3643.3(c)(1)-2.

(b) 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.

(c) This Figure is to be used only for definitions of terms, not for fabrication details.

(d) Use of reinforcing saddles and pads is limited as stated in NCD-3643.3(c)(7).

Figure NCD-3643.3(c)(1)-2
Some Representative Configurations Describing the t_e Reinforcement Dimension



(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.

NCD-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 NCD-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 NCD-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. NCD-3641.1(3) or eq. NCD-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. NCD-3641.1(3) or eq. NCD-3641.1(4), not including any allowance for corrosion, in. (mm)

(d) Radii

(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 $1^1/_2$ 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 $1^1/_4$ 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

(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

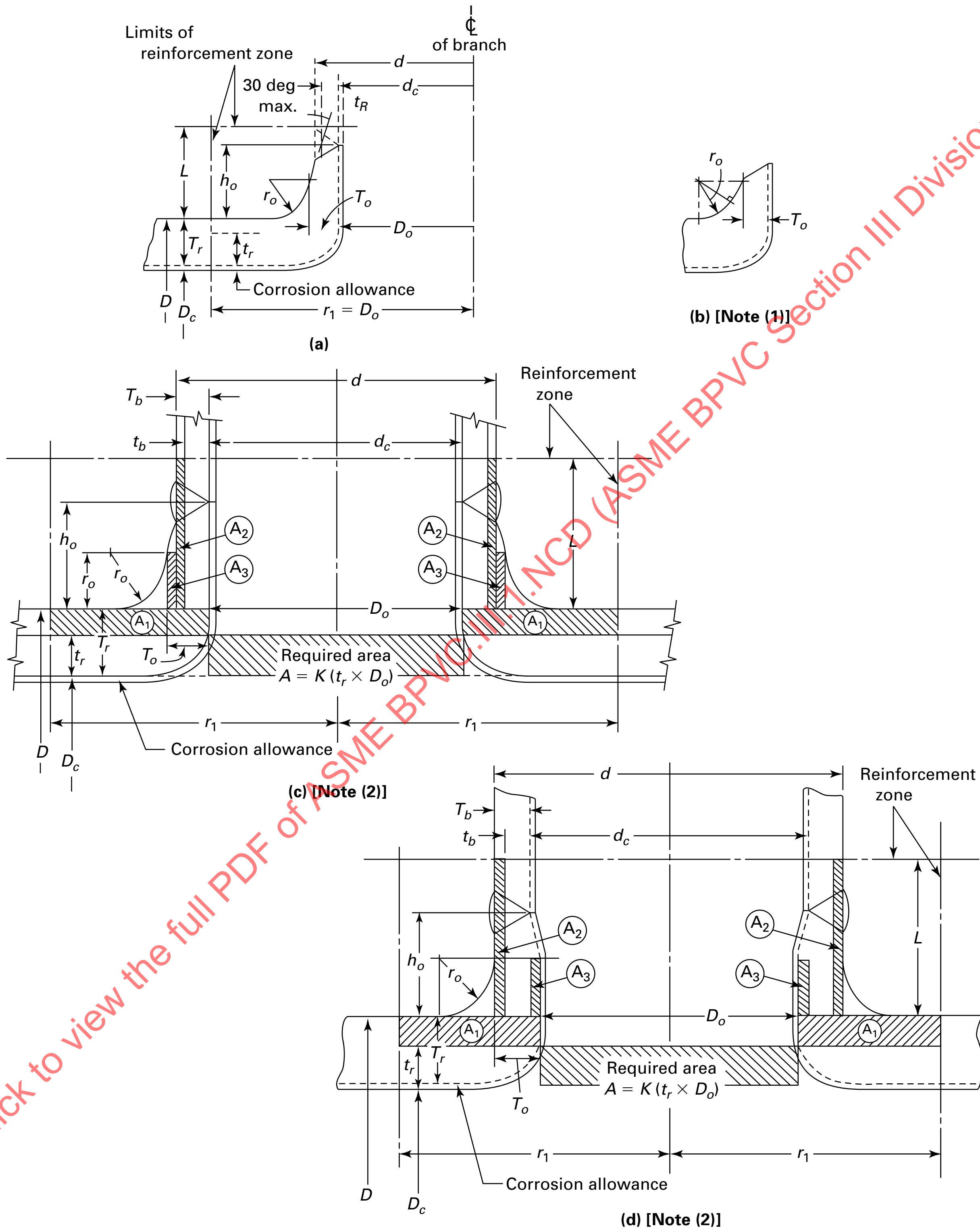
$$A_2 = 2L(T_b - t_b)$$

(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

Figure NCD-3643.4(a)-1
Reinforced Extruded Outlets



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.

shall be reinforced in accordance with NCD-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.

NCD-3643.5 Branch Connections Subject to External Pressure.

(a) The reinforcement area in in.^{2} (mm^2) required for branch connections subject to external pressure shall be $0.54(t_{mh})(d_1)(2 - \sin\alpha)$. All terms defined in NCD-3643.3(c)(1), except (t_{mh}) is the minimum required wall thickness as determined by NCD-3641.2.

(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

NCD-3643.6 Reinforcement of Other Designs. The adequacy of designs to which the reinforcement requirements of NCD-3643 cannot be applied shall be proven by burst or proof tests (NCD-3649) on scale models or on full-size structures, or by calculations previously substantiated by successful service of similar design.

NCD-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 NCD-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 NCD-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 NCD-3673.2(b)-1 shall not be more than $22^1/_2$ deg.

(d) The centerline distance between adjacent miters shall be in accordance with Table NCD-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

NCD-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 NCD-3135.

(c) The effect of rectangular and circular cross-section welded attachments on straight pipes may be evaluated using the procedures in Section III Appendices, Nonmandatory Appendix Y.

NCD-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 NCD-3300 using the equation

$$t_m = t + A$$

where

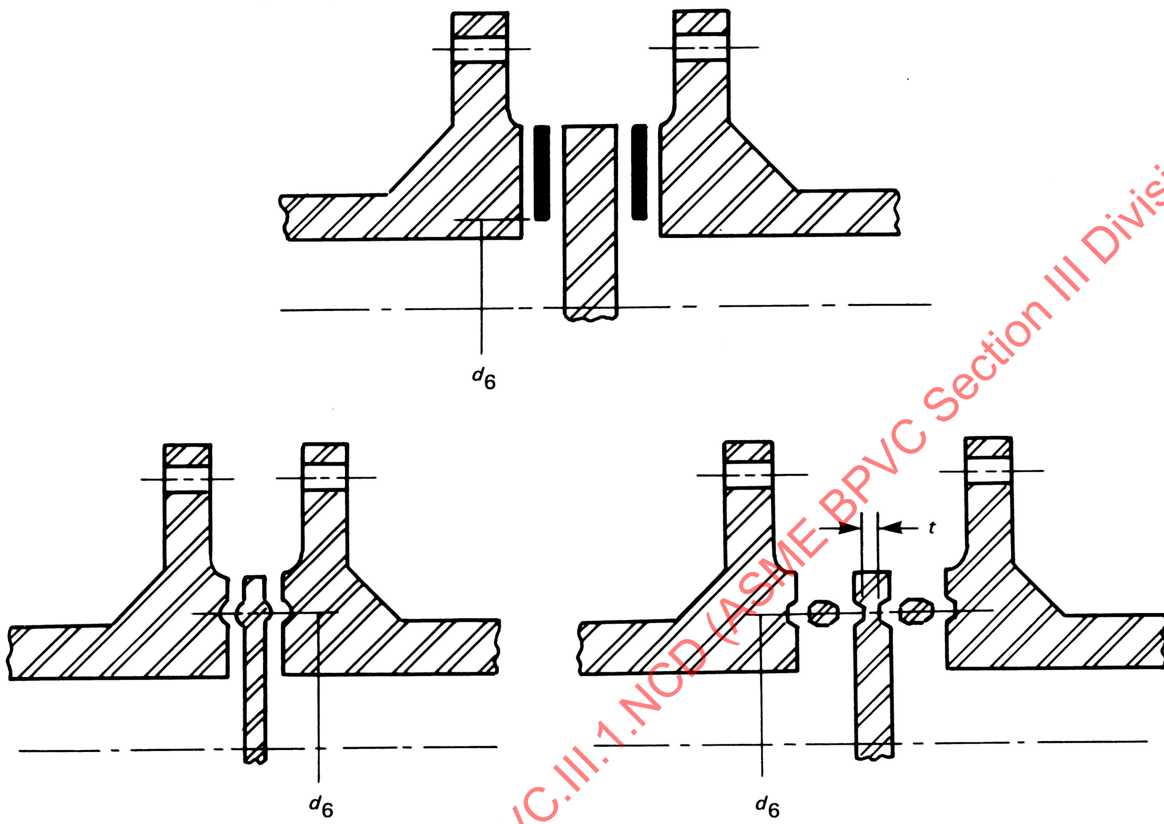
A = sum of mechanical allowances (NCD-3613), in. (mm)
t = pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in Article NCD-3000, in. (mm)
t_m = minimum required thickness, in. (mm)

(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 NCD-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 NCD-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_5t, where

d_5 = diameter of the finished opening, in. (mm)

Figure NCD-3647.2-1
Types of Permanent Blanks



t = pressure design thickness for the closure, in. (mm)

NCD-3647 Pressure Design of Flanged Joints and Blanks

NCD-3647.1 Flanged Joints.

(a) Flanged joints manufactured in accordance with the standards listed in Table NCA-7100-1, as limited by NCD-3612.1, shall be considered as meeting the requirements of NCD-3640.

(b) Flanged joints not included in Table NCA-7100-1 shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000.

NCD-3647.2 Permanent Blanks. The minimum required thickness of permanent blanks (Figure NCD-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A$$

where

A = sum of mechanical allowances (NCD-3613), in. (mm)

t = pressure design thickness calculated from the equation below, 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 Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)

t_m = minimum required thickness, in. (mm)

NCD-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 NCD-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).

NCD-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.

NCD-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.

NCD-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) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1^{1}/_{2}$ diameters in length. Studs greater than 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 $1^{1}/_{2}$ 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.

NCD-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.

NCD-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 (Section III Appendices, Mandatory Appendix II).

NCD-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.[20]

(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 Article NCD-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 NCD-4800.

NCD-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)

NCD-3649.3 Bellows Expansion Joint Material. Pressure-retaining material in the expansion joint shall conform to the requirements of Article NCD-2000.

NCD-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 Article NCD-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 $1^1/_2$ 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 [see Section III Appendices, Mandatory Appendix II, II-1520(g)], 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 Section III Appendices, Mandatory 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 NCD-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 Section II, Part D, Subpart 1, Tables 2A and 2B, and fatigue curves of Section III Appendices, Mandatory Appendix I 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 NCD-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, ..., n_n, respectively.

NOTE: In determining n_1, n_2, ..., n_n, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference S_1, S_2, ..., 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:

(a) Type 1 Cycle:

$$n_1 = 1{,}000$$
$$S_1 = (60{,}000 + 50{,}000) = 110{,}000 \text{ psi}$$

(b) Type 2 Cycle:

$$n_2 = 9{,}000$$
$$S_2 = (50{,}000 + 0) = 50{,}000 \text{ psi}$$

Step 2. For each value S_1, S_2, ..., 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, ..., 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, ..., 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, ..., S_n shall be reduced by a factor of 2, in which case S_1, S_2, ..., S_n become the alternating stresses.

Step 3. For each type of stress cycle, calculate the usage factors U_1, U_2, ..., U_n, from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, ..., $U_n = n_n/N_n$.

Step 4. Calculate the cumulative usage factor U from $U = U_1 + U_2 + ... + U_n$.

Step 5. The cumulative usage factor U shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with NCD-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 ensure 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.

NCD-3649.5 Metallic Braided Flexible Hoses. Metallic braided flexible hoses may be constructed in accordance with Section III Appendices, Nonmandatory Appendix BB.

NCD-3650 ANALYSIS OF PIPING DESIGNS

NCD-3651 General Requirements

(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 NCD-3650. The pressure portion of eqs. NCD-3652(8), NCD-3653.1(a)(9a), and NCD-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. NCD-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 NCD-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. The pressure term in eqs. NCD-3652(8), NCD-3653.1(a)(9a), NCD-3653.1(b)(9b) and NCD-3653.2(c)(11) may not apply for bellows and expansion joints.

(c) For analysis of flanged joints, see NCD-3658.

NCD-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of eq. (8)

$$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S_h \tag{8}$$

where

B_1, B_2 = primary stress indices for the specific product under investigation [Table NCD-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) (NCD-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} (mm^3) (NCD-3653.3)

NCD-3653 Consideration of Levels A and B Service Limits

NCD-3653.1 Occasional Loads. 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. Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

(a) The following requirements shall be met:

$$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \left(\frac{M_A + M_B}{Z} \right) \leq 1.8S_h \tag{9a}$$

but not greater than $1.5S_y$. Terms are the same as in NCD-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 $^1/_2$ 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. NCD-3653.2(a)(10a) or eq. NCD-3653.2(c)(11).
P_{max} = peak pressure, psi (MPa)
S_h = material allowable stress at a temperature consistent with the loading under consideration, psi (MPa)
S_y = material yield strength at a 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 Section II, Part D, Subpart 1, Table 2A, and limited to $(D_o/t_n) \leq 40$, if Level B Service limits are specified, which include reversing dynamic loads (NCD-3622.4) that are not required to be combined with nonreversing dynamic loads are specified, the requirements below shall apply.

$$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B'_2 \left(\frac{M_A + M'_B}{Z} \right) \leq 1.8S_h \tag{9b}$$

but not greater than $1.5S_y$. Terms are the same as in NCD-3652, except

B'_2 = as defined in NCD-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 $^1/_2$ the range. Effects of anchor displacement due to reversing dynamic loads may be excluded from eq. (9b) if they are included in either eq. NCD-3653.2(a)(10a) or eq. NCD-3653.2(c)(11).

P_{max} = peak pressure, psi (MPa)

S_h = material allowable stress at a temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

NCD-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)

$$S_E = \frac{iM_C}{Z} \leq S_A \tag{10a}$$

Terms are the same as in NCD-3652 and NCD-3653.1, except

i = stress intensification factor (NCD-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 nonreversing dynamic loads if anchor displacement effects were omitted from eq. NCD-3653.1(a)(9a) or eq. NCD-3653.1(b)(9b).

S_A = allowable stress range for expansion stresses (NCD-3611.2), psi (MPa)

(b) The effects of any single nonrepeated anchor movement shall meet the requirements of eq. (10b)

$$\frac{iM_D}{Z} \leq 3.0S_c \tag{10b}$$

Terms are the same as in NCD-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)

$$S_{TE} = \frac{PD_o}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \leq (S_h + S_A) \tag{11}$$

For eq. (11) 0.75i shall not be less than 1.0.

NCD-3653.3 Determination of Moments and Section Modulus.

(a) For purposes of eqs. NCD-3652(8), NCD-3653.1(a)(9a), NCD-3653.1(b)(9b), NCD-3653.2(a)(10a), NCD-3653.2(b)(10b), and NCD-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, or D which are the subscripts of M_A, M_B, M'_B, M_C, M_D defined in NCD-3652, NCD-3653.1, and NCD-3653.2

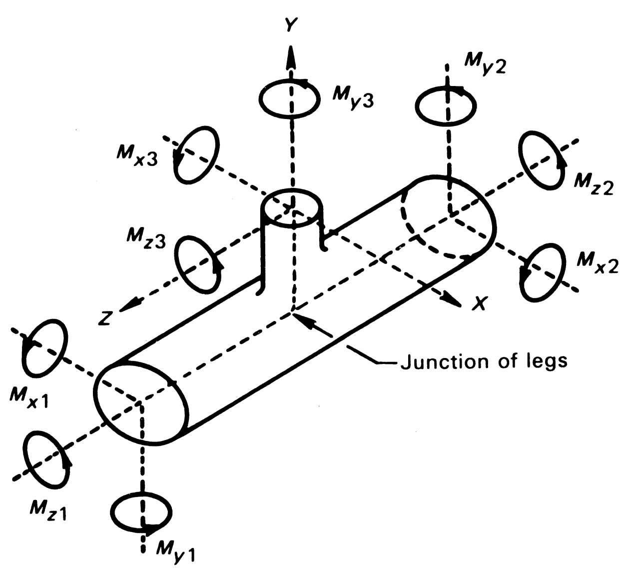
(b) For intersections (branch connections or tees), calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure NCD-3653.3-1) for full outlet intersections.

(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 NCD-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

$$Z = \pi(r'_m)^2 T'_b \text{ for the branch leg}$$

Figure NCD-3653.3-1
Reducing or Full Outlet Branch Connections, or Tees



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} (mm^4)
= 0.0491 $(D_o{}^4 - D_i{}^4)$
D_i = inside diameter, in. (mm)

NCD-3654 Consideration of Level C Service Limits

NCD-3654.1 Permissible Pressure. When Level C Service Limits [NCA-2142.4(b)(3) and NCD-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a, calculated in accordance with eq. NCD-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.

NCD-3654.2 Analysis of Piping Components. For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NCD-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 eq. NCD-3653.1(a)(9a) 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 $1.8S_y$. S_h and S_y are defined in NCD-3653.1. In addition, if the effects of anchor motion, M_{AM}, from reversing dynamic loads are not considered in NCD-3653, then the requirements of NCD-3655(b)(4) shall be satisfied using 70% of the allowable stress given in NCD-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 (NCD-3622.4) that are not required to be combined with nonreversing dynamic loads (NCD-3622.5), the requirements of NCD-3655(b) shall be satisfied using the allowable stress in NCD-3655(b)(2), 70% of the allowable stress in NCD-3655(b)(3), and 70% of the allowable loads in NCD-3655(b)(4).

NCD-3654.3 Deformation Limits. Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

NCD-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. NCD-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 eq. NCD-3653.1(a)(9a) 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 $2.0S_y$. S_h and S_y are defined in NCD-3653.1.

(3) If the effects of anchor motion, M_{AM}, from reversing dynamic loads are not considered in NCD-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 Section II, Part D, Subpart 1, Table 2A and limited to $D_o/t_n \le 40$, if Level D Service Limits are designated, which include reversing dynamic loads (NCD-3622.4) that are not required to be combined with nonreversing dynamic loads (NCD-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:

$$B_2 \frac{D_o}{2I} M_W \le 0.5S_h$$

where

M_W = resultant moment due to weight effects, in.-lb (N·mm)
S_h = as defined in NCD-3653.1

(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:

$$B_1 \frac{P_E D_o}{2t_n} + B_2' \frac{D_o}{2I} M_E \le 3S_h$$

where

$B_2{}'$ = B_2 from Table NCD-3673.2(b)-1, except as follows:

$B_2{}'$ = 1.33 for girth butt welds between items that do not have nominally identical wall thicknesses

= $0.87/h^{2/3}$ for curved pipe or butt welding elbows [h as defined in Table NCD-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 NCD-3673.2(b)-1], but neither less than 1.0

M_E = the amplitude of the resultant moment due to weight and the inertial loading resulting from reversing dynamic loads, 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 NCD-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} (mm^2)

C_2 = secondary stress index from Table NB-3681(a)-1

S_h = as defined in NCD-3653.1

(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 Section III Appendices, Mandatory Appendix XIII, XIII-3144(a) and XIII-3144(b) or Mandatory Appendix XXVII with the stress value S_m replaced by the stress value S may be used in evaluating these service loadings independently of all other Design and Service Loadings. When using Section III Appendices, Mandatory Appendix XXVII, the exclusion of XXVII-1300 shall not apply to anchor motion effects and the secondary stresses resulting from anchor motion effects shall be considered if either of the following applies:

(1) The loads under consideration are reversing dynamic loads in combination with nonreversing dynamic loads and the anchor motion effects were not considered in NCD-3653.

(2) The loads under consideration are reversing dynamic loads not in combination with nonreversing dynamic loads.

NCD-3657 Consideration of Test Limits

For loadings due to the Testing conditions defined in NCD-6221 and NCD-6321, the limits provided in (a) through (c) shall apply. The following nomenclature applies to (a) through (c):

P_{htest} = the actual hydrostatic test pressure, psi (MPa)

P_{ptest} = the actual pneumatic test pressure, psi (MPa)

M_{test} = the moments in the piping system during either the hydrostatic or pneumatic test, in.-lb (N-mm)

(a) The maximum pressure during a hydrostatic test (P_{htest}) shall not exceed the pressure P_a calculated in accordance with eq. NCD-3641.1(5). In lieu of S in eq. NCD-3641.1(5), $0.9S_y$ may be used, where S_y is taken at the test temperature.

(b) The maximum pressure during a pneumatic test (P_{ptest}) shall not exceed the pressure P_a calculated in accordance with eq. NCD-3641.1(5). In lieu of S in eq. NCD-3641.1(5), $0.8S_y$ may be used, where S_y is taken at the test temperature.

(c) The requirements of eq. NCD-3652(8) shall be met using the coincident test pressure P_{htest} or P_{ptest}, as applicable, and test moment M_{test}, which result in the maximum calculated stress. In lieu of $1.5S_h$, the larger of $1.5S_h$ or $1.1S_y$ may be used as the maximum stress permitted for eq. NCD-3652(8). Both S_h and S_y are to be taken at the test temperature.

NCD-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NCD-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either NCD-3658.1, NCD-3658.2, or NCD-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of NCD-3651 through NCD-3655 using appropriate stress intensification factors from Table NCD-3673.2(b)-1. The following nomenclature applies for NCD-3658:

A_b = total cross-sectional area of bolts at root of thread or section of least diameter under stress, in.^{2} (mm^2)
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 Section III Appendices, Mandatory Appendix XI, 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 NCD-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 (Section II, Part D, Subpart 1, Table Y-1)

NCD-3658.1 Any Flanged Joint. Flanged joints may be analyzed and the stresses evaluated by using the methods given in Section III Appendices, Mandatory Appendix XI as modified by (a) or by (b). Alternatively, they may be analyzed in accordance with Section III Appendices, Mandatory 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 NCD-3658 are satisfied.

(b) The Design Pressure used for the calculation of H in Section III Appendices, Mandatory 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

$$P_{eq} = 8M_{fd} / \pi G^3$$

NCD-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 NCD-3658, provided the following equations are satisfied:

$$M_{fs} \leq A_b CS / 4$$

and

$$M_{fd} \leq A_b CS / 2$$

NCD-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)

$$M_{fs} \leq 3{,}125\left(S_y/36{,}000\right) CA_b \tag{12}$$

(SI Units)

$$M_{fs} \leq 21.7\left(S_y/250\right) CA_b$$

(U.S. Customary Units)

$$M_{fd} \leq 6{,}250\left(S_y/36{,}000\right) CA_b \tag{13}$$

(SI Units)

$$M_{fd} \leq 43.4\left(S_y/250\right) CA_b$$

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)

$$M_{fd} \leq \left[78.1A_b - (\pi/16)D_f^{\ 2}P_{fd}\right]C\left(S_y/250\right) \tag{17}$$

(U.S. Customary Units)

$$M_{fd} \leq \left[11{,}250A_b - (\pi/16)D_f^{\ 2}P_{fd}\right]C\left(S_y/36{,}000\right)$$

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.

NCD-3660 DESIGN OF WELDS

NCD-3661 Welded Joints

NCD-3661.1 General Requirements. Welded joints shall be in accordance with the requirements of NCD-4200 and NCD-4420 except as limited herein.

NCD-3661.2 Socket Welded Joints.

(a) Socket welded piping joints shall be limited to pipe sizes of NPS 2 (DN 50) and less.

(b) Socket welds shall comply with the requirements of NCD-4427. Socket welds shall not be used where the existence of crevices could result in accelerated corrosion.

NCD-3661.3 Fillet Welds and Partial Penetration Welds for Branch Connections.

(a) Fillet welds and partial penetration welds may be used within the limitations of NCD-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.

Fillet and partial penetration welds should not be used where severe vibration is expected.

NCD-3670 SPECIAL PIPING REQUIREMENTS

NCD-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.

NCD-3671.1 Flanged Joints. Flanged joints shall conform to NCD-3647 and NCD-3658.

NCD-3671.2 Expanded or Rolled Joints. Expanded or rolled joints may be used when experience or test (NCD-3649) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

NCD-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 (NCD-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)
$^3/_4$ (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.

NCD-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 (NCD-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 NCD-3649.

(2) Prototypes of the fittings to be used shall successfully meet performance tests (NCD-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.

NCD-3671.5 Caulked Joints. Caulked or leaded joints shall not be used.

NCD-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 NCD-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).

NCD-3671.7 Sleeve-Coupled and Other Patented Joints. Mechanical joints for which no ASME standards exist, and other patented joints may be used, provided the requirements below are met.

(a) The pressure design shall meet the requirements of NCD-3649. Manufacturer's pressure and temperature ratings may be used if established in accordance with the Code.

(b) Either (1), (2), or (3) below is satisfied:

(1) Prototype joints have been subjected to performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are anticipated, the applicable conditions shall be incorporated in the tests. The mechanical joints shall be sufficiently leak tight to satisfy the requirement of the Design Specifications. A minimum of three specimens of each joint shall be tested. The results may be extrapolated to one-half and 1.5 times the NPS of the tested fitting.

(2) The supplier has furnished evidence of successful service experience or testing to an alternate Standard, and review of the experience or testing confirms that the service conditions are equivalent to the anticipated conditions in the Design Specification.

(3) The joints are designed in accordance with the rules of Section III Appendices, Mandatory Appendix XIII.

(c) The piping system stress analysis shall include appropriate stress intensification factors, flexibility factors, and fatigue strength reduction factors for the joint based on (b) above, and developed in accordance with Section III Appendices, Mandatory Appendix II and the rules of this Subsection.

NCD-3672 Expansion and Flexibility

NCD-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 NCD-3650. Other exceptions as stated in the following subparagraphs shall apply.

NCD-3672.2 Properties. Thermal expansion data and moduli of elasticity shall be determined from Section II, Part D, Subpart 2, Tables TE and TM, 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.

NCD-3672.3 Thermal Expansion Range. The thermal expansion range shall be determined from Section II, Part D, Subpart 2, Table TE 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.

NCD-3672.4 Moduli of Elasticity. The cold and hot moduli of elasticity E_c and E_h shall be as shown in Section II, Part D, Subpart 2, Table TM for the material based on the temperatures established in NCD-3672.3.

NCD-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.

NCD-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.

NCD-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.

NCD-3672.8 Expansion, Swivel, or Ball Joints. Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of NCD-3649.

NCD-3673 Analysis

NCD-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 NCD-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.

(21) **NCD-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 NCD-3673.2(b)-1 [see also Figure NCD-3673.2(b)-2]. The stress intensification factors and flexibility factors in Table NCD-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

$$k = \theta_{ab} / \theta_{\text{nom}}$$

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 NCD-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)

$$iS = 1\,700\,N^{-0.2}$$

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 NCD-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 Section III Appendices, Mandatory Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Section III Appendices, Mandatory Appendix II, Article 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. NCD-3653.2(a)(10a), NCD-3653.2(b)(10b) and NCD-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 Section III Appendices, Mandatory Appendix II, II-2050. The test report may be included and certified with the Design Report [NCA-3211.40(b) and NCA-3211.40(h)] for the individual piping system or a separate report furnished (Section III Appendices, Mandatory Appendix II, 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 Section III Appendices, Mandatory Appendix XXIII. The report shall be included and certified as part of the design

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

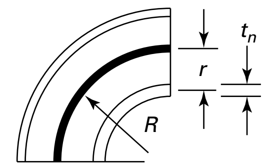
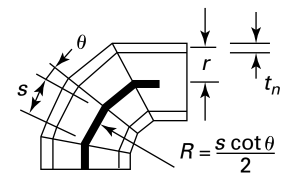
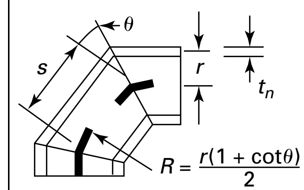
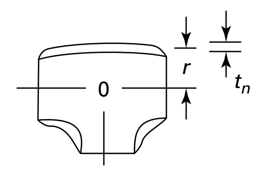
Description	Primary Stress Index		Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$-0.1 + 0.4h$, $0.5 \geq B_1 > 0$	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r\ (1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r\ (1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
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 NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

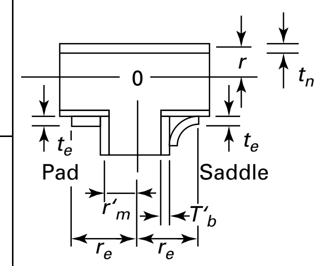
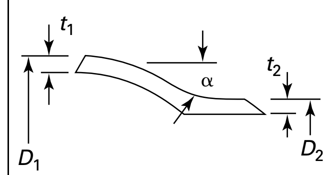
Description	Primary Stress Index		Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left(\frac{r'_m}{r}\right)^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \geq 1.0$ [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 $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \geq 2.1$	

Table NCD-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			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ 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 Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NCD-3673.2(b)-2
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \ge 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NCD-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...

Table NCD-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			
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 $C_x < 1.09t_n$, $i = 2.1\ (t_n/C_x) \geq 1.3$	Figure NCD-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NCD-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	$1.3 + 0.0036D_o/t_n \leq 1.9$	...
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	$0.5 + 0.01\,\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \leq 2.0$	
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)
- d_i = nominal inside diameter of branch, 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)

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

GENERAL NOTES: (Cont'd)

T_r = nominal wall thickness of run pipe, in. (mm)

For Figure NCD-3673.2(b)-2, sketches (a) and (b):

$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$

$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NCD-3673.2(b)-2, sketch (c):

$t_b = T'_b + (^2/_3)y$ if $\theta_n \leq 30$ deg

$= T'_b + 0.385L_1$ if $\theta_n > 30$ deg

For Figure NCD-3673.2(b)-2, sketch (d):

$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NCD-3643.2(b)-2 and NCD-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 NCD-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0

$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)

$Y = 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)

$Y = 1.0$ 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.

(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 $t_e > 1.5\ t_n$, $h = 4.05t_n/r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NCD-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 $t_e \geq 0.8t_n$

$r_{ps} = r'_m + (T'_b/2)$ for $t_e < 0.8t_n$

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

NOTES: (Cont'd)

(8) The definition of t'_e is:
$t'_e = t_e\ [(r_e/r'_m) - 1]$ but not greater than $1.0t_n$

(9) If an r_2 radius is provided [Figure NCD-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 $i_r \geq 1.5$. For $r'_m/R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m/R_m \leq 0.5$.

(11) In Figure NCD-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure NCD-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:

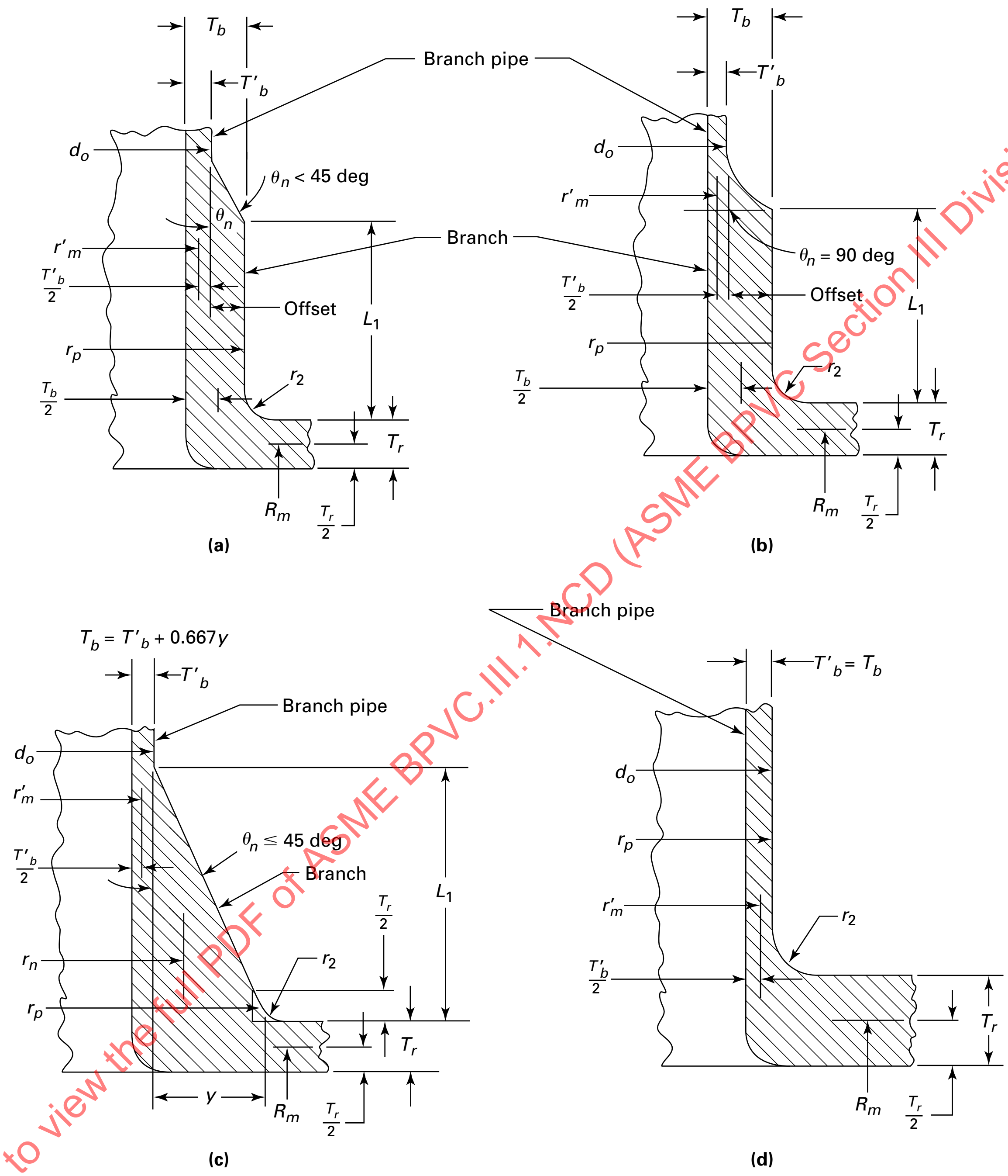
(o) Cone angle α does not exceed 60 deg.

(p) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(q) 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.

(r) For eccentric reducers, α is the maximum cone angle.

Figure NCD-3673.2(b)-2
Branch Connection Nomenclature



Legend:

d_o = outside diameter of branch pipe, in. (mm)
L_1 = height of nozzle reinforcement for branch connection, in. (mm)
r_2 = designated radius for reinforced branch connection, in. (mm)
R_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
r_p = outside radius of reinforced branch connection, in. (mm)
T'_b = nominal thickness of branch pipe, in. (mm)
T_b = nominal thickness of the reinforced pipe, in. (mm)
T_r = nominal thickness of run pipe, in. (mm)
y = slope offset distance, in. (mm)
θ_n = transition angle of branch reinforcement, deg

report for the piping system [NCA-3211.40(b) and NCA-3211.40(h)].

(l) The total expansion range as determined from NCD-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, NCD-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.

NCD-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.

NCD-3673.4 Movements. Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

NCD-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)

$$R_h = \left(1 - \frac{2}{3}C\right)\left(\frac{E_h}{E_c}\right)R \tag{14}$$

$$R_c = CR = \left[1 - \frac{(S_h)}{(S_E)}\cdot\frac{(E_c)}{(E_h)}\right]R \tag{15}$$

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) [NCD-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.

NCD-3673.6 Reaction Limits. The reactions computed shall not exceed limits that the attached equipment can safely sustain.

NCD-3674 Design of Pipe Supports

Pipe supports shall be designed in accordance with the requirements of Subsection NF.

NCD-3677 Pressure Relief Piping

NCD-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.

NCD-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 NCD-7142.

NCD-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 NCD-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 NCD-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.

NCD-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.

NCD-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

NCD-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NCA-7100-1.

NCD-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 NCD-3641.

NCD-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

NCD-3720 DESIGN RULES

(a) The design of the pressure-retaining portion of electrical and mechanical penetration assemblies shall be the same as for vessels (NCD-3300).

(b) For closing seams in electrical and mechanical penetration assemblies meeting the requirements of NCD-4730(c), the closure head shall meet the requirements of NCD-3325 using a factor C = 0.20. The fillet weld shall be designed using an allowable stress of 0.5S.

NCD-3800 DESIGN OF ATMOSPHERIC STORAGE TANKS

NCD-3810 GENERAL REQUIREMENTS

NCD-3811 Acceptability

The requirements for acceptability of atmospheric storage tanks are given in the following subparagraphs.

NCD-3811.1 Scope. The design rules for atmospheric storage tanks cover vertical cylindrical flat bottom above ground 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.

NOTE: 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.

NCD-3811.2 Design Requirements. The design rules for atmospheric storage tanks shall conform to the design requirements of NCD-3100 and NCD-3300, except as they may be modified by the requirements of this subarticle. For Class 2 construction, the design requirements of NCD-3200 may be used instead of the requirements of NCD-3800. For Class 2 construction, the joint efficiency, E, shall always be taken as 1. For Class 3 storage tanks, the joint efficiency, E, shall be based on the requirements of NCD-3352. The specific design requirements shall be stipulated in the Design Specifications.

NCD-3812 Design Report (21)

The Certificate Holder manufacturing a storage tank conforming to the design requirements of this subarticle is required to provide a Design Report as part of their responsibility for achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3211.40(h).

NCD-3820 DESIGN CONSIDERATIONS

NCD-3821 Design and Service Conditions

(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 NCD-3110 shall apply.

(c) The stress limits given in NCD-3821.5 shall be met.

Table NCD-3821.5-1
Design and Service Limits

Service Limit	Stress Limits [Note (1)] and [Note (2)]
Design and Level A	$\sigma_m \le 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.5S$
Level B	$\sigma_m \le 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.65S$
Level C	$\sigma_m \le 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.8S$
Level D	$\sigma_m \le 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 2.4S$

NOTES:
(1) See NCD-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.

NCD-3821.1 Design Pressure. The Design Pressure shall be atmospheric.

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 0.03 psig (0.2 kPa gage), especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

NCD-3821.2 Design Temperature. The Design Temperature shall not be greater than 200°F (95°C).

NCD-3821.3 Loadings. The requirements of NCD-3111 shall be met.

NCD-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 NCD-4246.6.

(c) All nozzle welds shall be in accordance with NCD-4246.5.

NCD-3821.5 Limits of Calculated Stresses for Design and Service Loadings. Stress[14] limits for Design and Service Loadings are specified in Table NCD-3821.5-1. The symbols used in Table NCD-3821.5-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, 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 Section III Appendices, Mandatory Appendix XIII, Table XIII-2600-1, with σ considered as equivalent to P in Section III Appendices, Mandatory Appendix XIII, Table XIII-2600-1.

NCD-3830 BOTTOM DESIGN

NCD-3831 Plate Sizes

(a) All bottom plates shall have a minimum nominal thickness of $^1/_4$ 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.

NCD-3832 Methods of Construction

Bottoms shall be built to either one of the alternative methods of construction given in NCD-4246.1.

NCD-3833 Shell-to-Bottom Attachment

The requirements for shell-to-bottom attachments are given in NCD-4246.2.

NCD-3840 SHELL DESIGN

NCD-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.

NCD-3842 Diameters and Thicknesses of Shell Plates

(a) For method of determining minimum thicknesses of shell plates, see NCD-3324.3 (and NCD-3121). See NCD-2121 for pressure-retaining material.

(b) In no case shall the nominal thickness[21] of shell plates be less than the following:

Ferrous Material		For Class 3 Only — Aluminum Material	
Nominal Tank Diameter, ft (m) [Note (1)]	Nominal Thickness, in. (mm)	Nominal Tank Diameter, ft (m) [Note (1)]	Nominal Thickness, in. (mm)
Smaller than 50 (15)	$^3/_{16}$ (5)	Smaller than 20 (6)	$^3/_{16}$ (5)
50 to 120 (15 to 37), incl.	$^1/_4$ (6)	20 to 120 (6 to 37), incl.	$^1/_4$ (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 $1^1/_2$ in. (38 mm).

NCD-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. (150 mm).

(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 (11 m) and smaller in diameter, $2^1/_2$ in. × $2^1/_2$ in. × $^1/_4$ in. (64 mm × 64 mm × 6 mm); tanks of more than 35 ft to 60 ft (11 m to 18 m), inclusive, in diameter, $2^1/_2$ in. × $2^1/_2$ in. × $^5/_{16}$ in. (64 mm × 64 mm × 8 mm); tanks larger than 60 ft (18 m) in diameter, 3 in. × 3 in. × $^3/_8$ in. (75 mm × 75 mm × 10 mm). The outstanding leg of the top angle may extend inside or outside the tank shell.

(c) See (1) and (2).

(1) For tanks not exceeding 35 ft (11 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 NCD-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 (11 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 1.75*t* nor more than 8*t*.

NCD-3850 ROOF DESIGN

NCD-3851 Types of Roofs

The types of roofs are defined in the following subparagraphs.

NCD-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.

NCD-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.

NCD-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.

NCD-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.

NCD-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.

NCD-3852 General Roof Design Requirements

NCD-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/ft^2 (1.2 kPa) 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/ft^2 (0.5 kPa).

NCD-3852.2 Minimum Plate Thickness. Roof plates shall have a minimum nominal thickness of $^3/_{16}$ 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.

NCD-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).

NCD-3852.4 Attachment of Roof Plates. Roof plates shall be attached to the top angle of the tank in accordance with NCD-4246.3. Roof plates of supported roofs shall not be attached to internal supporting members.

NCD-3852.5 Welding of Roof Plates.

(a) If the continuous fillet weld between the roof plates and the top angle does not exceed $^3/_{16}$ in. (5 mm) and the slope of the roof at the top angle attachment does not exceed 2 in./ft (167 mm/m) (16.7%), 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 $^3/_{16}$ in. (5 mm) or where the slope of the roof at the top angle attachment is greater than 2 in./ft (167 mm/m) (16.7%), emergency venting devices conforming to the specifications noted in API Standard 2000[22] shall be provided. The Certificate Holder shall provide a suitable tank connection for the device.

(c) Roof plates shall be welded in accordance with NCD-4246.4.

(21) **NCD-3852.6 Allowable Stresses for Ferrous Steel Structures.** 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. The decrease in yield stress at Design Temperature shall be taken into account.

(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

$$\left[1 - \frac{(L/r)^2}{34{,}700}\right]\frac{CY}{\mathrm{DF}}$$

where

C = 33 for U.S. Customary calculations
= 228 for SI calculations

For L/r over 120 to 131.7, inclusive

$$\frac{\left[1 - \frac{(L/r)^2}{34{,}700}\right]\frac{CY}{\mathrm{DF}}}{1.6 - L/200r}$$

where

C = 33 for U.S. Customary calculations
= 228 for SI calculations

For L/r over 131.7

$$\frac{(CY)}{(L/r)^2(1.6 - L/200r)}$$

where

C = 149,000 for U.S. Customary calculations
= 1.03×10^6 for SI calculations

DF = design factor

$$= \frac{5}{3} + \left[\frac{(L/r)}{350}\right] - \left[\frac{(L/r)^3}{18{,}300{,}000}\right]$$

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); $^1/_4$ in. (6 mm) minimum for main compression members, $^3/_{16}$ 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
= $(^{200}/_3)(t/R)[2 - (^{200}/_3)(t/R)]$ 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 (152 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 (138 MPa);

(3) in tension on extreme fibers of other rolled shapes, built-up members, and plate girders, 20.0 ksi (138 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)

(U.S. Customary Units)

$$20.0 - \frac{0.571}{1{,}000}\left(\frac{l}{r}\right)^2$$

(SI Units)

$$138 - \frac{3.94}{1\,000}\left(\frac{l}{r}\right)^2$$

or

(U.S. Customary Units)

$$\frac{12{,}000}{\left(ld/A_f\right)} \leq 20.0$$

(SI Units)

$$\frac{83\,000}{\left(ld/A_f\right)} \leq 138$$

where

A_f = area of compression flange, in.^{2} (mm^2)
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)

(U.S. Customary Units)

$$\frac{12{,}000}{\left(ld/A_f\right)} \leq 20.0$$

(SI Units)

$$\frac{83\,000}{\left(ld\,/\,A_f\right)} \leq 138$$

(d) Shearing

(1) in fillet, plug, slot, and partial penetration groove welds across throat area, 13.6 ksi (93.8 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 (89.6 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, ksi (MPa), shall not exceed

(U.S. Customary Units)

$$\frac{19.5}{1 + h^2\,/\,7{,}200t^2}$$

(SI Units)

$$\frac{134}{1 + h^2/7\,200t^2}$$

where

A = the gross area of the web, in.^{2} (mm^2)
V = the total shear, kips (N)

NCD-3852.7 For Class 3 Aluminum Storage Tanks Only — 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 NCD-3852.7-1 through NCD-3852.7-6.

NCD-3853 Supported Cone Roofs — General Requirements

NCD-3853.1 Slope of Roof. The slope of the roof shall be $^3/_4$ 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.

NCD-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 NCD-3852.6.

Table NCD-3852.7-1
For Class 3 Aluminum Storage Tanks Only — 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)

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 $^3/_8$ 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.

NCD-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 NCD-3852 through NCD-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%).

NCD-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 $5^1/_2$ ft (1.7 m).

NCD-3853.5 Roof Columns. Roof columns shall be made from structural shapes or pipe.

NCD-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.

NCD-3853.7 Welding of Roof Plates. Roof plates shall be welded in accordance with NCD-4246.4. The size of the roof-to-top angle weld shall be $^3/_{16}$ in. (5 mm) or smaller.

NCD-3854 Supported Flat Roofs

NCD-3854.1 General Requirements. The use of supported flat roofs shall be limited to tanks having diameters not greater than 35 ft (11 m). The design of supported flat roofs shall be in accordance with NCD-3853 except as noted below in NCD-3854.2.

NCD-3854.2 Main Supporting Members.

(a) Requirements of NCD-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.

NCD-3855 Self-Supporting Cone Roofs

NCD-3855.1 Nomenclature. The symbols used are defined as follows:

A_t = combined cross-sectional area of roof plate, shell plate, and top shell angle, in.^{2} (mm^2)
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/ft^2 (kPa)
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

NCD-3855.2 Design Requirements for Ferrous Material. Self-supporting cone roofs shall conform to the requirements of (a) through (c) below:

NOTE: The equations applying to self-supporting roofs provide for a uniform live load of 25 lb/ft^2 (1.2 kPa)

(a) Slope

Maximum θ = 37 deg (tangent = 9:12)

Minimum sin θ = 0.165 [slope 2 in./ft (167 mm/m) (16.7%)]

(b) Plate Thickness

(1) Minimum/Maximum

(U.S. Customary Units)

$$\text{Minimum } t_r = \frac{D}{400 \sin \theta}, \text{ but not less than } {}^3/_{16} \text{ in.}$$

$$\text{Maximum } t_r = {}^1/_2 \text{ in.}$$

Table NCD-3852.7-2
For Class 3 Aluminum Storage Tanks Only — Allowable Axial Compression Stresses for Roof Supports

Alloy and Temper	Maximum Temp., °F (°C)	Cross Sections Farther Than 1.0 in. (25 mm) From Any 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)
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 NCD-3852.7-2
For Class 3 Aluminum Storage Tanks Only — Allowable Axial Compression Stresses for Roof Supports (Cont'd)

Alloy and Temper	Maximum Temp., °F (°C)	Cross Sections Farther Than 1.0 in. (25 mm) From Any 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)
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 $^3/_8$ 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 $^3/_8$ 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 NCD-3852.7-3
For Class 3 Aluminum Storage Tanks Only — Allowable Bending Stresses for Roof Supports
Compression in Extreme Fibers of Shapes, Girders, and Built-Up Members, Subjected to Bending

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 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)
6061-T6	To 100 (40)	19 (131)	$\frac{L_b}{r_y} = 12$	$20.4 - 0.113\frac{L_b}{r_y}$ $\left(141 - 0.779\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 81$	$\frac{74,000}{(L_b/r_y)^2}$ $\left[\frac{510\,000}{(L_b/r_y)^2}\right]$	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L_b}{r_y} = 82$ [Note (2)]	$\frac{74,000}{(L_b/r_y)^2}$ $\left[\frac{510\,000}{(L_b/r_y)^2}\right]$
	150 (70)	19 (131)	$\frac{L_b}{r_y} = 11$	$20.2 - 0.112\frac{L_b}{r_y}$ $\left(139 - 0.772\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 80$	$\frac{72,000}{(L_b/r_y)^2}$ $\left[\frac{496\,000}{(L_b/r_y)^2}\right]$	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L_b}{r_y} = 81$ [Note (2)]	$\frac{72,000}{(L_b/r_y)^2}$ $\left[\frac{496\,000}{(L_b/r_y)^2}\right]$
	200 (90)	18 (124)	$\frac{L_b}{r_y} = 16$	$19.8 - 0.111\frac{L_b}{r_y}$ $\left(136 - 0.765\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 80$	$\frac{71,000}{(L_b/r_y)^2}$ $\left[\frac{489\,000}{(L_b/r_y)^2}\right]$	11 (76) [Note (1)]	...	11 (76) [Note (1)]	$\frac{L_b}{r_y} = 80$ [Note (2)]	$\frac{71,000}{(L_b/r_y)^2}$ $\left[\frac{489\,000}{(L_b/r_y)^2}\right]$
6063-T6	To 100 (40)	13.5 (93)	$\frac{L_b}{r_y} = 14$	$14.4 - 0.066\frac{L_b}{r_y}$ $\left(99.2 - 0.455\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 96$	$\frac{74,000}{(L_b/r_y)^2}$ $\left[\frac{510\,000}{(L_b/r_y)^2}\right]$	6.5 (45)	...	6.5 (45)	$\frac{L_b}{r_y} = 107$	$\frac{74,000}{(L_b/r_y)^2}$ $\left[\frac{510\,000}{(L_b/r_y)^2}\right]$
	150 (70)	13 (90)	$\frac{L_b}{r_y} = 13$	$13.8 - 0.064\frac{L_b}{r_y}$ $\left(99.1 - 0.441\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 97$	$\frac{72,000}{(L_b/r_y)^2}$ $\left[\frac{496\,000}{(L_b/r_y)^2}\right]$	6.5 (45)	...	6.5 (45)	$\frac{L_b}{r_y} = 105$	$\frac{72,000}{(L_b/r_y)^2}$ $\left[\frac{496\,000}{(L_b/r_y)^2}\right]$
	200 (90)	12.5 (86)	$\frac{L_b}{r_y} = 13$	$13.3 - 0.061\frac{L_b}{r_y}$ $\left(91.6 - 0.420\frac{L_b}{r_y}\right)$	$\frac{L_b}{r_y} = 98$	$\frac{71,000}{(L_b/r_y)^2}$ $\left[\frac{489\,000}{(L_b/r_y)^2}\right]$	6 (41)	...	6 (41)	$\frac{L_b}{r_y} = 109$	$\frac{71,000}{(L_b/r_y)^2}$ $\left[\frac{489\,000}{(L_b/r_y)^2}\right]$

Table NCD-3852.7-3
For Class 3 Aluminum Storage Tanks Only — Allowable Bending Stresses for Roof Supports
Compression in Extreme Fibers of Shapes, Girders, and Built-Up Members, Subjected to Bending (Cont'd)

GENERAL NOTES:

(a) L_b = length of beam between points at which the compression flange is supported against 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 $^3/_8$ 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 $^3/_8$ 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 NCD-3852.7-4
For Class 3 Aluminum Storage Tanks Only — Allowable Shear Stresses for Roof Supports Shear in Webs of Beams and Girders

Alloy and Temper	Maximum Temp., °F (°C)	Cross Sections Farther Than 1.0 in. (25 mm) From Any 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)	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 Greater Than S_1, ksi (MPa)
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 $^3/_8$ 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 $^3/_8$ 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 NCD-3852.7-5
For Class 3 Aluminum Storage Tanks Only — 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)
	Shear		
2024-T4 bolts	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.

Table NCD-3852.7-6
For Class 3 Aluminum Storage Tanks Only — 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 $^3/_8$ 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.

(SI Units)

$$\text{Minimum } t_r = \frac{D}{4.8 \sin \theta}, \text{ but not less than 5 mm.}$$
$$\text{Maximum } t_r = 13 \text{ mm.}$$

(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 $^3/_{16}$ in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches (square millimeters) 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)

$$\frac{D^2}{3{,}000 \sin \theta}$$

(SI Units)

$$\frac{D^2}{0.43 \sin \theta}$$

NCD-3855.3 For Class 3 Aluminum Storage Tanks Only — Design Requirements for Aluminum Material. Self-supporting cone roofs shall conform to the requirements of (a) through (c) below:

(a) Slope

(1) Minimum sin θ = 0.165 [slope 2 in./ft (167 mm/m) (16.7%)]

(2) Maximum θ = 37 deg (tangent = 9:12)

(b) Plate Thickness

(U.S. Customary Units)

$$t_r = \frac{D}{1{,}414 \sin \theta}\sqrt{P}$$

(SI Units)

$$t_r = \frac{D}{3.71 \sin \theta}\sqrt{P}$$

but not less than $^3/_{16}$ in. (5 mm) nominal.

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches (square millimeters) 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)

$$\text{Minimum } A_t = \frac{125PD^2}{f \sin\theta}$$

NCD-3856 Self-Supporting Dome and Umbrella Roofs

NCD-3856.1 Nomenclature. See NCD-3855.1 for nomenclature.

NCD-3856.2 Design Requirements for Ferrous Material. Self-supporting dome and umbrella roofs shall conform to the requirements of (a) through (c) below.

NOTE: The equations applying to self-supporting roofs provide for a uniform live load of 25 lb/ft^2 (1.2 kPa)

(a) Radius of Curvature
$R = D$ unless otherwise specified
Minimum $R = 0.80D$
Maximum $R = 1.2D$
(b) Plate Thickness
(1) Minimum/Maximum

(U.S. Customary Units)

$$\text{Minimum } t = R/200, \text{ but not less than } {}^3/_{16} \text{ in.}$$
$$\text{Maximum } t = {}^1/_2 \text{ in.}$$

(SI Units)

$$\text{Minimum } t = R/2.4, \text{ but not less than 5 mm}$$
$$\text{Maximum } t = 13 \text{ mm}$$

(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 $^3/_{16}$ in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches (square millimeters), 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)

$$\frac{DR}{1{,}500}$$

(SI Units)

$$\frac{DR}{0.216}$$

NCD-3856.3 For Class 3 Aluminum Storage Tanks Only — 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)

$$t_r = \frac{R}{1.86}\sqrt{P}$$

but not less than $^3/_{16}$ 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)

$$\text{Minimum } A_t = \frac{250PRD}{f}$$

NCD-3856.4 Top Angle Attachment for Self-Supporting Roofs.

(a) The top angle sections for self-supporting roofs shall meet the requirements of NCD-4246.4. 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.

NCD-3860 TANK CONNECTIONS AND APPURTENANCES

NCD-3861 Roof Manholes

Roof manholes shall conform to Figure NCD-3861-1 and Table NCD-3861-1, except that alternative designs that provide equivalent strength are permissible if agreed to by the Owner or his designee.

NCD-3862 Roof Nozzles

(a) Flanged roof nozzles shall conform to Figure NCD-3862(a)-1 and Table NCD-3862(a)-1. Threaded nozzles shall conform to Figure NCD-3862(a)-2 and Table NCD-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.

NCD-3863 Bottom Outlet Elbows

Bottom outlet elbows shall conform to Figure NCD-3863-1 and Table NCD-3863-1.

NCD-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.

NCD-3865 Platforms, Walkways, and Stairways

Platforms, walkways, and stairways shall be in accordance with Tables NCD-3865-1 through NCD-3865-3.

NCD-3866 Nozzle Piping Transitions

The stress limits of Table NCD-3821.5-1 shall apply to all portions of nozzles that lie within the limits of reinforcement given in NCD-3334, except as provided in NCD-3867. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NCD-3600.

NCD-3867 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NCD-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NCD-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 NCD-3821.5-1 for (σ_m or σ_L) + σ_b. In this case, the pressure-induced stresses in the (σ_m or σ_L) + σ_b category may be assumed to be no greater than the limit specified for σ_m in Table NCD-3821.5-1, for a given loading.

NCD-3900 DESIGN OF 0 PSI TO 15 PSI (0 KPA TO 100 KPA) STORAGE TANKS

NCD-3910 GENERAL REQUIREMENTS

NCD-3911 Acceptability

NCD-3911.1 Scope. The design rules for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks shall cover above ground 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.

NOTE: 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.

NCD-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 NCD-3100 and NCD-3300 except where they are modified by the requirements of this subarticle. For Class 2 construction, joint efficiency, *E*, shall always be taken as 1. For Class 3 construction, joint efficiency, *E*, shall be based on the requirements of NCD-3352. For Class 2 construction, the design requirements of NCD-3200 may be used instead of the requirements of NCD-3900. 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.

NCD-3912 Design Report (21)

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-3211.40(h).

NCD-3920 DESIGN CONSIDERATIONS

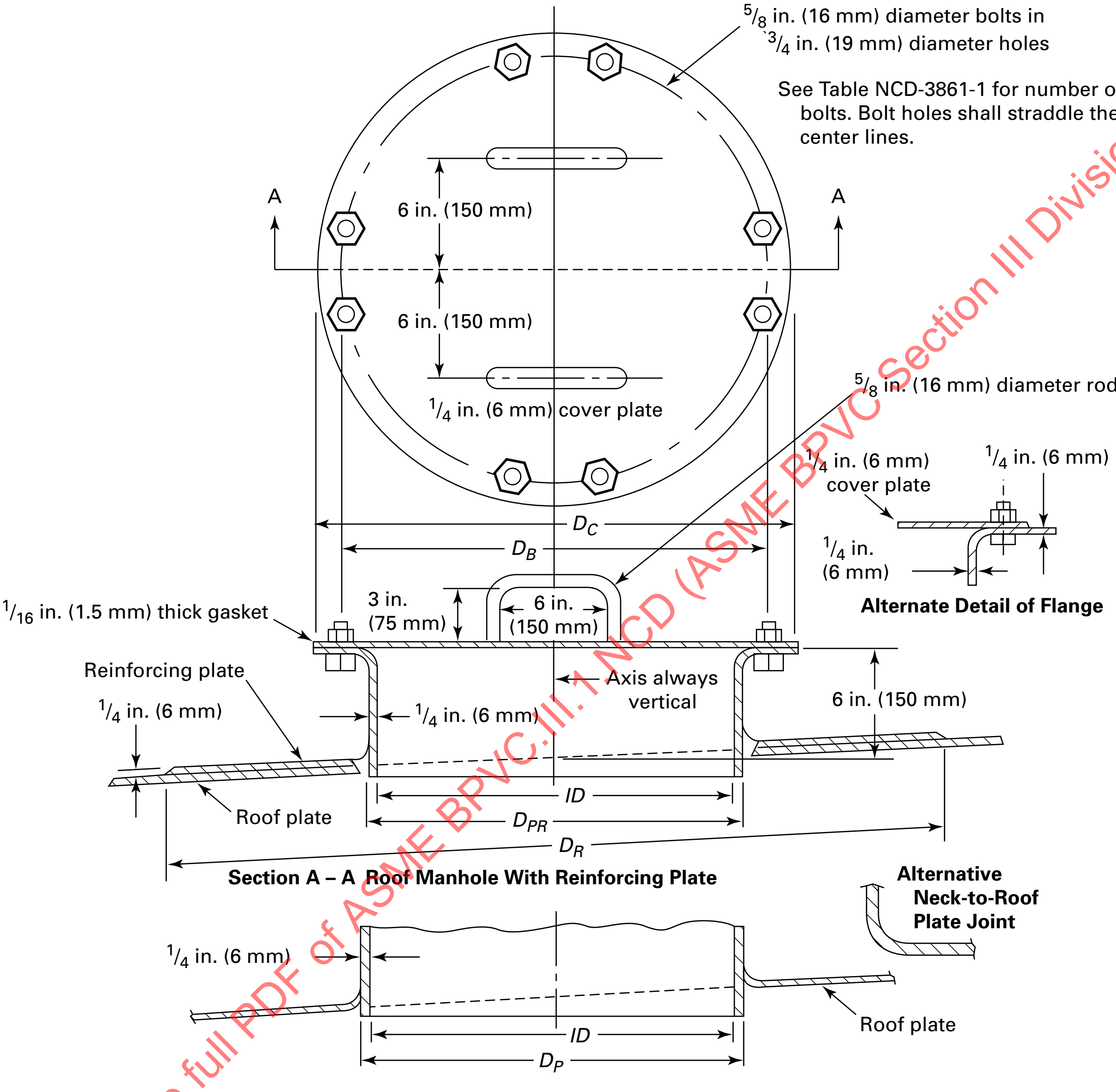
NCD-3921 Design and Service Loadings

(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 NCD-3110 shall apply.

(c) The stress limits of NCD-3921.8 shall be met.

Figure NCD-3861-1
Roof Manholes



Base for Roof Manhole Without Reinforcing Plate

(Must be compatible with allowable roof plate stresses.)

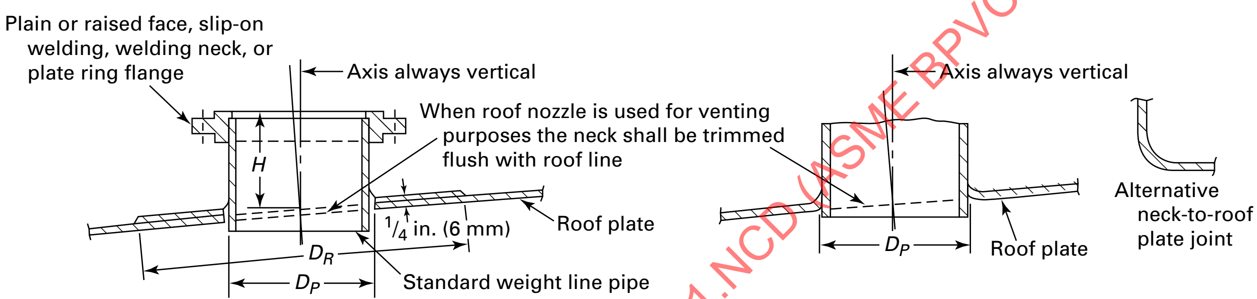
GENERAL NOTE: See Table NCD-3861-1.

Table NCD-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 I.D., in. (mm)	Diameter of Gasket O.D., in. (mm)	Diameter of Hole in Roof Plate or Reinforcing Plate D_P, in. (mm)	O.D. of Reinforcing Plate D, in. (mm)
20 (500)	20 (500)	26 (650)	23$^1/_2$ (589)	16	21$^1/_2$ (538)	26 (650)	20$^5/_8$ (516)	42 (1 050)
24 (600)	24 (600)	30 (750)	27$^1/_2$ (689)	20	25$^1/_2$ (638)	30 (750)	24$^5/_8$ (616)	46 (1 150)

GENERAL NOTE: See Figure NCD-3861-1.

Figure NCD-3862(a)-1 Flanged Roof Nozzles



(a) Nozzle With Reinforcing Plate

(b) Base for Nozzles Without Reinforcing Plate

GENERAL NOTES:
(a) See Table NCD-3862(a)-1.
(b) 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.
(c) 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.

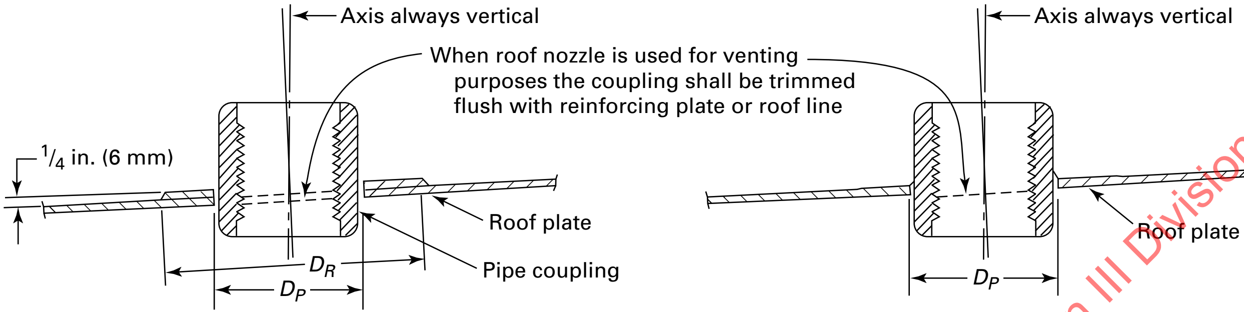
Table NCD-3862(a)-1 Flanged Roof Nozzles

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)
1$^1/_2$ (DN 40)	1.900 (48)	2 (50)	6 (150)	5 (125) [Note (1)]
2 (DN 50)	2$^3/_8$ (60)	2$^1/_2$ (64)	6 (150)	7 (175) [Note (1)]
3 (DN 80)	3$^1/_2$ (89)	3$^5/_8$ (91)	6 (150)	9 (225) [Note (1)]
4 (DN 100)	4$^1/_2$ (114)	4$^5/_8$ (116)	6 (150)	11 (275) [Note (1)]
6 (DN 150)	6$^5/_8$ (168)	6$^3/_4$ (169)	6 (150)	15 (375) [Note (1)]
8 (DN 200)	8$^5/_8$ (219)	8$^7/_8$ (222)	6 (150)	18 (450)
10 (DN 250)	10$^3/_4$ (273)	11 (275)	8 (200)	22 (550)
12 (DN 300)	12$^3/_4$ (324)	13 (325)	8 (200)	24 (600)

GENERAL NOTE: See Figure NCD-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 NCD-3862(a)-2
Screwed or Socket Weld Roof Nozzles



GENERAL NOTE: See Table NCD-3862(a)-2 and NCD-3864.

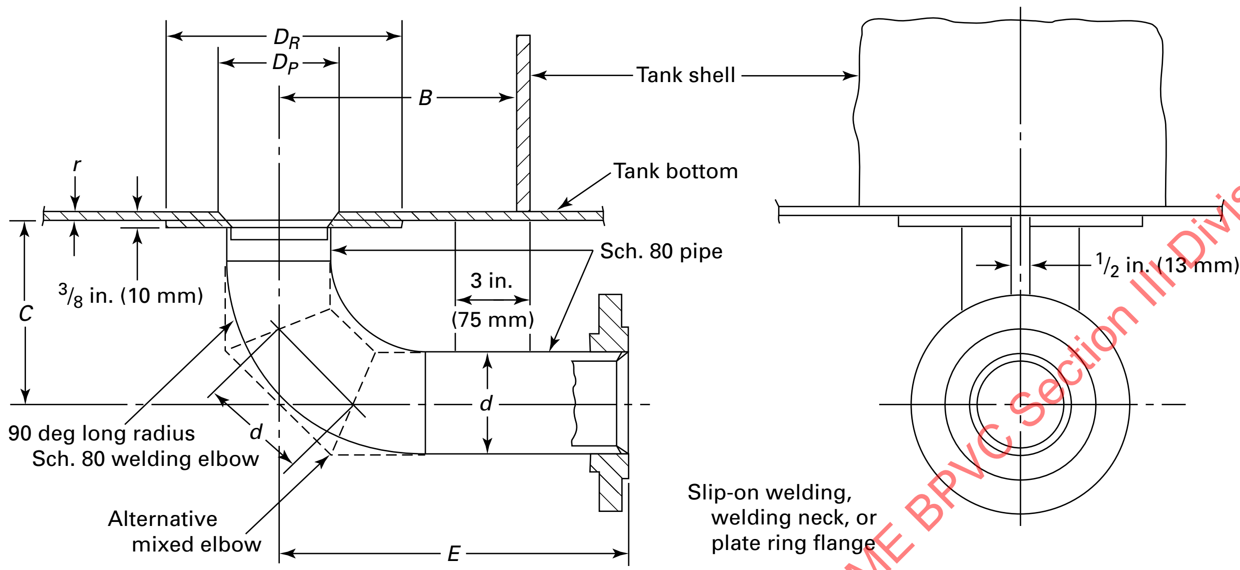
Table NCD-3862(a)-2
Screwed or Socket Weld Roof Nozzles

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)
$^3/_4$ (DN 20)	$^3/_4$ (DN 20)	$1^7/_{16}$ (37)	4 (100) [Note (1)]
1 (DN 25)	1 (DN 25)	$1^{23}/_{32}$ (44)	$4^1/_2$ (113) [Note (1)]
$1^1/_2$ (DN 40)	$1^1/_2$ (DN 40)	$2^{11}/_{32}$ (60)	5 (125) [Note (1)]
2 (DN 50)	2 (DN 50)	3 (75)	7 (175) [Note (1)]
3 (DN 75)	3 (DN 75)	$4^1/_8$ (105)	9 (225) [Note (1)]
4 (DN 100)	4 (DN 100)	$5^{11}/_{32}$ (136)	11 (275) [Note (1)]
6 (DN 150)	6 (DN 150)	$7^{17}/_{32}$ (191)	15 (375) [Note (1)]
8 (DN 200)	8 (DN 200)	$9^7/_8$ (251)	18 (450)
10 (DN 250)	10 (DN 250)	12 (300)	22 (550)
12 (DN 300)	12 (DN 300)	$14^1/_4$ (362)	24 (600)

GENERAL NOTE: See Figure NCD-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 NCD-3863-1
Welded Bottom Outlet Elbow



GENERAL NOTES:

(a) See Table NCD-3863-1.

(b) 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.

(c) 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 NCD-3863-1
Welded Bottom Outlet Elbow

Nominal Pipe Size, in. (mm) [Note (1)]	Distance from Center of Elbow to Shell, *B*, in. (mm)	Distance from Center of Outlet to Bottom, *C*, in. (mm)	Diameter of Hole in Tank Bottom, D_P, in. (mm)	O.D. of Reinforcing Plate, D_R, in. (mm)	Distance from Center of Elbow to Face of Flange, *E*, in. (mm)
2 (DN 50)	7$^1/_2$ (191)	6 (150)	3$^1/_8$ (79)	6$^1/_4$ (159)	12 (300)
3 (DN 80)	8$^1/_2$ (216)	7 (175)	4$^1/_4$ (108)	7$^3/_4$ (197)	13 (325)
4 (DN 100)	9$^1/_2$ (241)	7$^{13}/_{16}$ (198)	5$^1/_4$ (133)	9$^3/_4$ (248)	14 (350)
6 (DN 150)	11 (280)	9$^3/_8$ (238)	7$^3/_8$ (187)	12$^3/_4$ (324)	16 (400)
8 (DN 200)	13 (330)	12$^3/_8$ (314)	9$^3/_8$ (238)	16$^1/_2$ (419)	18 (450)

GENERAL NOTE: See Figure NCD-3863-1.

NOTE: (1) Extra-strong pipe, refer to ASME B36.10M.

Table NCD-3865-1
Platforms and Walkways

1. All parts to be made of metal.
2. Width of floor level (min.): 24 in. (600 mm).
3. Flooring to be made of grating or nonslip material.
4. Height of top railing above floor: 42 in. (1 050 mm) [Note (1)].
5. Height of toeboard (min.): 3 in. (75 mm).
6. Space between top of floor and bottom of toeboard (max.): $^1/_4$ in. (6 mm).
7. Height of midrail: approximately one-half the distance from top of walkway to top of railing.
8. Distance between railing posts (max.): 96 in. (2 400 mm).
9. 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.
10. Handrails to be on both sides of platform, discontinuing where necessary for access.
11. At handrail openings, any space between tank and platform wider than 6 in. (150 mm) should be floored.
12. 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 NCD-3865-2
Stairways

1. All parts to be made of metal.
2. Width of stairs (min.): 24 in. (600 mm).
3. Angle of stairway with a horizontal line (max.): 50 deg [Note (1)].
4. 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. (650 mm). Rises shall be uniform throughout the height of the stairway.]
5. Treads to be made of grating or nonslip material.
6. 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).
7. Distance between railing posts (max.) measured along slope of railing: 96 in. (2 400 mm).
8. 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.
9. 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).
10. 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 NCD-3865-3
Stairway Rise, Run, and Angle Relationships

	$2R + r$ = 24 in. (600 mm)			$2R + r$ = 26 in. (650 mm)		
		Angle			Angle	
Height of Rise, R, in. (mm)	Width of Run, r, in. (mm)	deg	min	Width of Run, r, in. (mm)	deg	min
$5^1/_4$ (131)	$13^1/_2$ (338)	21	15	...	...	...
$5^1/_2$ (138)	13 (325)	22	56	15 (375)	20	9
$5^3/_4$ (144)	$12^1/_2$ (313)	24	43	$14^1/_4$ (356)	21	38
6 (150)	12 (300)	26	34	14 (350)	23	12
$6^1/_4$ (156)	$11^1/_2$ (288)	28	30	$13^1/_2$ (338)	24	53
$6^1/_2$ (163)	11 (275)	30	35	13 (325)	26	34
$6^3/_4$ (169)	$10^1/_2$ (263)	32	45	$12^1/_2$ (313)	28	23
7 (175)	10 (250)	35	0	12 (300)	30	15
$7^1/_4$ (181)	$9^1/_2$ (238)	38	20	$11^1/_2$ (288)	32	13
$7^1/_2$ (188)	9 (225)	39	50	11 (275)	34	18
$7^3/_4$ (194)	$8^1/_2$ (213)	42	22	$10^1/_2$ (263)	36	26
8 (200)	8 (200)	45	0	10 (250)	38	40
$8^1/_4$ (206)	$7^1/_2$ (188)	47	43	$9^1/_2$ (238)	41	0
$8^1/_2$ (213)	...	...	...	9 (225)	43	23
$8^3/_4$ (219)	...	...	...	$8^1/_2$ (213)	45	49
9 (225)	...	...	...	8 (200)	48	22

NCD-3921.1 Design Pressure.

(a) At or Above Maximum Liquid Level. The walls of the gas or vapor space and other components shall be designed for a pressure not less than that at which the pressure relief valves are to be set. The relief valve set points shall allow a suitable margin from the pressure normally existing in this space 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 space. Walls and components in this space shall also be designed for the maximum partial vacuum that can be developed in the space when the inflow of air, gas, or vapor through the vacuum relief valves is at its maximum specified rate; this partial vacuum shall be greater than that at which the vacuum relief valves are set to open.

NOTE: 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 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 top of the roof, overfill protection is required. 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) Below the Maximum Liquid Level. All portions shall be designed for the most severe combination of gas pressure or partial vacuum and static liquid head.

NCD-3921.2 Design Temperature. The Design Temperature shall not be greater than 200°F (95°C).

NCD-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.

NCD-3921.4 Loadings. See NCD-3111 for loadings to be considered.

NCD-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.

NCD-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.

NCD-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 NCD-4247.

(c) All nozzle welds shall be in accordance with NCD-4244.

Table NCD-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 NCD-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.

NCD-3921.8 Limits of Calculated Stresses for Design and Service Loadings. Stress[14] limits for Design and Service Loadings are specified in Table NCD-3921.8-1. The symbols used in Table NCD-3921.8-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, 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 Section III Appendices, Mandatory Appendix XIII, Table XIII-2600-1 with σ in Table NCD-3921.8-1 considered as equivalent to P in Section III Appendices, Mandatory Appendix XIII, Table XIII-2600-1.

NCD-3922 Maximum Allowable Stress Values for Tanks

NCD-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} (Figures NCD-3922.1-1 and NCD-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 NCD-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) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

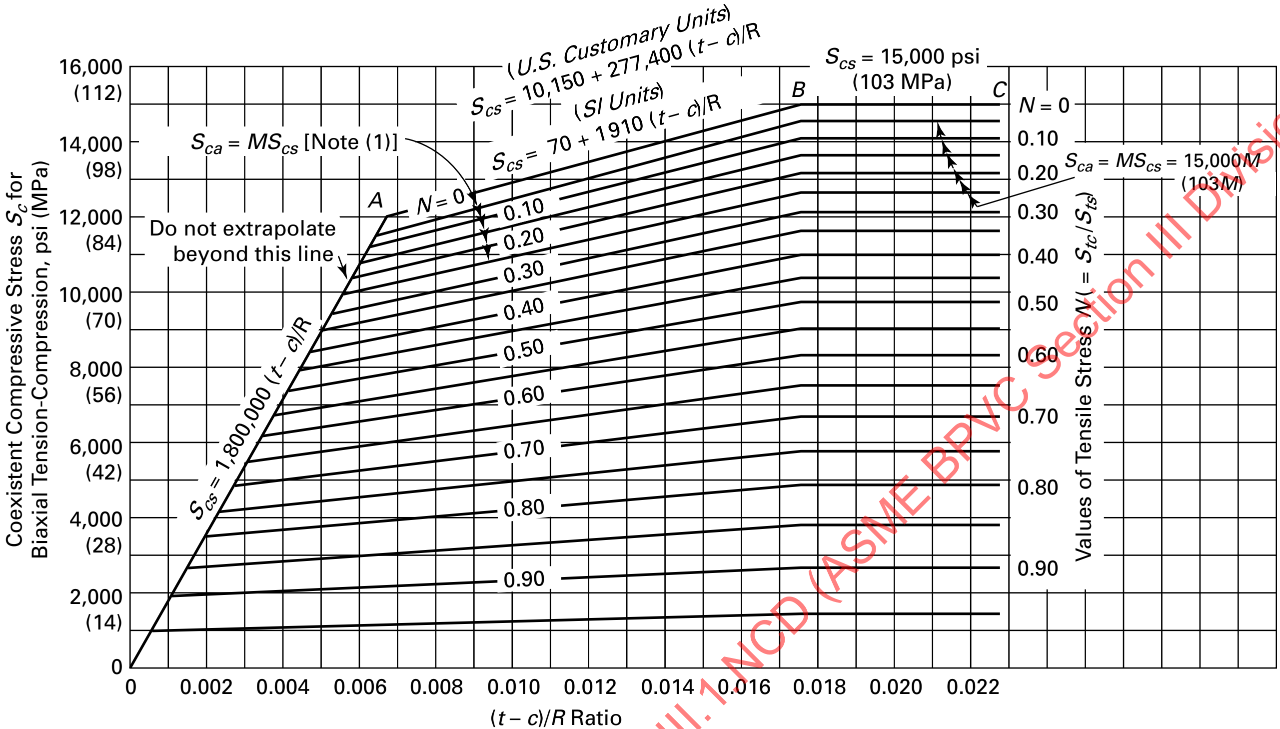
t = thickness, in. (mm), of sidewalls, roof, or bottom, including corrosion allowance

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

NCD-3922.2 Maximum Tensile Stresses. The maximum tensile stresses in the outside walls of a tank, as determined for any loadings or any concurrent

Figure NCD-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 Figure NCD-3922.1-2 for relationships between factors M and N.)

(b) If compressive stress is latitudinal, use $R = R_1$.

(c) If compressive stress is meridional, use $R = R_2$.

NOTE: (1) See below.

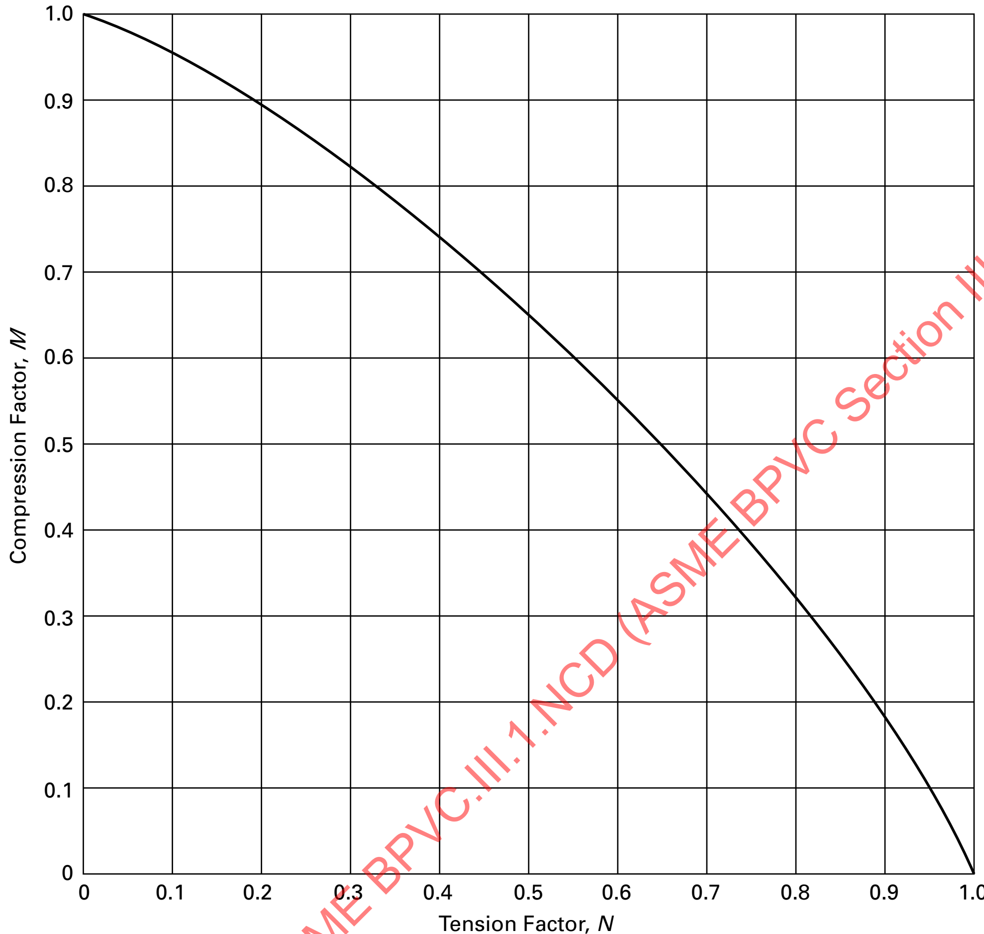
(U.S. Customary Units)

$$S_{ca} = MS_{cs} = M[10{,}150 + 277{,}400(t - c)/R]$$

(SI Units)

$$S_{ca} = MS_{cs} = M[70 + 1910(t - c)/R]$$

Figure NCD-3922.1-2
Reduction of Design Stresses Required to Allow for Biaxial Stresses of Opposite Sign



GENERAL NOTE:

$$N^2 + MN + M^2 = 1$$

or

$$(S_t/S_{ts})^2 + (S_t/S_{ts})(S_c/S_{cs}) + (S_c/S_{cs})^2 = 1$$

where

M = S_c/S_{cs}

N = S_t/S_{ts}

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 NCD-3922.3(a) for the thickness to radius ratio involved

S_t = the tensile stress, psi (MPa), at the point under consideration

S_{ts} = the maximum allowable stress for simple tension, psi (MPa) 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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

(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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 by the appropriate value of N obtained from Figure NCD-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.[23] 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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3. For Class 2 construction, joint efficiency shall be taken as 1.

NCD-3922.3 Maximum Compressive Stresses. Except as provided in NCD-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 (for example, compressive circumferential stress due to pressure), the computed compressive stress S_{cc} shall not exceed a value S_{cs} established for the applicable thickness–radius ratio as follows:

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)

$$S_{cs} = 70 + 1910(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175

$$S_{cs} = 15{,}000\text{ psi }(103\text{ MPa})$$

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 ratio 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)

$$S_{ca} = 6900(t - c)/R$$

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)

$$S_{ca} = 39 + 1060(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175

$$S_{ca} = 8{,}340\text{ psi }(57.5\text{ MPa})$$

(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:

$$\frac{(\text{larger stress}) + 0.8\,(\text{smaller stress})}{S_{cs}\text{ determined using }R\text{ for the larger unit force}} \le 1.0$$

$$\frac{1.8\ (\text{smaller stress})}{S_{cs}\ \text{determined using}\ R\ \text{for the smaller unit force}} \leq 1.0$$

NOTE: 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.

(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 NCD-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}.

(e) The allowable compressive stresses specified in the preceding subparagraphs 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 NCD-3933.2 and the applicable joint efficiency. For Class 2 construction, joint efficiency shall be taken as 1.

NCD-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}.

NCD-3923 Maximum Allowable Stress Values for Structural Members

NCD-3923.1 General Stress Limits. Subject to the provisions of NCD-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 NCD-3923.1-1.

NCD-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 NCD-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

Table NCD-3923.1-1
Maximum Allowable Stress Values for Structural Members

	Column 1 for Members Not Subject to Pressure-Imposed Loads, ksi	Column 1 for Members Not Subject to Pressure-Imposed Loads, MPa	Column 2 for Internal Members Resisting Pressure, 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	$\dfrac{18}{1+\dfrac{l^2}{18,000r^2}}$ but not to exceed 15	$\dfrac{124}{1+\dfrac{l^2}{18\,000r^2}}$ but not to exceed 103	Same values as for Column 1
For axially loaded tubular columns, tubular bracing, and tubular secondary members, on gross section [minimum permissible thickness, $^1/_4$ in. (6.4 mm)]	$\dfrac{18.0Y}{1+\dfrac{l^2}{18,000r^2}}$ but not to exceed 15Y	$\dfrac{124Y}{1+\dfrac{l^2}{18,000r^2}}$ but not to exceed 103Y	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
  = $^2/_3(100t/R)[2 - {}^2/_3(100t/R)]$ for values of t/R less than 0.015

	ksi	MPa	Column 2, ksi (MPa)
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	$\dfrac{10,800.0}{ld\,/\,bt}$	$\dfrac{74\,400.0}{ld\,/\,bt}$	$\dfrac{600 \times \text{tension value}^1}{ld\,/\,bt}$

where
- b = width of its compression flange, in. (mm)
- d = depth of the member, in. (mm)
- l = unsupported length of the member, in. (mm), 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
- t = thickness of its compression flange, in. (mm)

Table NCD-3923.1-1
Maximum Allowable Stress Values for Structural Members (Cont'd)

	Column 1 for Members Not Subject to Pressure-Imposed Loads, ksi	Column 1 for Members Not Subject to Pressure-Imposed Loads, MPa	Column 2 for Internal Members Resisting Pressure, ksi (MPa)
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.			
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	$\dfrac{18.0}{1 + \dfrac{h^2}{7,200t^2}}$	$\dfrac{124}{1 + \dfrac{h^2}{7,200t^2}}$	$\dfrac{\text{Tension value}^1}{1 + \dfrac{h^2}{7,200t^2}}$
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 Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.
(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.

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 NCD-3921.4 may be proportioned for unit stresses 25% greater than those specified in Table NCD-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 NCD-3923.1-1. A corresponding increase may be applied to the allowable unit stresses in the connecting bolts or welds.

NCD-3930 DESIGN PROCEDURE

NCD-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 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 NCD-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 NCD-3933.

NCD-3932 Design of Sidewalls, Roofs, and Bottoms

NCD-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} (mm^2)

E = efficiency, expressed as a decimal, of the weakest joint across which the stress under consideration acts
 = 1 for Class 2 construction

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 NCD-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 NCD-3932.2(f).

S_{ca} = allowable compression stress, psi (MPa), as required in NCD-3922.3

S_{cc} = computed compression stress, psi (MPa), at the point under consideration

S_{ta} = allowable tension stress, psi (MPa), as required in NCD-3922.2(b)

S_{tc} = computed tension stress, psi (MPa), at the point under consideration

S_{ts} = maximum allowable stress for simple tension, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

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 (N), of that portion of the tank and its contents either above the level under consideration, as in Figure NCD-3932.1-1 sketch (b), or below such level, as in Figure NCD-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.

Figure NCD-3932.1-1
Some Typical Free Body Diagrams for Certain Shapes of Tanks

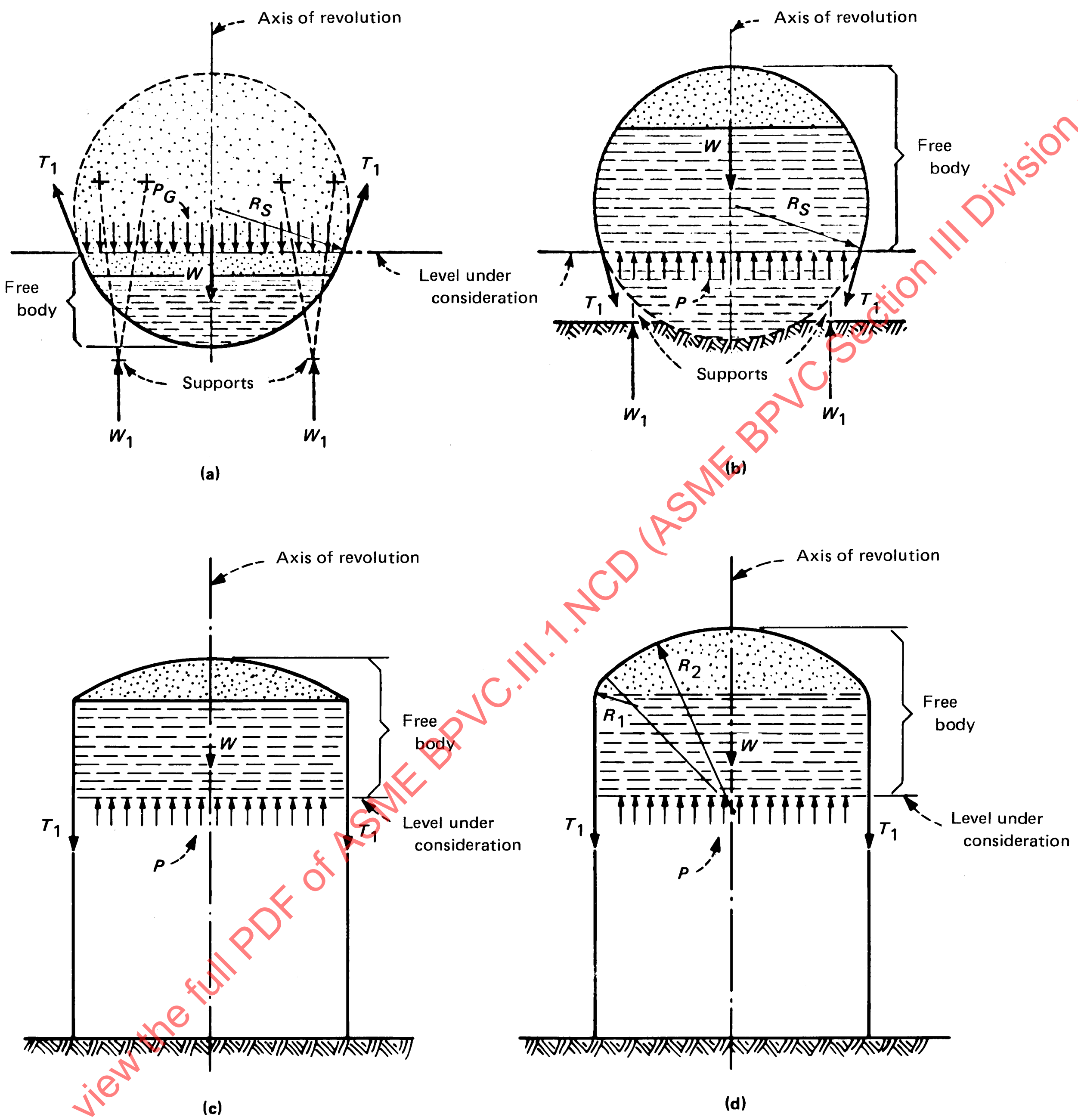


Table NCD-3932.2(d)-1
Factors for Determining Values of R_1 and R_2 for 2:1 Ellipsoidal Roofs and Bottoms

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
$R_1 = u\alpha$
$R_2 = v\alpha$

NCD-3932.2 Computation of Unit Forces.

(a) At each level of the tank selected for free body analysis as specified in NCD-3931 (Figure NCD-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. (1) and (2)[24] below, except as provided in NCD-3932.6 or NCD-3933.

$$T_1 = \frac{R_2}{2}\left(P + \frac{W + F}{A_T}\right) \qquad (1)$$

$$\begin{aligned} T_2 &= R_2\left(P - \frac{T_1}{R_1}\right) \\ &= R_2\left[P\left(1 - \frac{R_2}{2R_1}\right) - \frac{R_2}{2R_1}\left(\frac{W + F}{A_T}\right)\right] \end{aligned} \qquad (2)$$

(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.

(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 NCD-3932.2(d)-1. Values for ellipsoidal shapes of other proportions shall be calculated from the following equations:

$$R_1 = \frac{b^2}{a^4}\left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2}\right)x^2\right]^{3/2} = \frac{b^2(R_2)^3}{a^4} \qquad (3)$$

$$R_2 = \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2}\right)x^2\right]^{1/2} \qquad (4)$$

(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.

(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

$$T_1 = \frac{R_s}{2}\left(P + \frac{W + F}{A_T}\right) \qquad (5)$$

$$T_2 = R_s P - T_1 \qquad (6)$$

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

$$T_1 = T_2 = \tfrac{1}{2}P_G R_S \qquad (7)$$

(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

$$T_1 = \left(\frac{R_3}{2 \cos \alpha}\right)\left(P + \frac{W + F}{A_T}\right) \quad (8)$$

$$T_2 = \frac{PR_3}{\cos \alpha} \quad (9)$$

(3) For Cylindrical Sidewalls of a Vertical Tank. R_1 = infinity and $R_2 = R_c$, the radius of the cylinder, and eqs. (a)(1) and (a)(2) become

$$T_1 = \frac{R_c}{2}\left(P + \frac{W + F}{A_T}\right) \quad (10)$$

$$T_2 = PR_c \quad (11)$$

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 NCD-3932.1-1(d), applicable equations for the meridional and latitudinal unit forces in the walls of the segment are as follows:

$$T_1 = (\textit{in preparation}) \quad (14)$$

$$T_2 = (\textit{in preparation}) \quad (15)$$

NCD-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 NCD-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 NCD-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_{ta} and the calculated compression stress S_{cc} satisfy the requirements of NCD-3922.2(b) and NCD-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 NCD-3922.2(b). For Class 2 construction, the value of E is always 1.

(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 NCD-3922.3(b) and NCD-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

$$t = \frac{\sqrt{(T' + 0.8\,T'')R'}}{1342} + c \qquad (18)$$

and

$$t = \frac{\sqrt{T''R''}}{1000} + c \qquad (19)$$

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

$$t = \frac{T' + 0.8\,T''}{15{,}000} + c \qquad (20)$$

and

$$t = \frac{T''}{8340} + c \qquad (21)$$

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:

$$\frac{10{,}150(t - c) + 277{,}400(t - c)^2}{R'} = T' + 0.8T'' \qquad (22)$$

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:

$$\frac{5{,}650(t - c) + 154{,}200(t - c)^2}{R''} = T'' \qquad (23)$$

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 NCD-3922.3(c). Adjustment in the thickness may be required to make the values of S_{cc} satisfy the requirements of NCD-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 NCD-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)].

NCD-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.

NCD-3932.5 External Pressure Limitations. The thickness computed by the equations and procedures specified in NCD-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 liquids[25] with the thickness of upper courses not less than specified in NCD-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 0.06 psig (0.4 kPa gage) with the operating liquid level in the tank at any stage from full to empty. The vacuum relief valve or valves shall be set to open at a smaller partial vacuum so that the 0.06 psig (0.4 kPa gage) partial vacuum will not be exceeded when the inflow of air or gas through the valves is at its maximum specified rate.

NCD-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 uplift 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.

NOTE: 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 $^1/_4$ in. (6 mm) on the diameter.

(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.

NCD-3933 Design of Roof and Bottom Knuckle Regions, and Compression Ring

NCD-3933.1 Nomenclature. The symbols used are defined as follows:

A_c = net area, in.^{2} (mm^2), 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

= 1 for Class 2 construction

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) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

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

NOTE: Force computed by applicable equation in NCD-3932.

T_{2s} = circumferential unit force 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

NOTE: Force computed by applicable equation in NCD-3932.

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.

NCD-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.

NCD-3933.3 Requirements for Knuckle Regions.

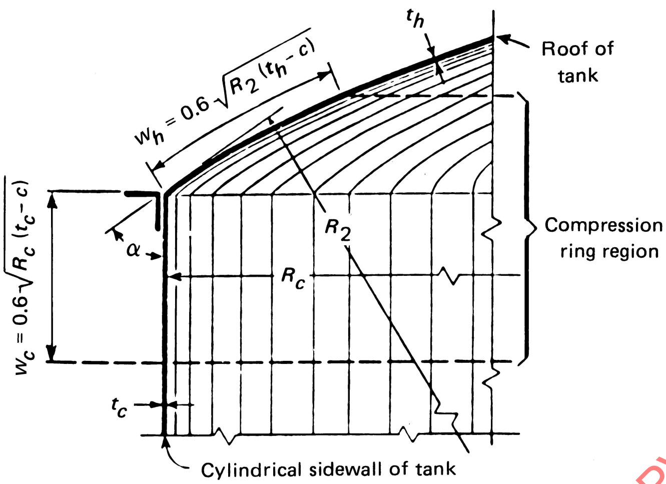
(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%, of the diameter of the sidewalls.

NOTE: 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.

Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of NCD-3932.

(b) Application of the equations in NCD-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a

Figure NCD-3933.4(a)-1
Compression Ring Region



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.

NCD-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 NCD-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 NCD-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

$$w_h = 0.6\sqrt{R_2(t_h - c)} \tag{24}$$

$$w_c = 0.6\sqrt{R_c(t_c - c)} \tag{25}$$

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

$$Q = T_2 w_h + T_{2s} w_c - T_1 R_c \sin\alpha \tag{26}$$

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)

$$A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{ts}E} \tag{27}$$

(SI Units)

$$A_c = \frac{Q}{103}$$

depending on whether the value of Q as determined by eq. (26) is negative or positive.

NOTE: 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. NCD-3933.4(b)(26). Experience has shown that a compressive stress of the order of 15,000 psi (100 MPa), as indicated in eq. NCD-3933.4(b)(27), is permissible in this case, provided the requirements of NCD-3933.5 are satisfied.

NCD-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 NCD-3933.4 is of such magnitude that the area required by eq. NCD-3933.4(b)(27) is not provided in a compression ring region with plates of the minimum thicknesses established by the requirements of NCD-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, 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.

NOTE: 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.

(c) Such an angle, bar, or ring girder, if used, may be located either inside or outside of the tank [see Figure NCD-3933.5(d)-1 for some acceptable details of construction of compression rings] 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. NCD-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. NCD-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, Q_p, 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 NCD-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 NCD-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 NCD-4247.6(d)-1.

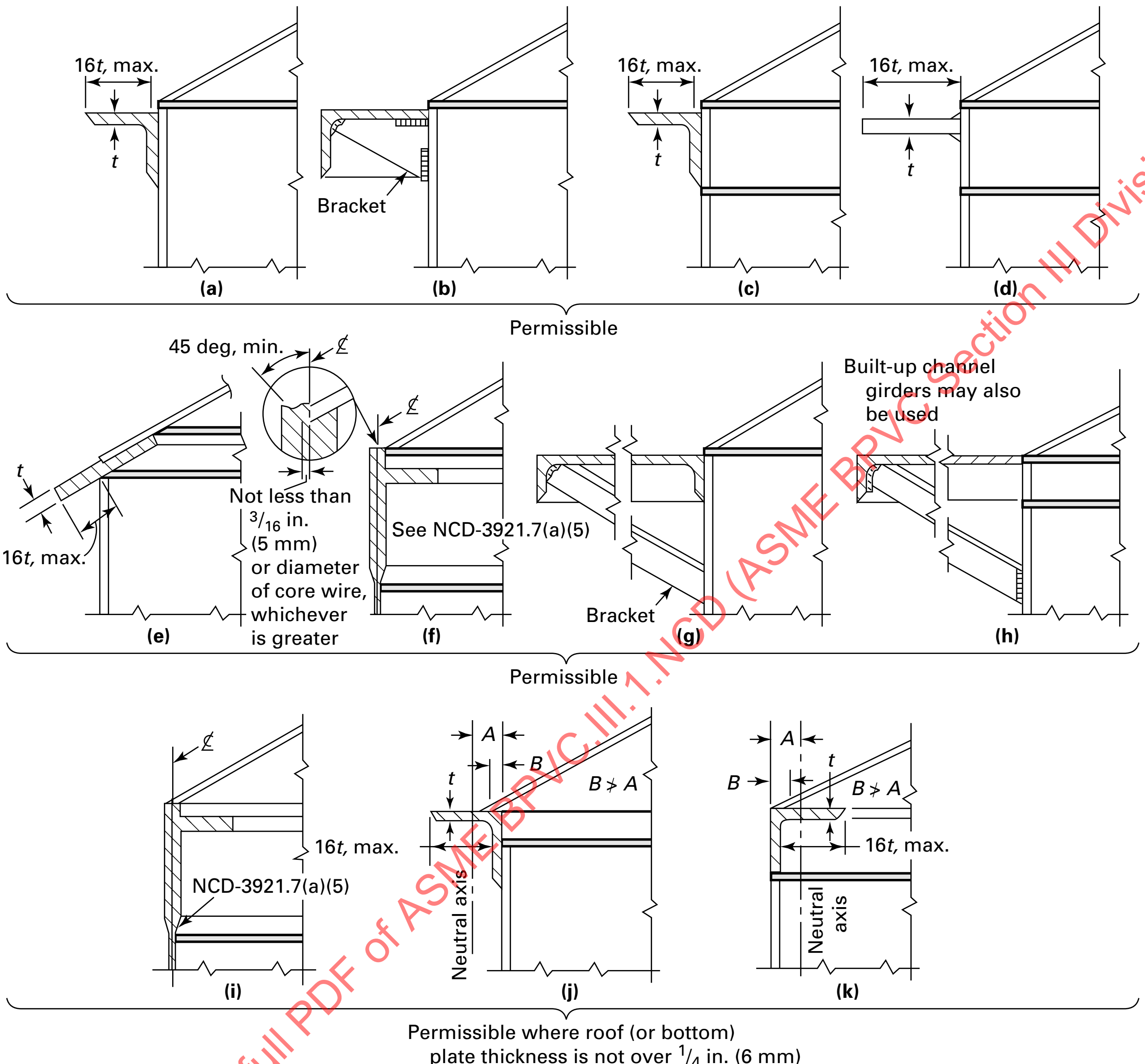
(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

(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 $^3/_4$ 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:

NOTE: The value required for I_1 as calculated from eq. NCD-3933.5(h)(28) is not applicable for materials other than steel.

Figure NCD-3933.5(d)-1
Permissible Details of Compression Ring Construction



GENERAL NOTES:
(a) See NCD-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*.

Table NCD-3933.5(h)-1
Some Values for k Based on n, θ

n	30	24	20	18	15	12	10	9	8	6	5	4
θ, deg	12	15	18	20	24	30	36	40	45	60	72	90
k	186.6	119.1	82.4	66.6	45.0	29.1	20.0	16.0	12.5	6.7	4.4	2.6

GENERAL NOTE: In no case shall θ be larger than 90 deg.

(U.S. Customary Units)

$$I_1 = \frac{1.44 Q_p {R_c}^2}{29,000,000k} = 5\frac{Q_p {R_c}^2}{k} \times 10^{-8} \quad (28)$$

(SI Units)

$$I_1 = \frac{1.44\, Q_p {R_c}^2}{200\,000k} = 7.2\frac{Q_p {R_c}^2}{k} \times 10^{-6}$$

where

I_1 = required moment of inertia, in.^{4} (mm^4), 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 leg

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 NCD-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. NCD-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 sidewall of the tank at its juncture with the roof or bottom

NCD-3934 Nozzle Piping Transitions

The stress limits of Table NCD-3921.8-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NCD-3334, except as provided in NCD-3935. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NCD-3600.

NCD-3935 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NCD-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NCD-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 NCD-3921.8-1 for (σ_m or σ_L) + σ_b. In this case, the pressure-induced stresses in the (σ_m or σ_L) + σ_b category may be assumed to be no greater than the limit specified for σ_m in Table NCD-3921.8-1, for a given condition.

NCD-3940 ALTERNATE RULES FOR AXIAL COMPRESSIVE MEMBRANE STRESSES IN THE CYLINDRICAL WALLS OF 0 PSI TO 15 PSI (0 KPA TO 100 KPA) STORAGE TANKS

The rules of this subsubarticle provide an alternative to the allowable compressive stress rules of NCD-3922.3 for loadings associated with Service Limits A, B, C, and D. The remaining rules of the subarticle are still applicable.

NCD-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 NCD-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. NCD-3946(40a), NCD-3946(40b), NCD-3946(40c), and NCD-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 NCD-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 NCD-3900 shall be satisfied.

NCD-3942 Nomenclature

The symbols used in this subsubarticle have the following definitions:

DF = design factor applied to $\sigma_{a,u}$ in order to establish $\sigma_{a,\text{allow}}$; dimensionless (see NCD-3945)

E = modulus of elasticity of the cylindrical wall material, at the corresponding temperature, given in the appropriate Section II, Part D, Subpart 2, Table TM; 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 NCD-3947)

p = net internal radial pressure, i.e., internal radial pressure minus external pressure; ksi (MPa) [see NCD-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 Section II, Part D, Subpart 1, Table 1A or Table 1B; ksi (MPa)

S_y = yield strength of the cylindrical wall material, at the corresponding temperature, given in Section II, Part D, Subpart 1, Table Y-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_o = buckling capacity reduction factor for a cylindrical wall with no net internal radial pressure; dimensionless [see eqs. NCD-3943(29a) and NCD-3943(29b)]

α_p = buckling capacity reduction factor that includes the effect of net internal radial pressure; dimensionless [see eq. NCD-3943(b)(31)]

β = nondimensional parameter used in the formulation of axial compressive stress criteria; dimensionless [see eq. NCD-3943(g)(35)]

Δ_x = geometric imperfection; in. (mm) (see NCD-3947)

λ_p = slenderness parameter that includes the effect of net internal radial pressure; dimensionless [see eq. NCD-3943(g)(36)]

υ = Poisson's ratio of the cylindrical wall material given in Section II, Part D, Subpart 2, Table NF-1; dimensionless. If no value is given for the material, use υ = 0.3

ρ = parameter involving internal pressure; dimensionless [see eq. NCD-3943(a)(30)]

σ_a = axial membrane compressive stress (compressive stress is positive); ksi (MPa) (see NCD-3946)

$\sigma_{a,\text{allow}}$ = allowable value of the axial membrane compressive stress (compressive stress is positive); ksi (MPa) [see eq. NCD-3944(b)(39)]

$\sigma_{a,u}$ = lower bound for the axial membrane buckling stress (compressive stress is positive); ksi (MPa) (see NCD-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. NCD-3943(d)(32)]

σ_{eff} = lower bound for the total effective membrane buckling or collapse stress; ksi (MPa) (see NCD-3943)

σ_h = hoop membrane stress (tensile stress is positive); ksi (MPa) [see eq. NCD-3943(e)(33)]

NCD-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 NCD-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).

$$\alpha_o = \frac{0.83}{\sqrt{1.0 + 0.01\,R\,/\,t}} \qquad for\;\; R/t \;\leq\; 212 \tag{29a}$$

$$\alpha_o = \frac{0.70}{\sqrt{0.1 + 0.01\,R/t}} \qquad for\ \ R/t\ >\ 212 \tag{29b}$$

(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).

$$\rho = \frac{p}{E}\left(\frac{R}{t}\right)^{\frac{3}{2}} \tag{30}$$

(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).

$$\alpha_p = \alpha_o + (1 - \alpha_o)\frac{\rho}{\rho + 0.007} \tag{31}$$

(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).

$$\sigma_{cl} = \frac{E}{\sqrt{3\,(1 - \nu^2)}}\left(\frac{t}{R}\right) \tag{32}$$

(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).

$$\sigma_h = p\,\frac{R}{t} \tag{33}$$

(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).

$$\sigma_{eff} = \sqrt{\sigma_{a,u}^2 + \sigma_h^2 + \sigma_{a,u}\sigma_h} \tag{34}$$

$$\beta = \frac{\sigma_{a,u}}{\sigma_{eff}} \tag{35}$$

$$\lambda_p = \sqrt{\frac{\beta S_y}{\alpha_p \sigma_{cl}}} \tag{36}$$

$$\frac{\sigma_{eff}}{S_y} = \frac{0.75}{\lambda_p^2}\ \text{for}\ \lambda_p \geq 1.414 \tag{37a}$$

$$\frac{\sigma_{eff}}{S_y} = (1.0 - 0.4123\lambda_p^{1.2})\ \text{for}\ \lambda_p < 1.414 \tag{37b}$$

(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 NCD-3944 must be used.

NCD-3944 Allowable Axial Membrane Compressive Stresses

Any method of solving the system of equations given in NCD-3943 is satisfactory. Provided herein is one acceptable method. Note that eq. NCD-3943(g)(34) can be rearranged as shown in eq. (38).

$$\sigma_{a,u} = \sqrt{(\sigma_{eff}^2 - 0.75\,\sigma_h^2\,)} - 0.5\sigma_h \tag{38}$$

(a) The algorithm proceeds as follows:

Step 1. Compute parameters α_0, ρ, α_p, σ_{cl}, and σ_h for the set of conditions being evaluated.

Step 2. Estimate a value of β [note eq. NCD-3943(g)(35)] and call the value β'.

Step 3. Compute λ_p from eq. NCD-3943(g)(36) using β' for β.

Step 4. Compute σ_{eff} from eqs. NCD-3943(g)(37a) and NCD-3943(g)(37b).

Step 5. Compute $\sigma_{a,u}$ from eq. (38).

Step 6. Compute β from eq. NCD-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 ±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, $\sigma_{\text{a,allow}}$, shall be established from eq. (39).

$$\sigma_{a,\text{allow}} = \frac{\sigma_{a,u}}{DF} \tag{39}$$

(c) In eq. (b)(39), the minimum values of the design factors against buckling, DF, are provided in NCD-3945 for the different service levels.

(d) As an alternative to solving the equations of NCD-3943 by methods as described above, the plotted curves provided in Figures NCD-3944-1 through NCD-3944-6 (NCD-3944-1M through NCD-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 Section II, Part D, Subpart 1, Table Y-1.

The value of ρ [see eq. NCD-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 Figures NCD-3944-1 through NCD-3944-6 (NCD-3944-1M through NCD-3944-6M) are for ferrous materials at temperatures equal to or less than 300°F (150°C). Other Code temperature limits may also apply.

NCD-3945 Axial Compressive Stress Design Factors

The design factors, DF, for use in establishing the allowable values of axial membrane compressive stress with eq. NCD-3944(b)(39) shall be as follows:

Service Level	Design Factors, DF
A	2
B	2
C	$^5/_3$
D	$^4/_3$

NCD-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. NCD-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 Section II, Part D, Subpart 1, Table 1A or Table 1B, the following requirements expressed as eqs. (40a), (40b), (40c), and (40d) shall be satisfied:

$$|\sigma_a| + |\sigma_h| \leq 1.0\ S, \text{ for Service Level A} \quad (40a)$$

$$|\sigma_a| + |\sigma_h| \leq 1.1\ S, \text{ for Service Level B} \quad (40b)$$

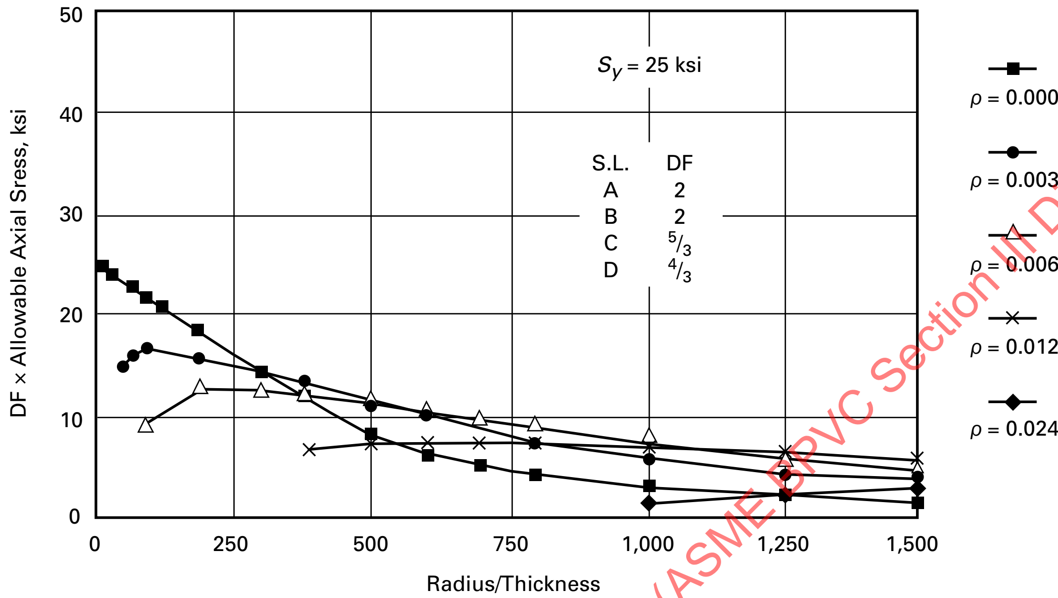
$$|\sigma_a| + |\sigma_h| \leq 1.5\ S, \text{ for Service Level C} \quad (40c)$$

$$|\sigma_a| + |\sigma_h| \leq 2.0\ S, \text{ for Service Level D} \quad (40d)$$

NCD-3947 Construction Tolerances

In addition to the applicable requirements established in NCD-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 Figure NCD-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 NCD-4220, apply only to regions of the cylindrical walls where allowable compressive stresses are established by the rules of this subsubarticle.

Figure NCD-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 ≤ 300°F

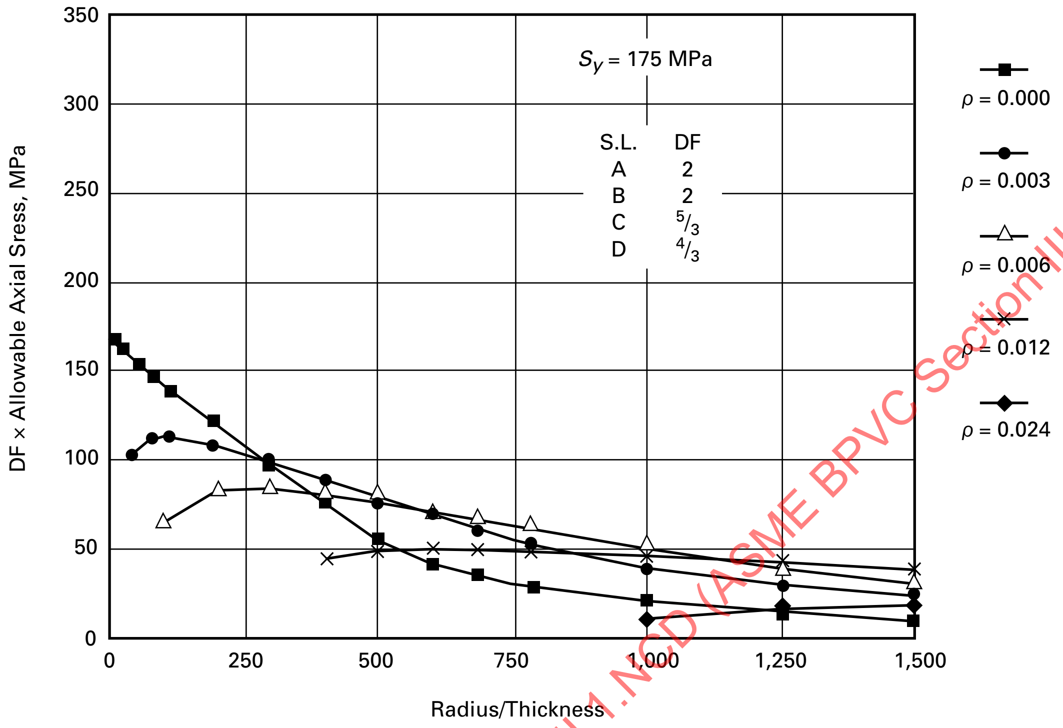


Tabular Values

R/*t*	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

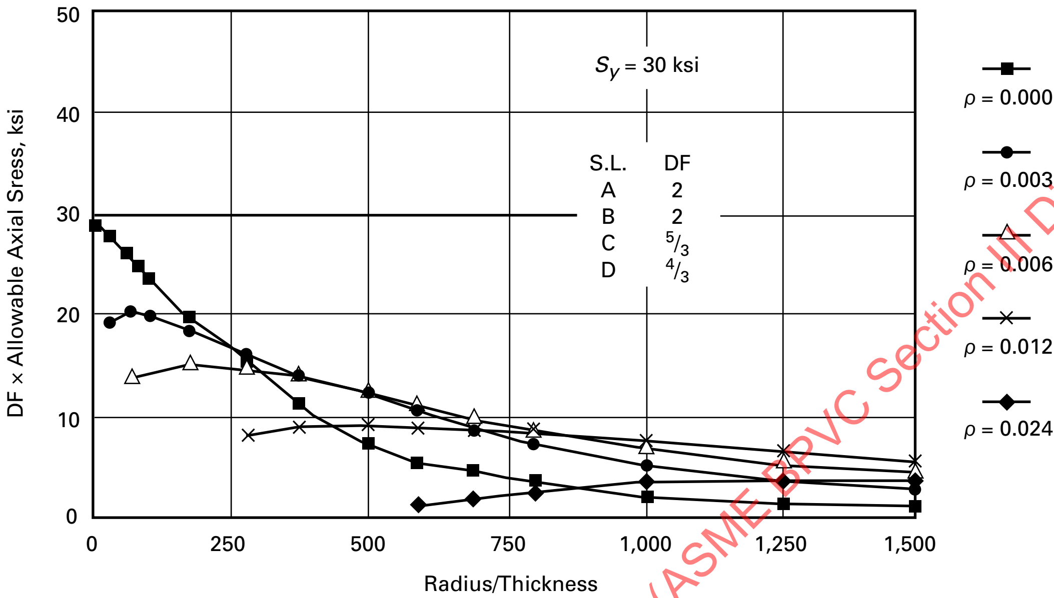


Tabular Values

R/*t*	*ρ* = 0.000	*ρ* = 0.003	*ρ* = 0.006	*ρ* = 0.012	*ρ* = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-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 ≤ 300°F

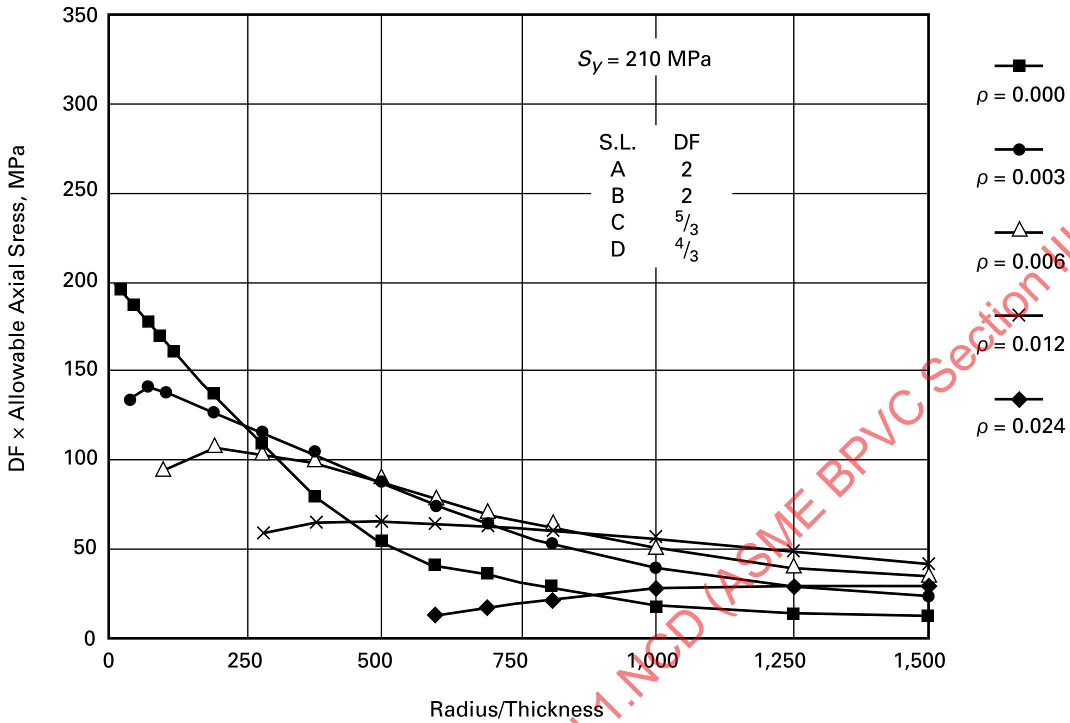


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

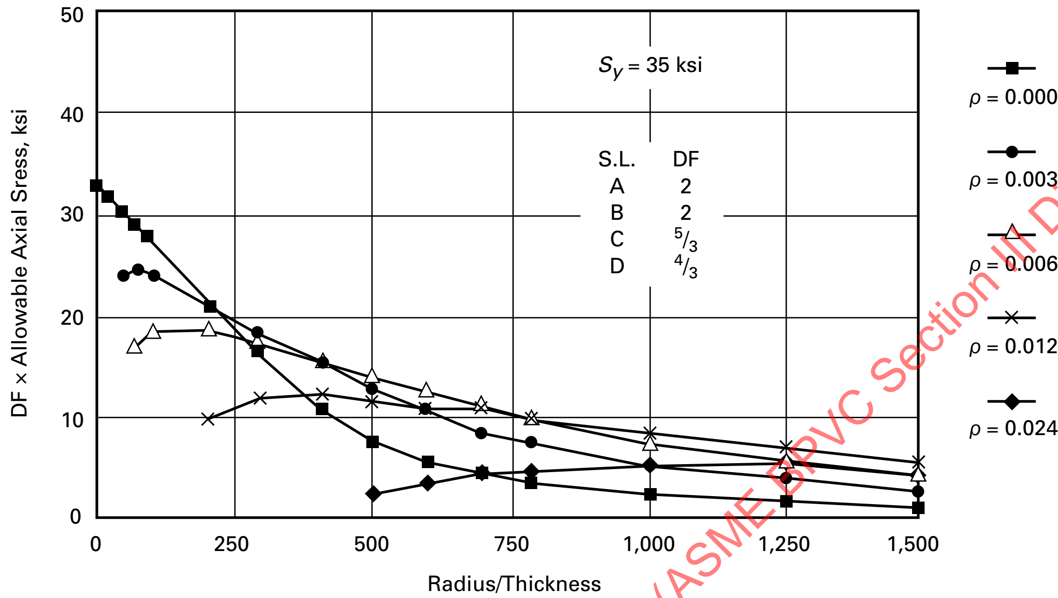


Tabular Values

R/*t*	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-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 ≤ 300°F

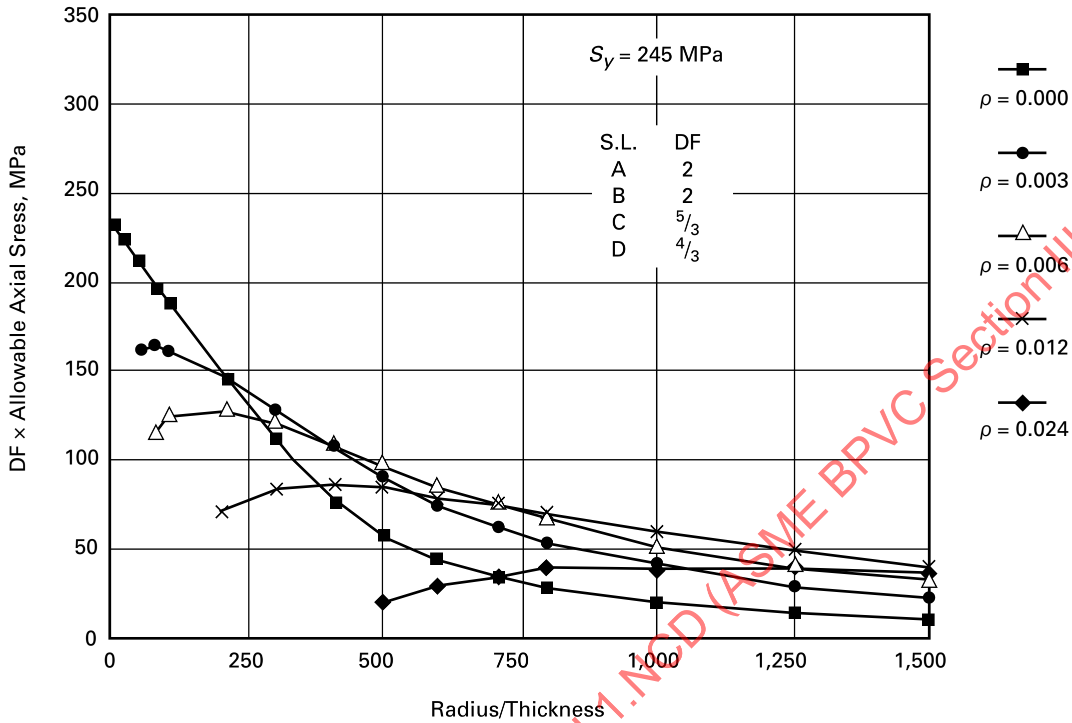


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

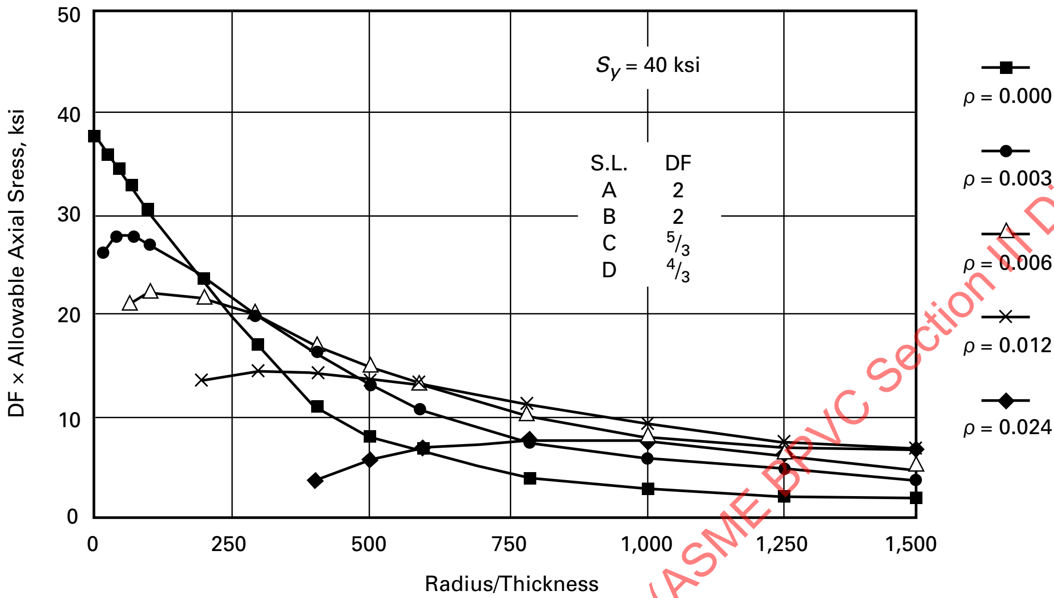


Tabular Values

R/*t*	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-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 ≤ 300°F

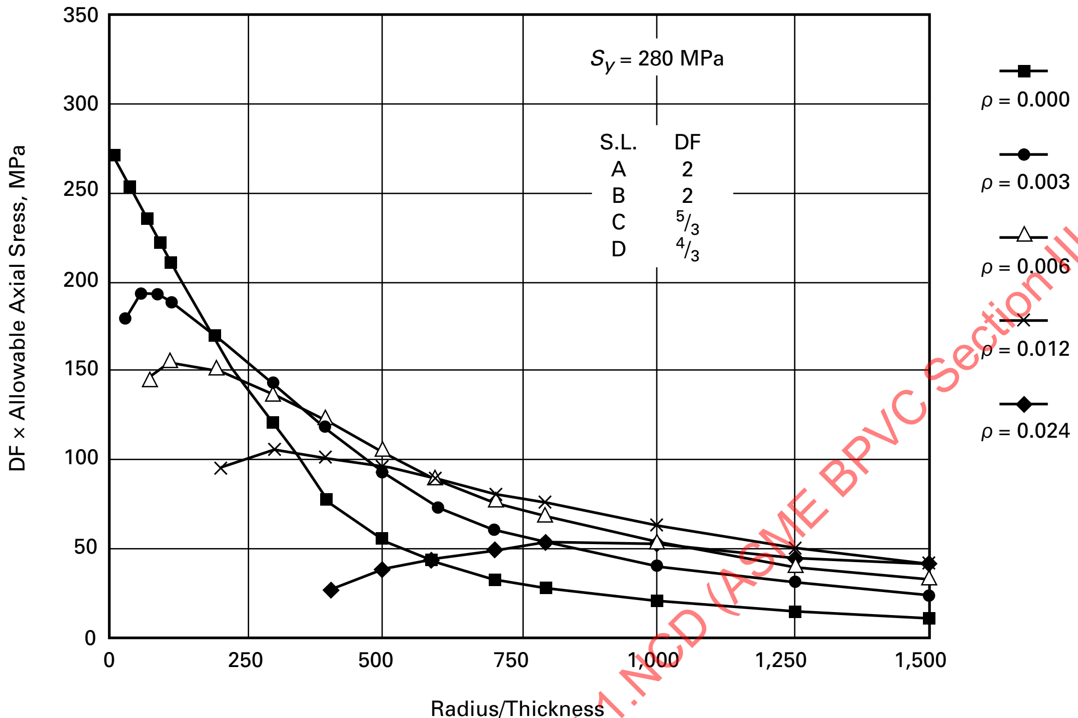


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

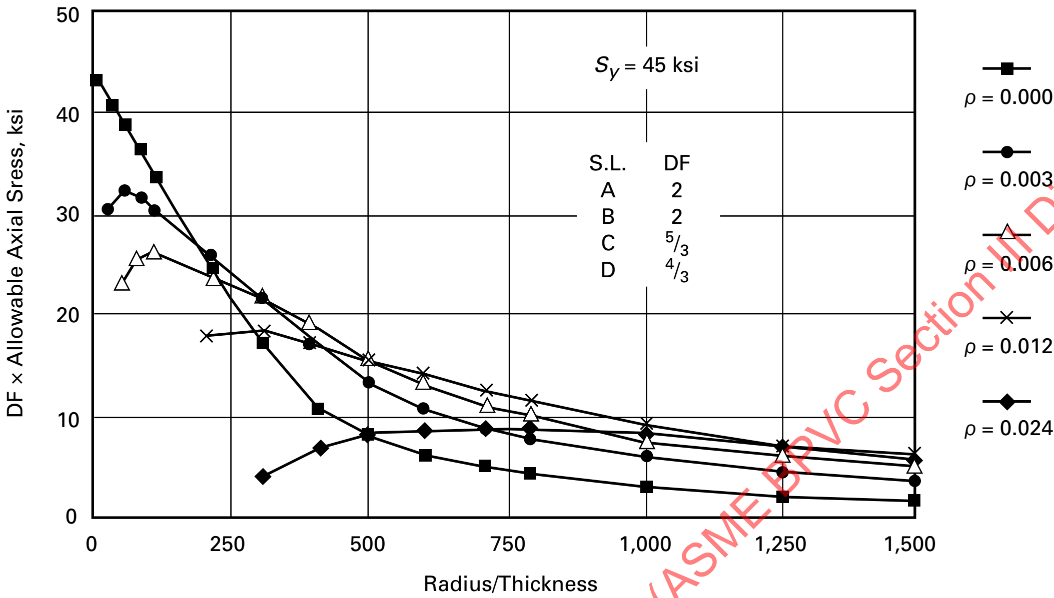


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-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 ≤ 300°F

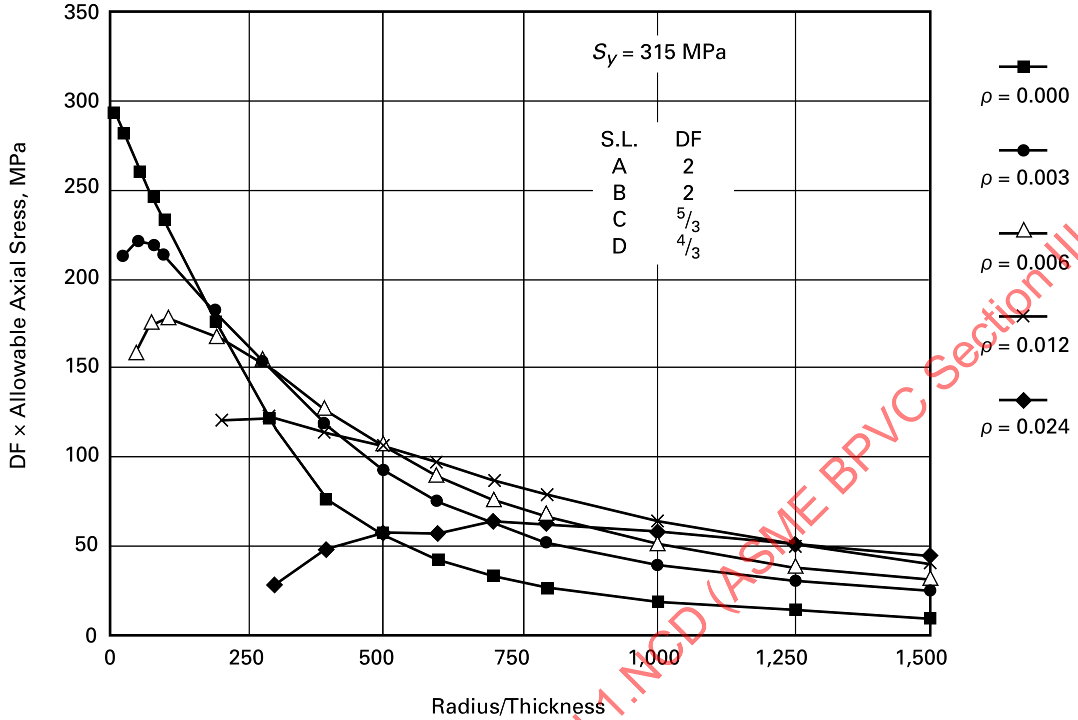


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

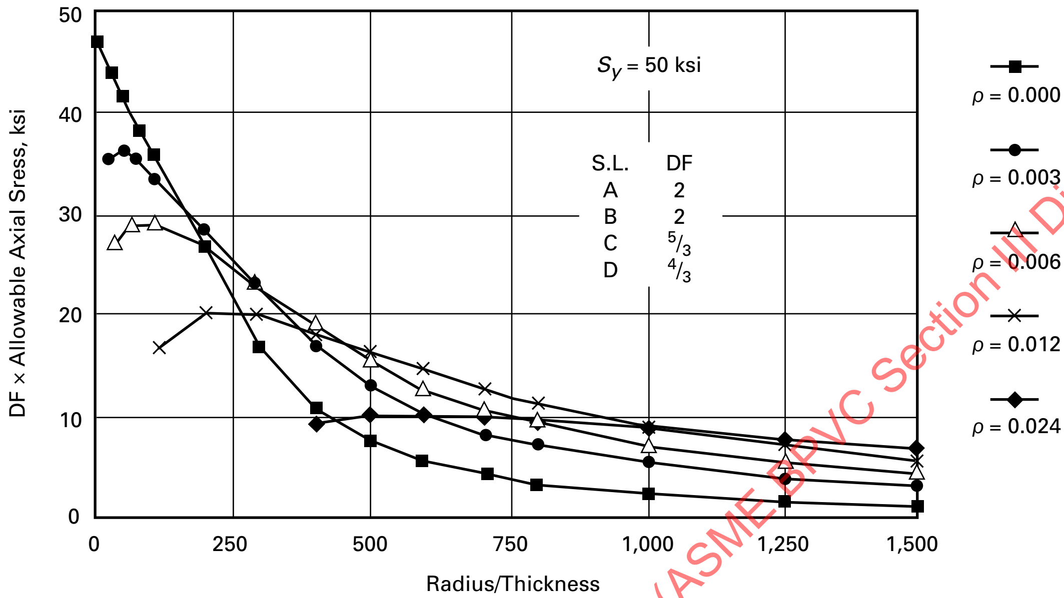


Tabular Values

R/*t*	*ρ* = 0.000	*ρ* = 0.003	*ρ* = 0.006	*ρ* = 0.012	*ρ* = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-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 ≤ 300°F

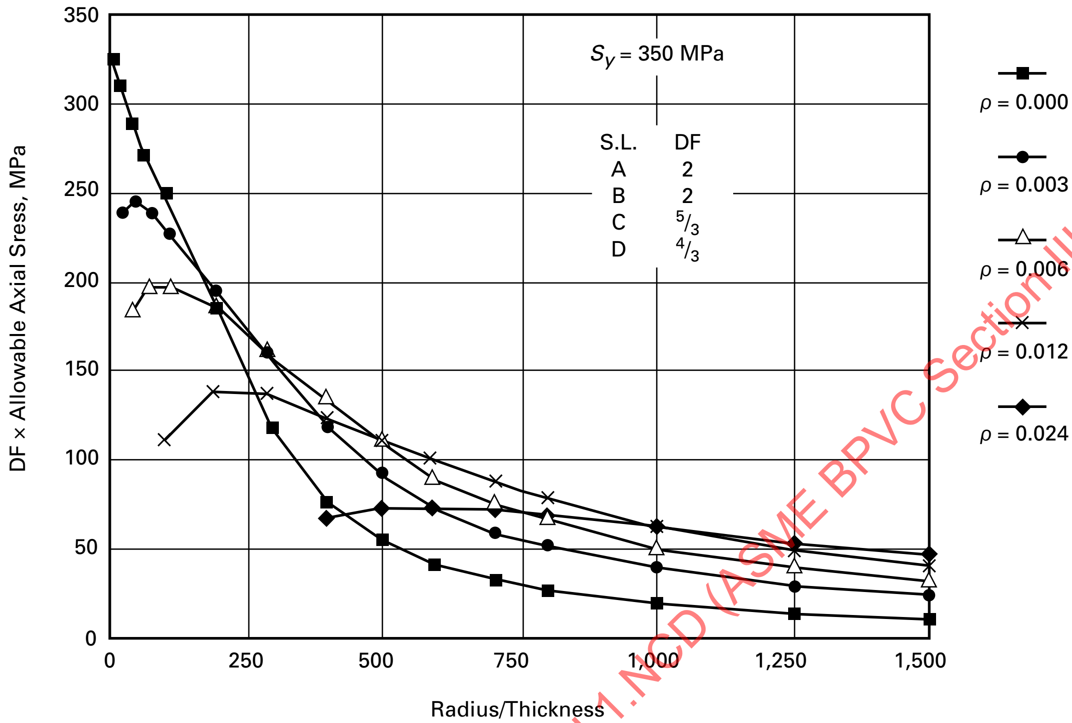


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 300°F; other code temperature limits may also apply.

Figure NCD-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 ≤ 150°C

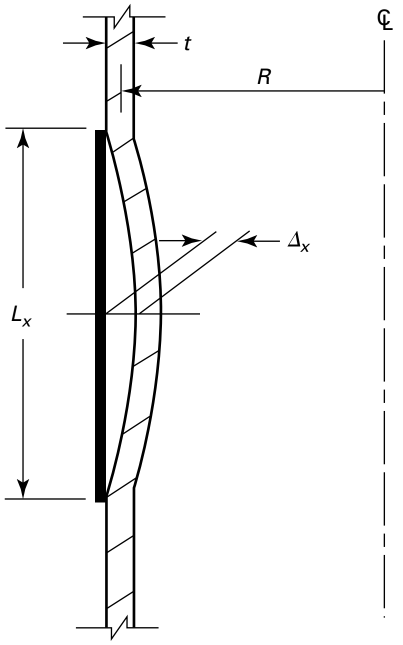


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 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 ≤ 150°C; other code temperature limits may also apply.

Figure NCD-3947-1
Meridional Straightness Tolerance



ARTICLE NCD-4000 FABRICATION AND INSTALLATION

NCD-4100 GENERAL REQUIREMENTS

NCD-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 which meet the requirements of Article NCD-2000.

(b) Atmospheric and 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks shall be fabricated in accordance with the rules of this Article.

(c) Class 2 vessels designed to the requirements of NCD-3200 shall meet the requirements of this Article except for NCD-4240 and NCD-4433. In this case, the requirements of NCD-4260 apply.

NCD-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

NCD-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 Article NCA-8000, that the materials used comply with the requirements of Article NCD-2000 and that the fabrication or installation complies with the requirements of this Article.

NCD-4121.1 Certification of Treatments, Tests, and Examinations. If the 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 or NCA-8410). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NCD-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 (NCD-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 Article NCD-2000.

NCD-4121.3 Repetition of Surface Examination After Machining. During the fabrication or installation of an item, if materials for pressure-containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with NCD-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with NCD-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $^1/_8$ in. (3 mm) or 10% of the minimum required thickness of the part.

NCD-4122 Materials Identification

(a) Material for pressure-retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, either the marks shall be transferred to the parts cut or a coded marking shall be used to ensure 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 materials 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.

NCD-4122.1 Marking Materials. Material shall be marked in accordance with NCD-2150.

NCD-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 Article NCD-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 NCD-5100 and NCD-5500 respectively, unless so specified.

NCD-4125 Testing of Welding and Brazing Materials

All welding and brazing materials shall meet the requirements of NCD-2400.

NCD-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of NCD-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 NCD-2500 for the applicable product form, except that:

(a) the limitation on the depth of the weld repair does not apply;

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NCD-5130 for Class 2 or NCD-5120 for Class 3;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is ¼ in. (6 mm) or less;

(d) radiographic examination is not required for welded repairs in material used in storage tanks, 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 mm^2) of the surface area, and the magnetic particle or liquid penetrant examination of the repair is made as required by NCD-2539.4.

NCD-4200 FORMING, CUTTING, AND ALIGNING

NCD-4210 CUTTING, FORMING, AND BENDING

NCD-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NCD-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 Section III Appendices, Nonmandatory Appendix D.

NCD-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure-retaining materials, including weld metal, provided the required dimensions are attained (see NCD-4214 and NCD-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 NCD-4213. When required, the process shall be qualified to meet thickness requirements as outlined in NCD-4223.1.

NCD-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 materials 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 NCD-2300 are met after straining.

NCD-4213.1 Exemptions. Procedure qualification tests are not required for material listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed materials represented by test coupons required in either NCD-2211 or NCD-4121.2 which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) materials which do not require impacts in accordance with NCD-2300;

(d) materials which have 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 NCD-2300 is performed on each heat and lot, as applicable, after forming.

NCD-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 Article NCD-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

(1) For cylinders

$$\%\ \text{strain} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(2) For spherical or dished surfaces

$$\%\ \text{strain} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(3) 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 (NCD-2300). In addition, drop weight tests shall be made when required by NCD-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(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 (NCD-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NCD-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.

NCD-4213.4 Requalification. A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering NCD-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.

NCD-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NCD-2124 and Article NCD-3000, the material may be repaired in accordance with NCD-4130.

NCD-4220 FORMING TOLERANCES

NCD-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel, except formed heads covered by NCD-4222, shall meet the requirements of the following subparagraphs at all cross sections.

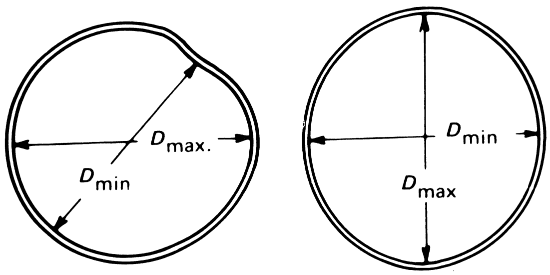
NCD-4221.1 Maximum Difference in Cross-Sectional Diameters.

(a) The difference in inches (millimeters) between the maximum and minimum diameters at any cross-section shall not exceed the smaller of

(U.S. Customary Units)

$$\frac{D + 50}{200} \text{ and } \frac{D}{100}$$

Figure NCD-4221.1-1
Maximum Difference in Cross-Sectional Diameters



(SI Units)

$$\frac{D + 1\,250}{200} \text{ and } \frac{D}{100}$$

where D is the nominal inside diameter, in. (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 NCD-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.

(b) For Class 3 vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

NCD-4221.2 Maximum Deviation From True Theoretical Form for External Pressure. Vessels designed for external pressure shall meet the tolerances given in (a) through (e) below.

(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 deviation obtained from Figure NCD-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 NCD-4221.2(a)-2. For Figure NCD-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Figure NCD-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t at any cross section

(1) The value of t, in., 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.

(2) For Class 3 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 NCD-4221.2(a)-1 and NCD-4221.2(a)-2 is determined by (1), (2), and (3) below.

(1) For cylinders, L is as given in NCD-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 (millimeters) 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 which 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.

NCD-4221.3 Deviations From Tolerances. Deviations from the tolerance requirements stipulated in NCD-4221.1 and NCD-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

NCD-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.

NCD-4221.5 Localized Thin Areas. Localized thin areas are permitted if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in NCD-3330.

NCD-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NCD-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 between the maximum and minimum diameters does not exceed the lesser of

(U.S. Customary Units)

$$\frac{D + 50}{200} \text{ and } \frac{D + 12}{100}$$

Figure NCD-4221.2(a)-1
Maximum Permissible Deviation *e* From a True Circular Form

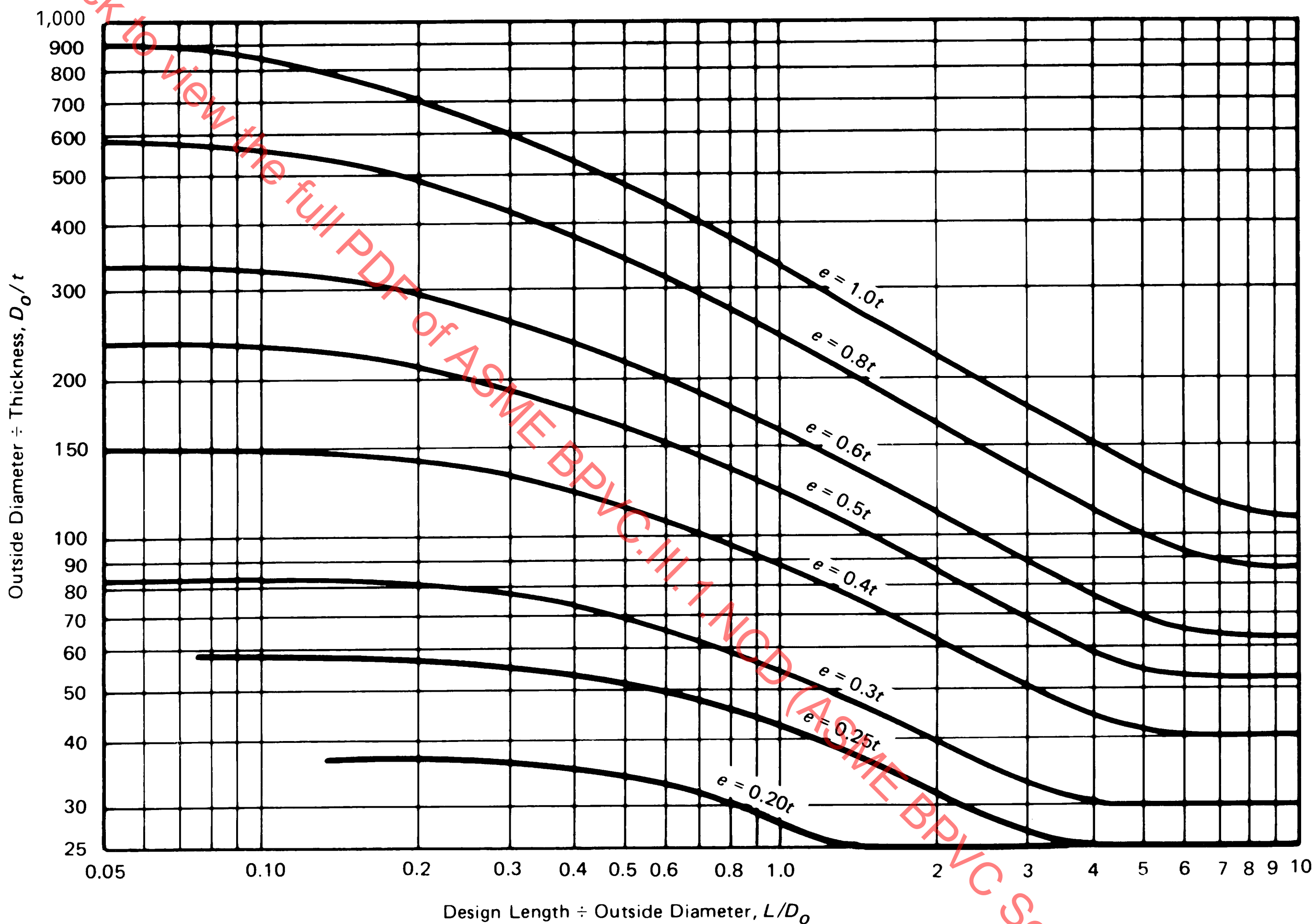
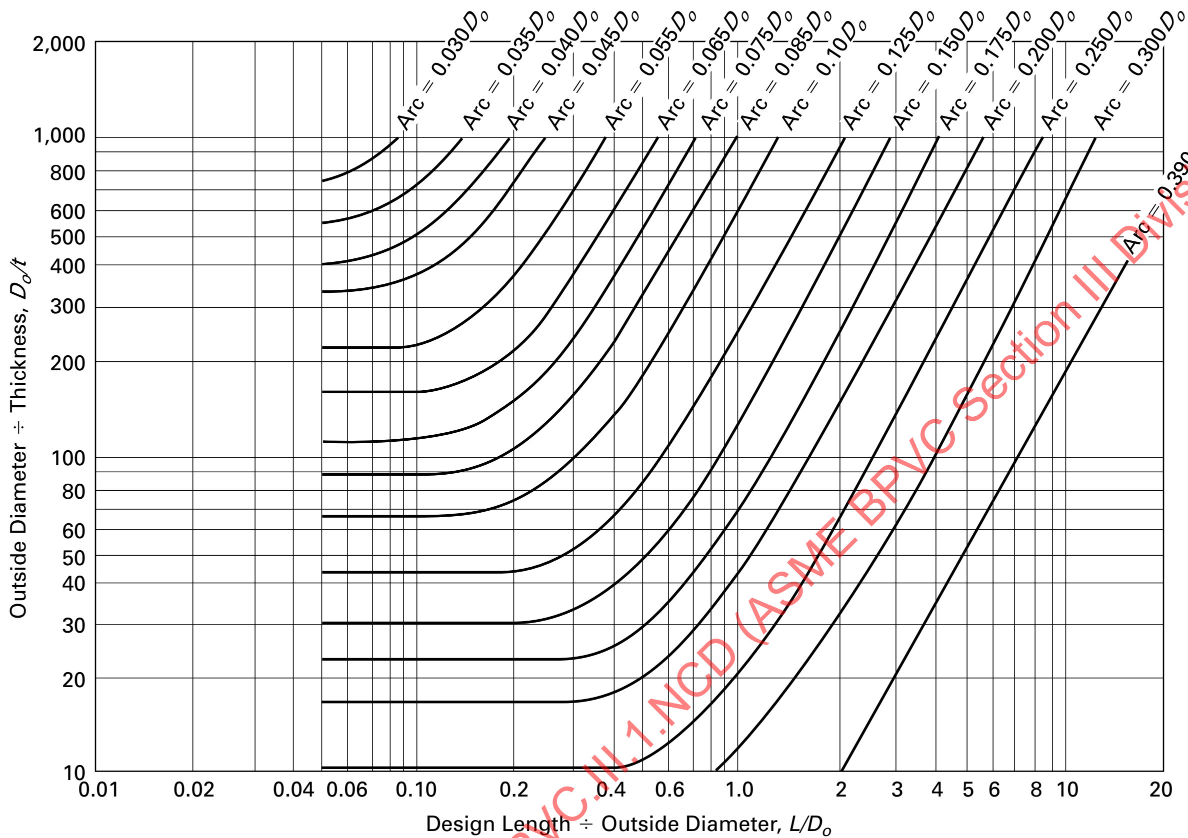


Figure NCD-4221.2(a)-2
Maximum Arc Length for Determining Plus or Minus Deviation



(SI Units)

$$\frac{D + 1\,250}{200} \text{ and } \frac{D + 300}{100}$$

where D is the nominal inside diameter, in. (mm), and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in NCD-4232.

NCD-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 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 NCD-4221.2, using L as the outside spherical radius in inches (millimeters) and D_o as 2 times L.

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NCD-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

NCD-4223.1 Minimum Wall Thickness. In order to ensure 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.

NCD-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_{min} = the minimum outside diameter after bending or forming

D_{max} = the maximum outside diameter after bending or forming

D_o = the nominal pipe outside diameter

NCD-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 and bottom juncture, respectively, if these junctures are of a type which 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 $^1\!/_2$% of the average diameter or 6 in. (150 mm), whichever is less.

NCD-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 $^1\!/_2$% 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 NCD-4224.2.

NCD-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.

NCD-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.

NCD-4230 FITTING AND ALIGNING

NCD-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.

NCD-4231.1 Tack Welds. Tack welds used to secure alignment shall either 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.

NCD-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which 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 NCD-4232(a)-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels, joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NCD-4232(a)-1 for longitudinal joints.

NCD-4232.1 Fairing of Offsets. Any offset within the allowable tolerance provided above shall be faired to at least 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.

NCD-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with NCD-4232, alignment of sections shall meet the requirements of (1) and (2) below.

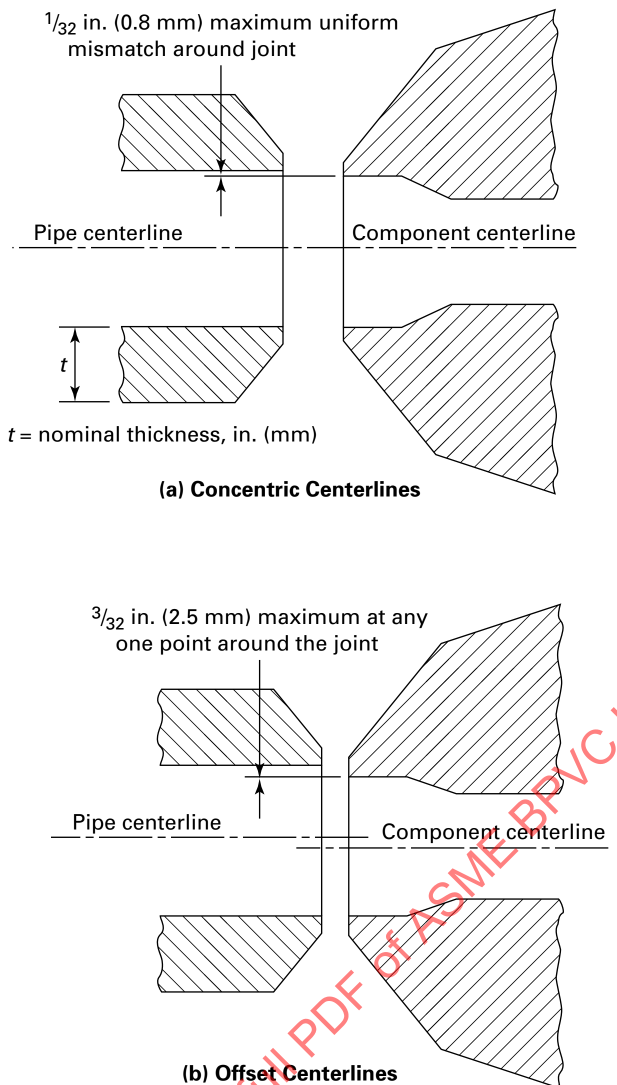
(1) See (-a) and (-b) below

(-a) For circumferential joints the inside diameters shall match each other within $^1\!/_{16}$ in. (1.5 mm) When the items are aligned concentrically, a uniform mismatch of $^1\!/_{32}$ in. (0.8 mm) all around the joint can result, as shown in Figure NCD-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

Table NCD-4232(a)-1
Maximum Allowable Offset in Final Welded Joints

Section Thickness, in. (mm)	Direction of Joints	
	Longitudinal	Circumferential
Up to $^1\!/_2$ (13), incl.	$^1\!/_4t$	$^1\!/_4t$
Over $^1\!/_2$ to $^3\!/_4$ (13 to 19), incl.	$^1\!/_8$ in. (3 mm)	$^1\!/_4t$
Over $^3\!/_4$ to 1 $^1\!/_2$ (19 to 38), incl.	$^1\!/_8$ in. (3 mm)	$^3\!/_{16}$ in. (5 mm)
Over 1 $^1\!/_2$ to 2 (38 to 50), incl.	$^1\!/_8$ in. (3 mm)	$^1\!/_8t$
Over 2 (50)	Lesser of $^1\!/_{16}t$ or $^3\!/_8$ in. (10 mm)	Lesser of $^1\!/_8t$ or $^3\!/_4$ in. (19 mm)

Figure NCD-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 NCD-4250 for weld end transition requirements.

maximum misalignment at any one point around the joint shall not exceed $^3/_{32}$ in. (2.5 mm) as shown in Figure NCD-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variation which does not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of NCD-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 $^3/_{32}$ 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 NCD-4232.

NCD-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS[26]

NCD-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

NCD-4241.1 For Class 2 Only. Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed, and those welded from one side without backing, are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of NCD-4424.

NCD-4241.2 For Class 3 Only. 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 NCD-3352.1(a) or NCD-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 NCD-4245.2.

(b) When the design is based on a joint efficiency permitted by NCD-3352.1(c), any joint Type as described in NCD-4245.2 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 NCD-4245.2 shall be used.

NCD-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

NCD-4242.1 For Class 2 Only. Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping NPS 2 (DN 50) and smaller may be socket welded. Joints prepared with opposing lips to form an integral backing ring and joints with backing strips which are not later removed are acceptable, provided the requirements of NCD-3352.2 are met.

NCD-4242.2 For Class 3 Only. 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 NCD-3352.2(a) or NCD-3352.2(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 NCD-4245.2.

(b) When the design is based on a joint efficiency permitted by NCD-3352.2(c), any joint Type as described in NCD-4245.2 may be used, provided the limitations of the joint are followed.

NCD-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

NCD-4243.1 For Class 2 Only. Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, as shown in Figures NCD-4243.1-1 and NCD-4243.1-2, except that socket welded flanges of NPS 2 (DN 50) and less and slip-on flanges may be used.

NCD-4243.2 For Class 3 Only. 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 NCD-4245.2 when a butt weld detail is used and the provisions of NCD-3352.1(a) or NCD-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 NCD-4243.2-1 and Section III Appendices, Mandatory 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.

NCD-4243.3 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Figure NCD-4243.3-1 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.[27] 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.

NCD-4244 Category D Weld Joints

NCD-4244.1 For Class 2 Only — Category D Weld Joints in Vessels and Branch and Piping Connection Weld Joints in Other Components. Category D weld joints in vessels and similar weld joints in other components shall be welded using one of the details of (a) through (e) below.

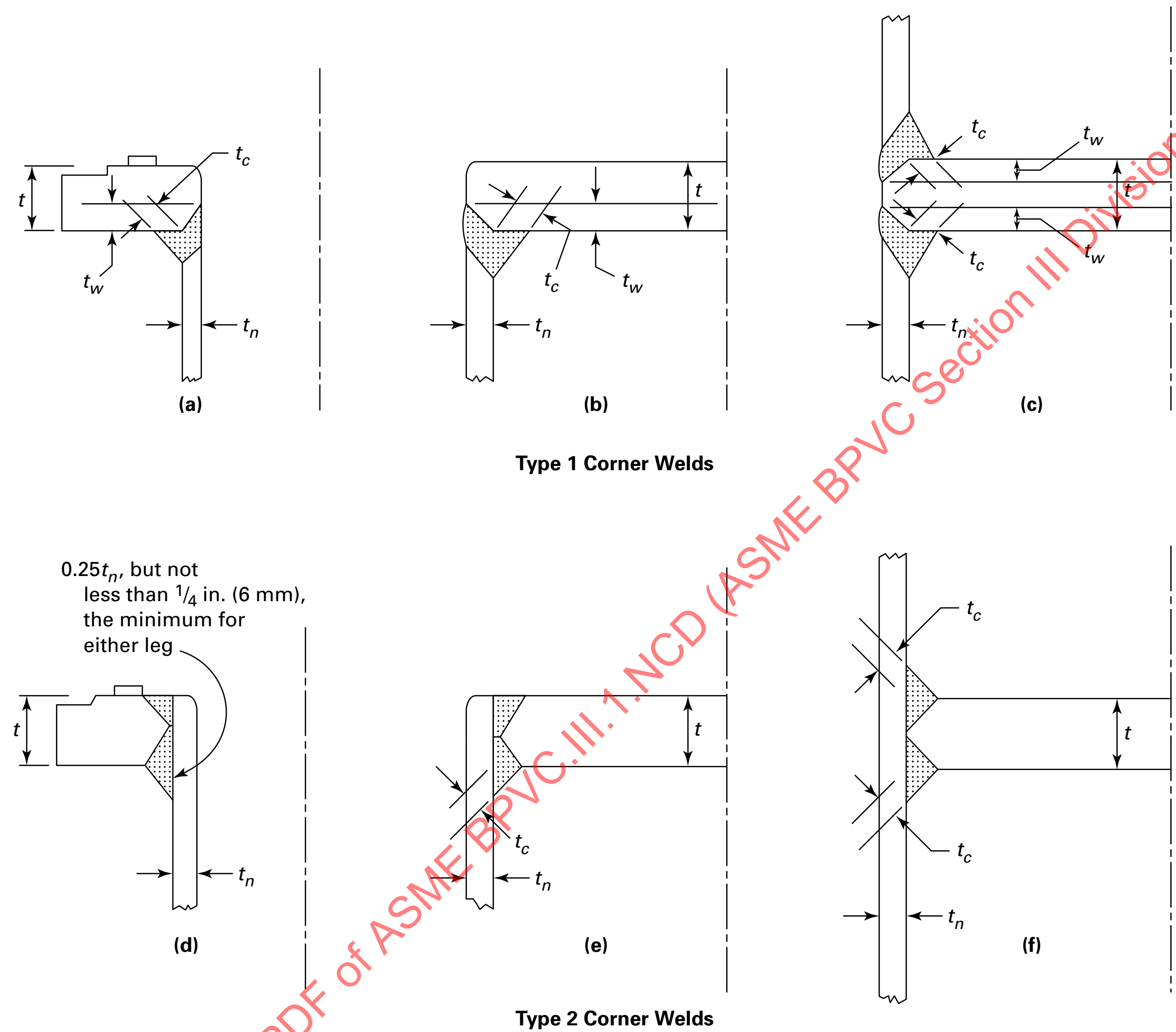
(a) Butt Welded Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Figure NCD-4244.1-1. Backing strips, if used, may be left in place.

(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 NCD-4244.1-2. 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 NCD-4244.1-3. 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.

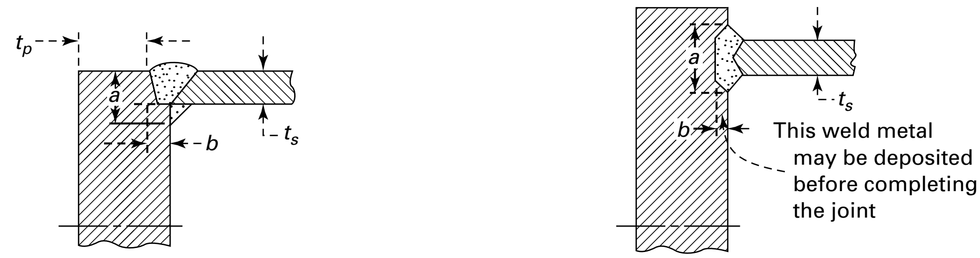
(d) Partial Penetration Welded Nozzles and Branch Piping Connections. Partial penetration welds in components and branch piping connections, shall meet the weld design requirements of NCD-3352.4(d) and NCD-3359. Nozzles shall be attached as shown in Figure NCD-4244.1-4. Reinforcing plates of nozzles 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

Figure NCD-4243.1-1
For Class 2 Only — Acceptable Full Penetration Weld Details for Category C Joints



GENERAL NOTE: For definitions of nomenclature, see NCD-3358.3(e)(1).

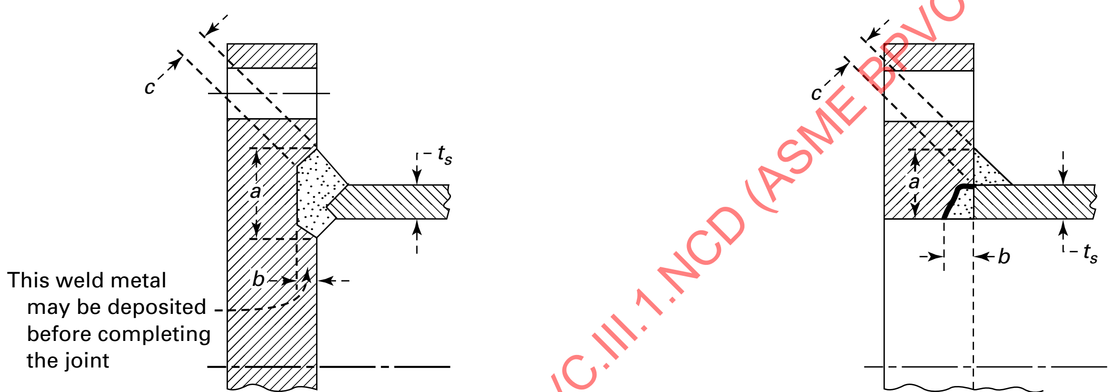
Figure NCD-4243.1-2
For Class 2 Only — Attachment of Pressure Parts to Plates to Form a Corner Joint



(a)

(b)

Typical Unstayed Flat Heads, Supported and Unsupported Tubesheets Without a Bolting Flange, and Side Plates of Rectangular Vessels

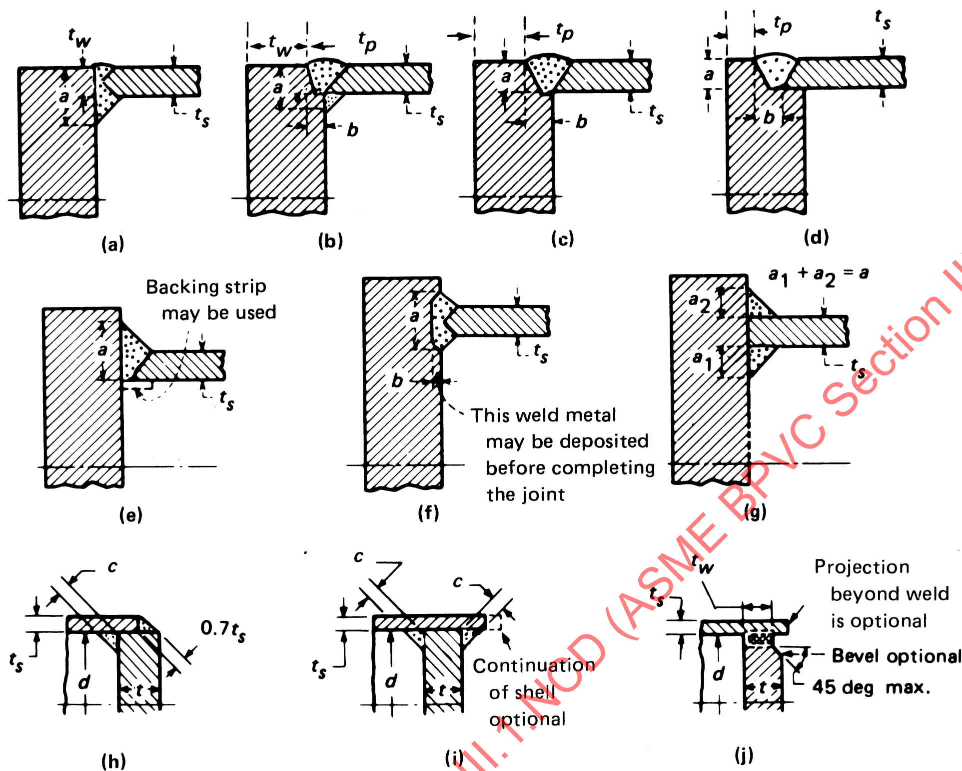


(c) Typical Supported and Unsupported Tubesheets With a Bolting Flange

(d) Typical Bolted Flange Connections

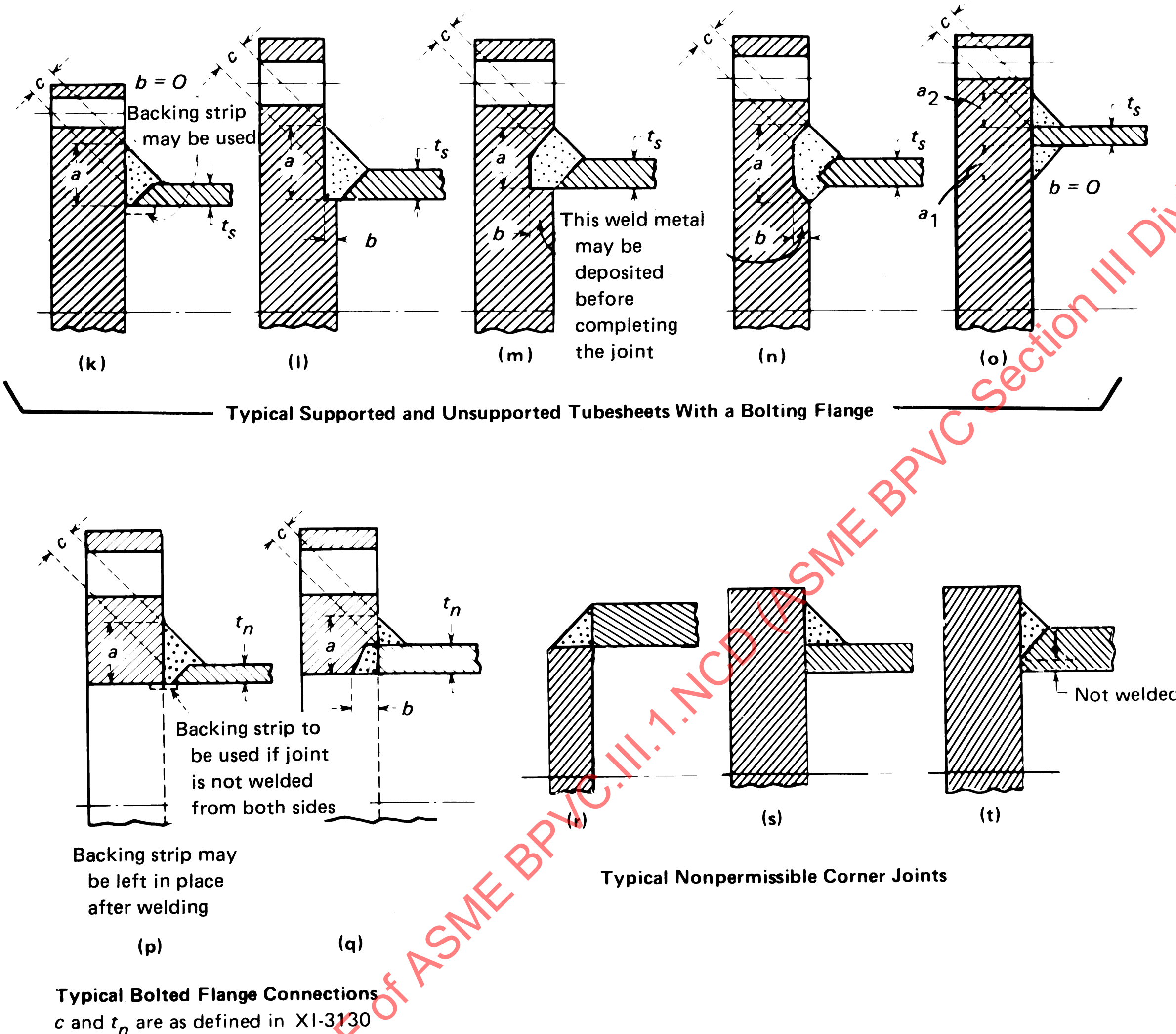
GENERAL NOTE: For definitions of nomenclature, see NCD-3358.3(e)(2).

Figure NCD-4243.2-1
For Class 3 Only — Attachment of Pressure Parts to Plates to Form a Corner Joint



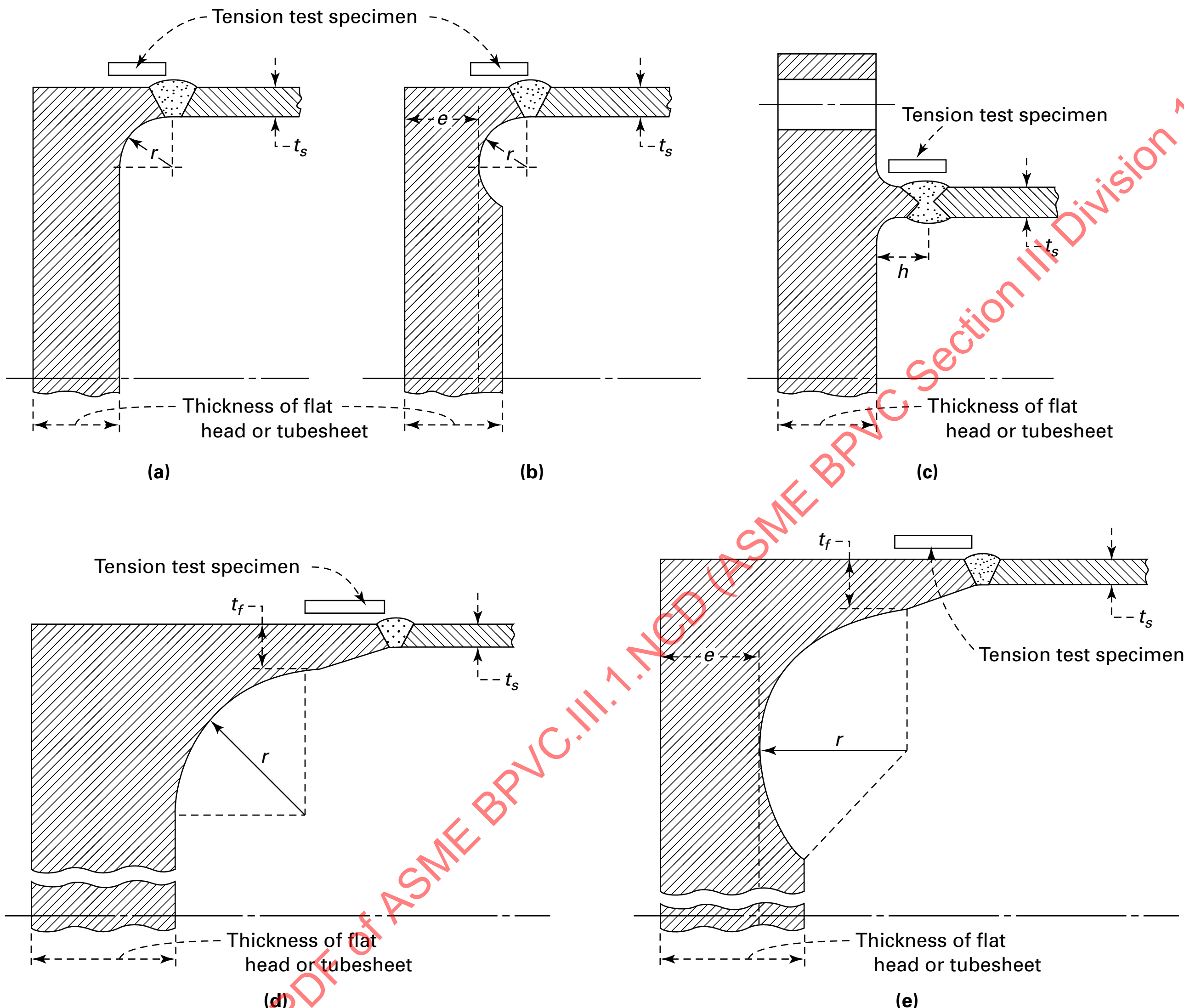
Typical Unstayed Flat Heads, Supported and Unsupported Tubesheets Without a Bolting Flange, and Rectangular Vessels [Sketches (a) Through (j)]

Figure NCD-4243.2-1
For Class 3 Only — Attachment of Pressure Parts to Plates to Form a Corner Joint (Cont'd)



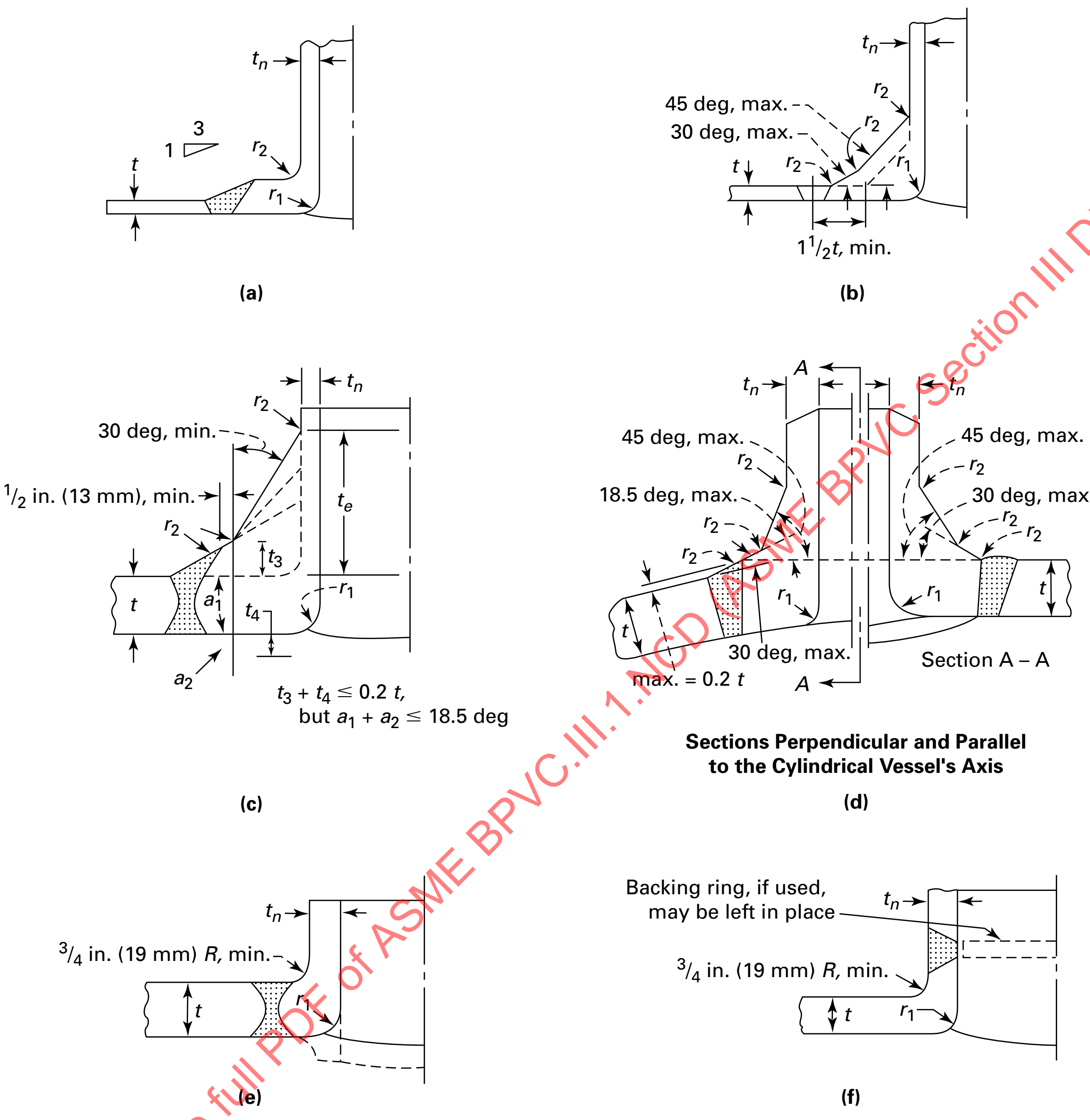
GENERAL NOTE: See NCD-3325, NCD-3358.2, and NCD-3358.3, as applicable, for sketches (a) through (j) and sketches (k) through (q), except as modified by Section III Appendices, Mandatory Appendix XI, XI-3130 for sketches (p) and (q).

Figure NCD-4243.3-1
Typical Flat Heads and Supported and Unsupported Tubesheet With Hubs



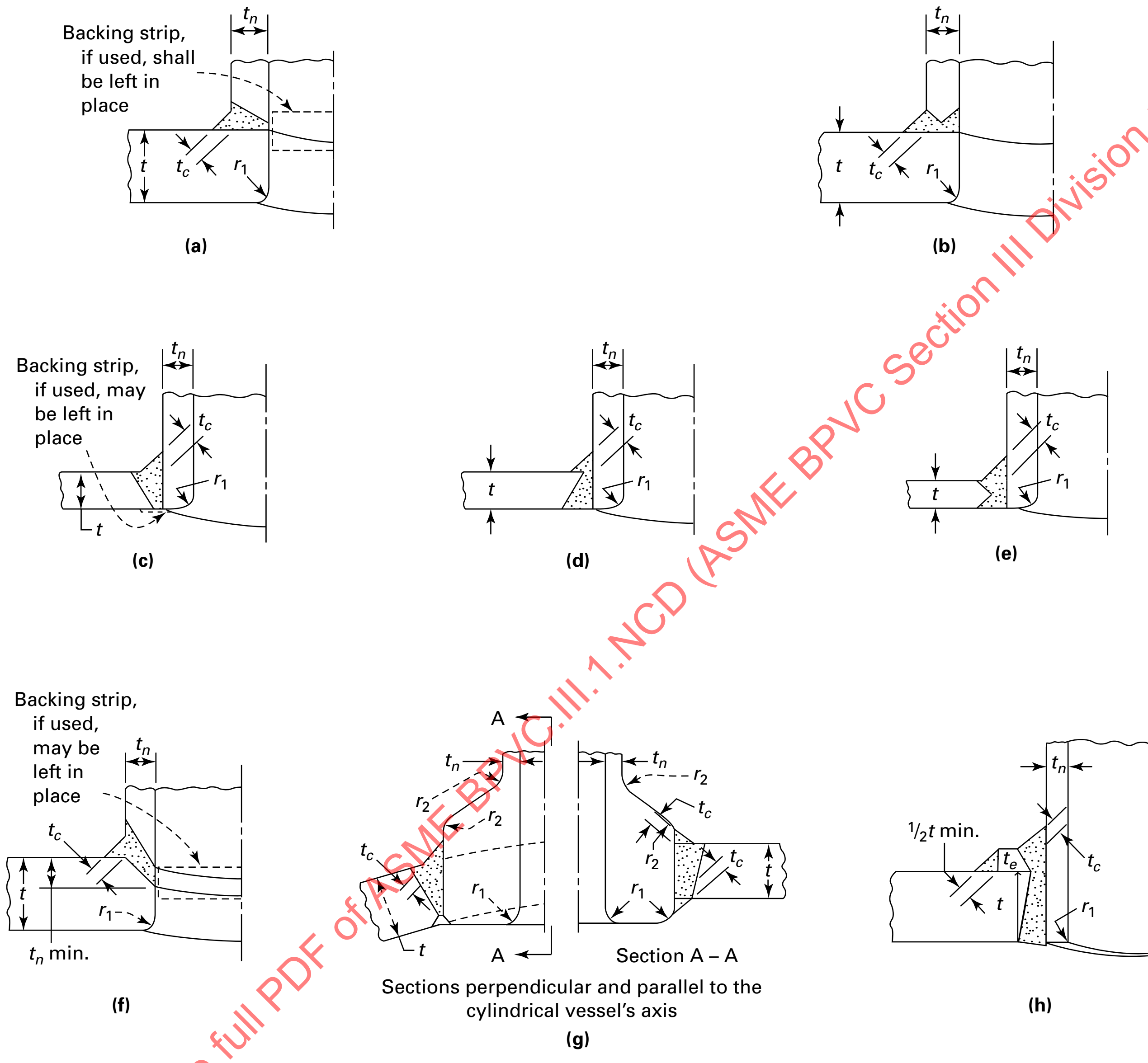
GENERAL NOTES:
(a) For definitions of nomenclature, see NCD-3358.4.
(b) Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

Figure NCD-4244.1-1
Nozzles, Branch, and Piping Connections Joined by Full Penetration Butt Welds



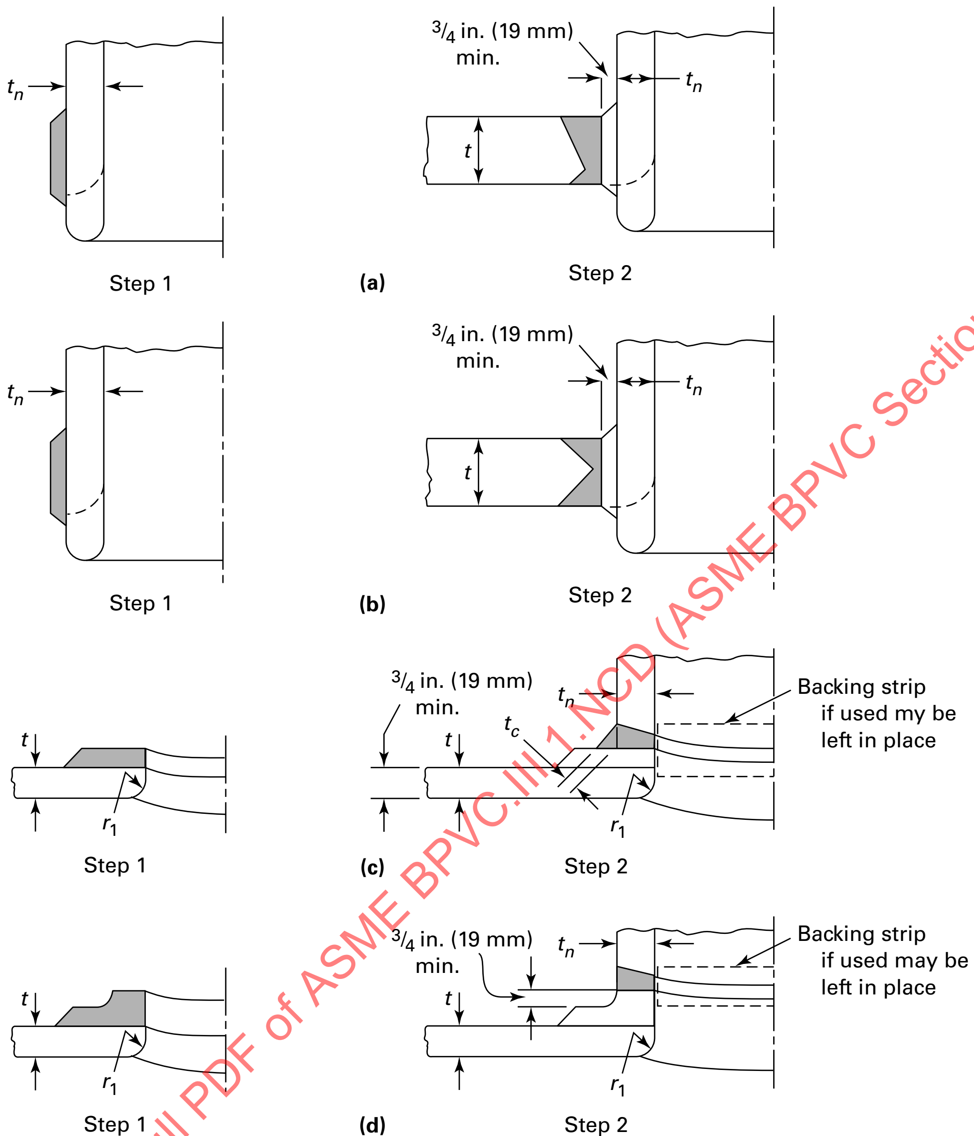
GENERAL NOTE: For definition of symbols, see NCD-3352.4(a).

Figure NCD-4244.1-2 Nozzles, Branch, and Piping Connections Joined by Full Penetration Corner Welds



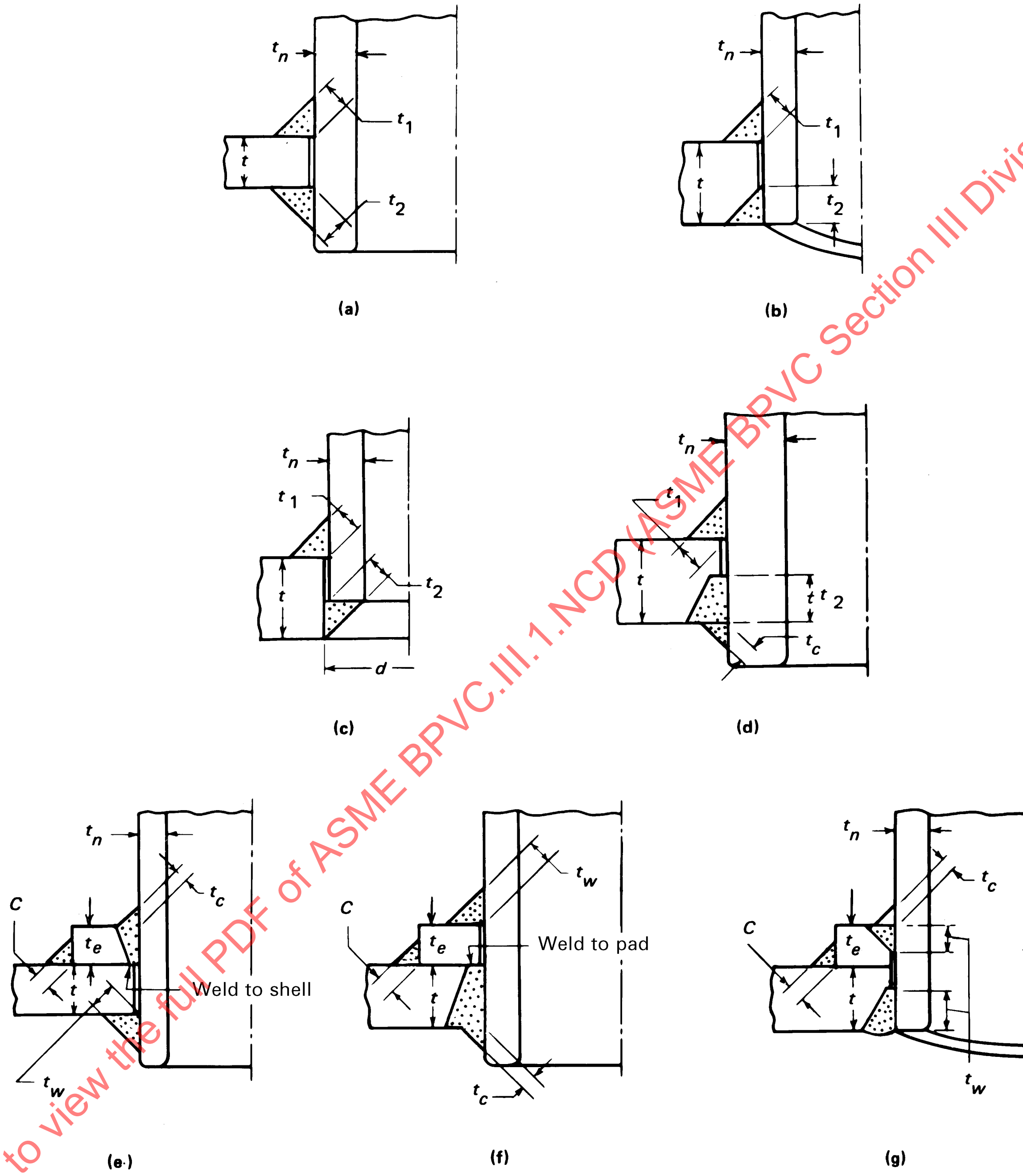
GENERAL NOTE: For definition of symbols, see NCD-3352.4(b).

Figure NCD-4244.1-3
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles, Branch, and Piping Connections



GENERAL NOTE: For definition of symbols, see NCD-3352.4(c).

Figure NCD-4244.1-4
Some Acceptable Types of Welded Nozzles, Branch, and Piping Connections



GENERAL NOTE: For definition of symbols, see NCD-3352.4(d).

air and soapsuds test for tightness of welds. 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.[28] 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 NCD-4244.1-5 sketch (c-3). Internally threaded fitting and bolting pads not exceeding NPS 3 (DN 80), as shown in Figure NCD-4244.1-6 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 NCD-3352.4(e) shall be met for all components.

NCD-4244.2 For Class 3 Only — 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 NCD-4244.1-1, NCD-4244.1-2, and NCD-4244.1-3.

(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 NCD-4244.1-1. 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 NCD-4244.1-2. 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 NCD-4244.1-3. 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 NCD-3352.4(d) and NCD-3359. Nozzles shall be attached as shown in Figure NCD-4244.1-4. 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.[28] 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 NCD-4244.1-5 sketch (c-3). Internally threaded fitting and bolting pads not exceeding NPS 3 (DN 80), as shown in Figure NCD-4244.1-6, 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 NCD-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 NCD-3352.4(f) are met. Typical connections are shown in Figure NCD-4244.2-1.

(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 NCD-4244.2-2.

NCD-4245 Complete Joint Penetration Welds

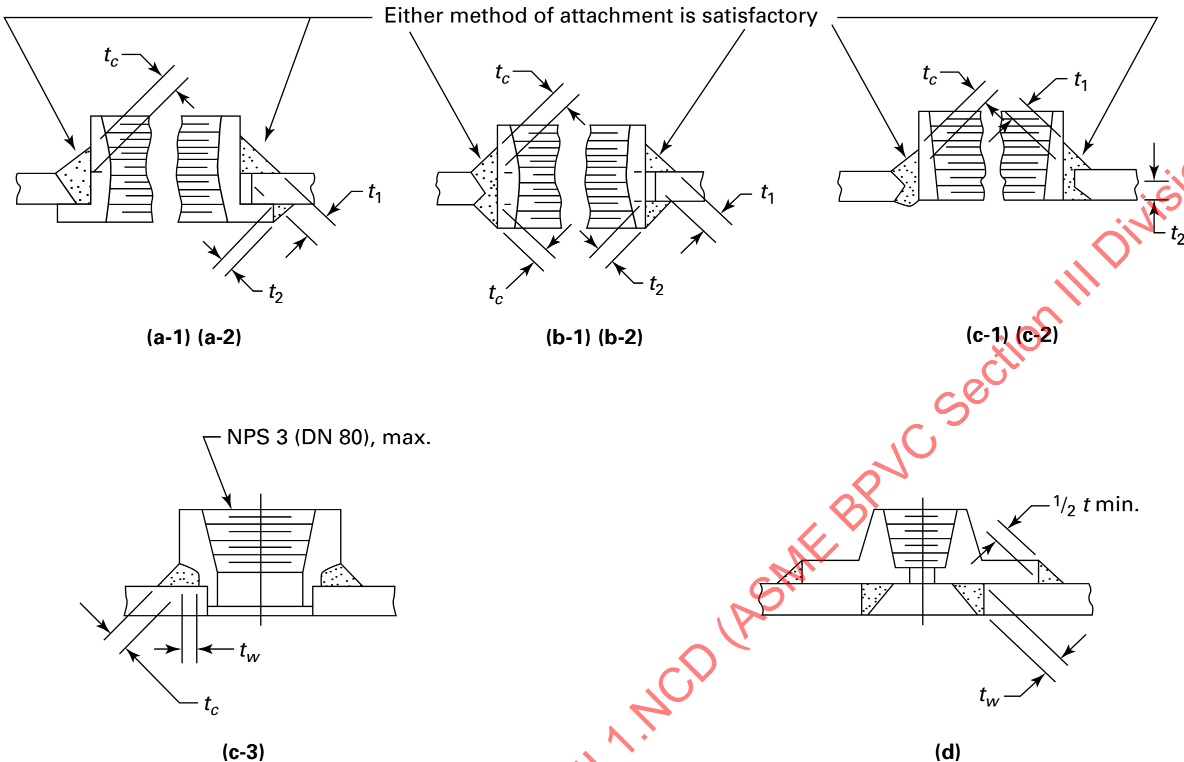
NCD-4245.1 For Class 2 Only. Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination is required to assess that complete penetration has been achieved.

NCD-4245.2 For Class 3 Only. Acceptable joint Types and limitations are listed in Table NCD-4245.2-1. Some typical configurations are shown in Figure NCD-4245.2-1.

NCD-4246 Atmospheric Storage Tank Special Joints

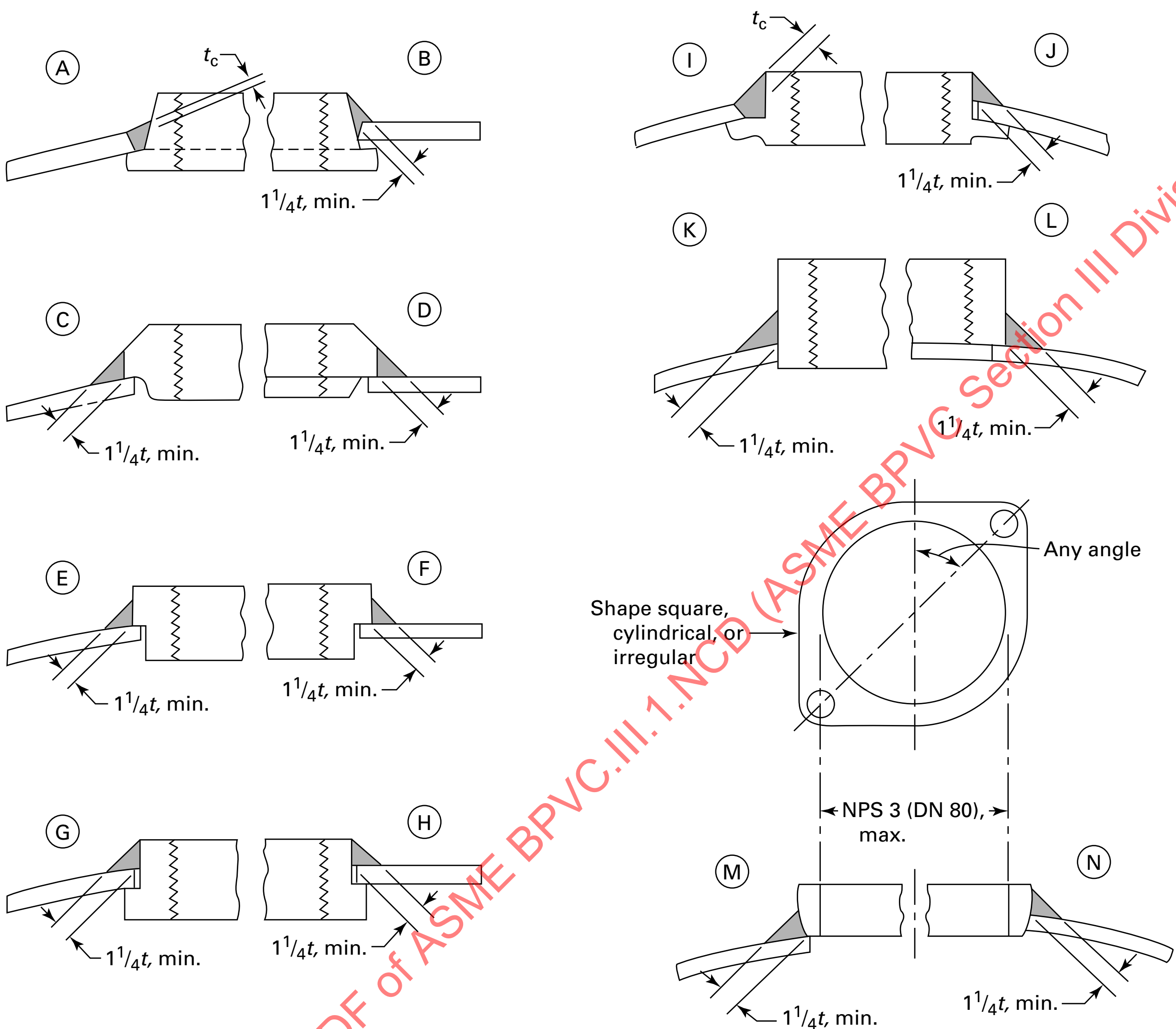
Requirements for special joints for atmospheric storage tanks are given below.

Figure NCD-4244.1-5
Some Acceptable Types of Welded Nozzles



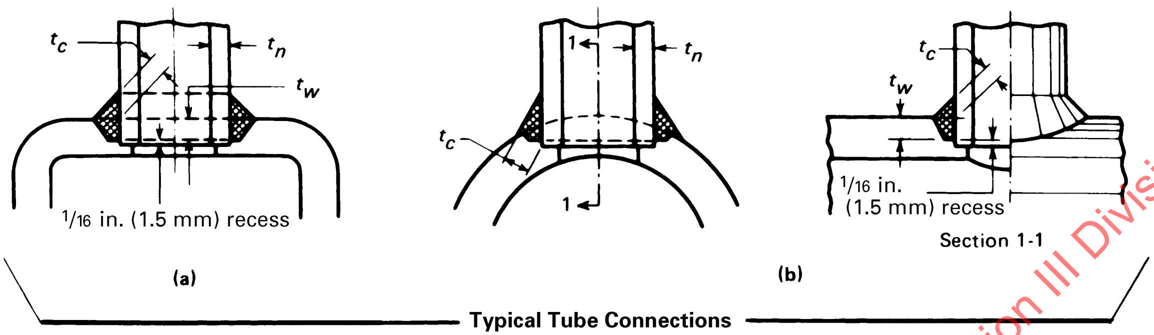
GENERAL NOTE: For definition of symbols, see NCD-3352.4(e).

Figure NCD-4244.1-6
Some Acceptable Types of Small Fitting



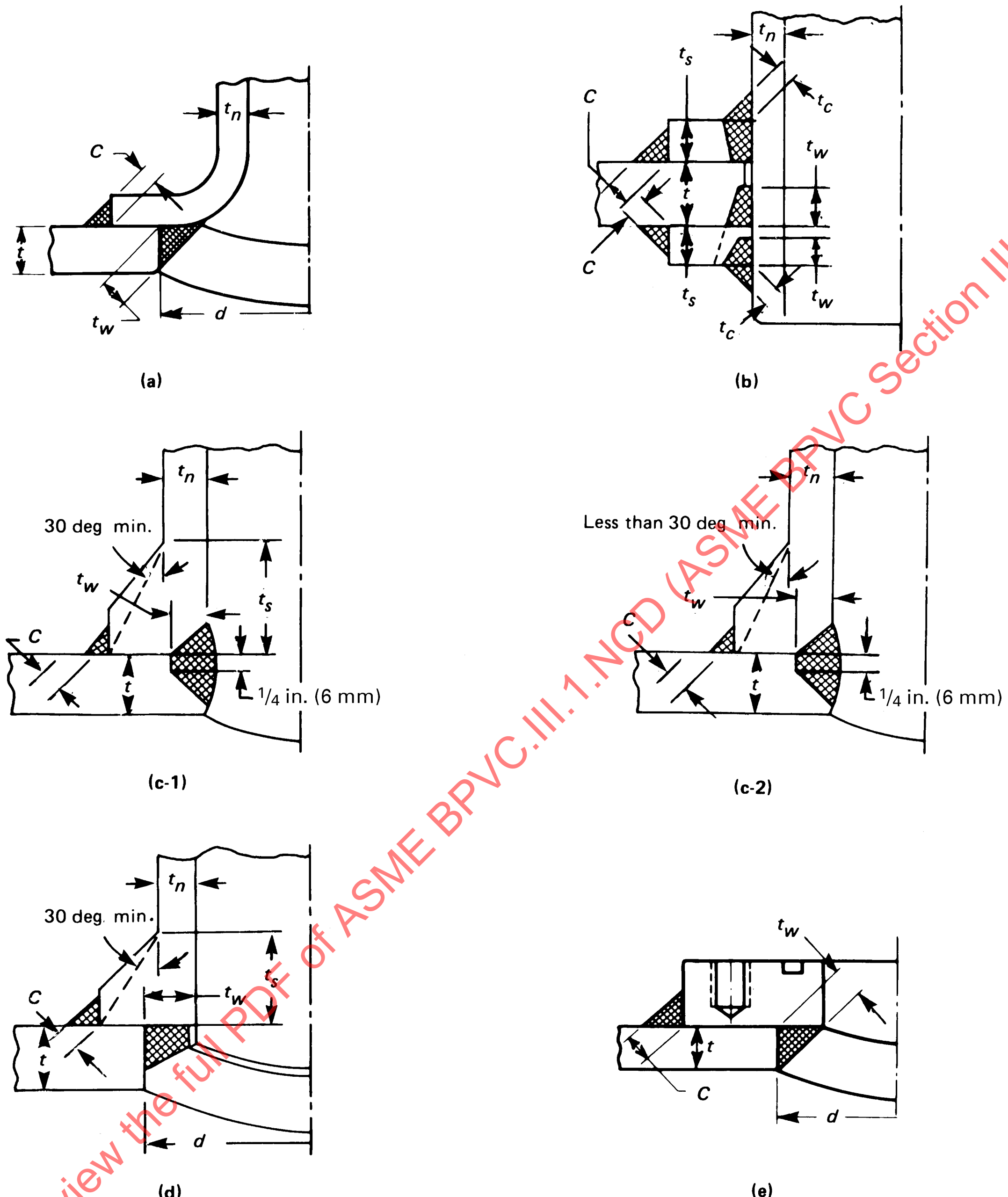
GENERAL NOTES:
(a) For definitions of nomenclature, see NCD-3352.4(e).
(b) Maximum shell thickness = $^3/_8$ in. (10 mm).
(c) Maximum internal thread diameter = $3^1/_2$ in. (89 mm).
(d) Maximum dimension of opening in shell = no greater than $5^3/_8$ in. (135 mm) or 0.5 × shell diameter.

Figure NCD-4244.2-1
Tube Connections



GENERAL NOTES:
(a) For definitions of symbols, see NCD-3352.4(f).
(b) When used for other than square, round, or oval headers, round off corners.

Figure NCD-4244.2-2
Some Acceptable Types of Welded Nozzles, and Branch and Piping Connections



GENERAL NOTE: For definitions of symbols, see NCD-3352.4(g).

Table NCD-4245.2-1

Type	Description	Limitations
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 NCD-4426. Welds using metal backing strips that remain in place are excluded.	The use of this joint Type is not limited
2	Single-welded butt joints with backing strips other than those included in Type 1	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 NCD-3358.5.1 [Figure NCD-4245.2-1, sketch (k)]
3	Single-welded butt joints without the use of a backing strip	This joint Type is limited to circumferential joints only, which are not over $^5/_8$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter
4	Double full fillet lap joints	This joint Type is limited to longitudinal joints not over $^3/_8$ in. (10 mm) thick and circumferential joints not over $^5/_8$ in. (16 mm) thick
5	Single full fillet lap joints with plug welds conforming to NCD-3356.2	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 $^1/_2$ in. (13 mm) thick. This joint Type cannot be used for attaching hemispherical heads to shells.
6	Single full fillet lap joints without plug welds	This joint Type is limited to attachment of heads convex to pressure to shells not over $^5/_8$ 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 $^1/_4$ in. (6 mm) required thickness with the fillet welds on the outside of the head flange only.

Figure NCD-4245.2-1
Attachment Welds

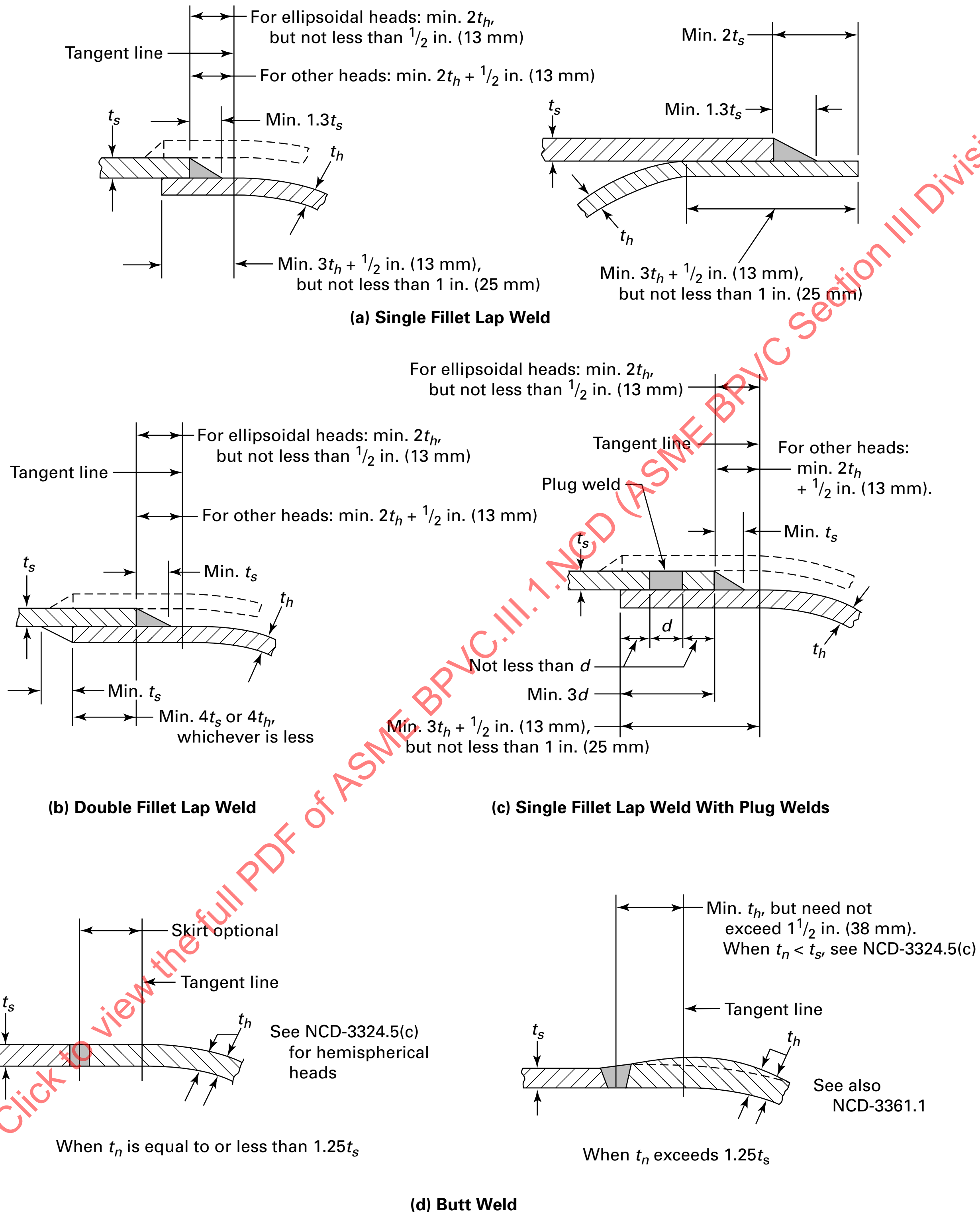
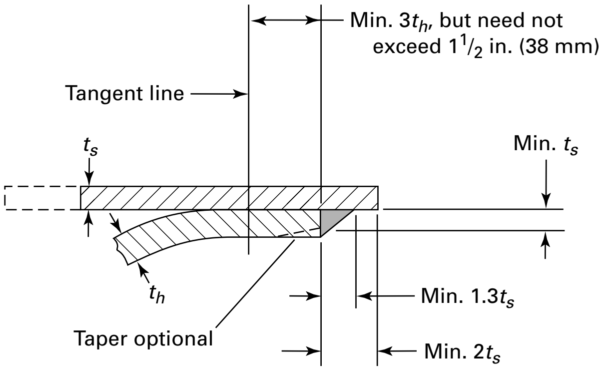
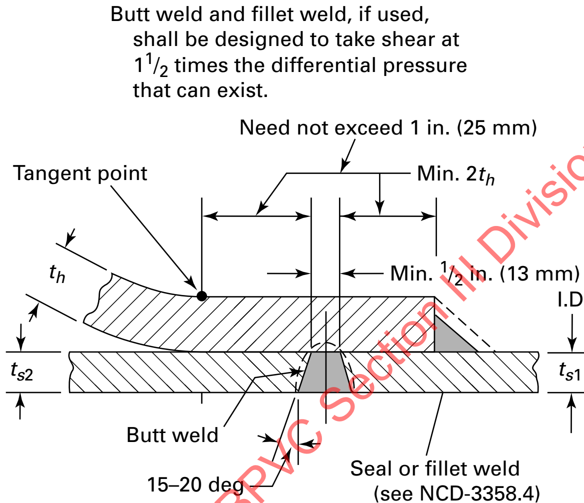


Figure NCD-4245.2-1
Attachment Welds (Cont'd)

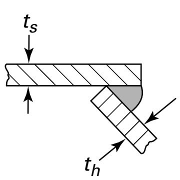


(e) Single Fillet Lap Weld

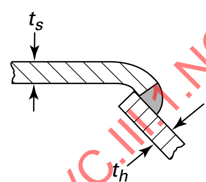


(f) Intermediate Head

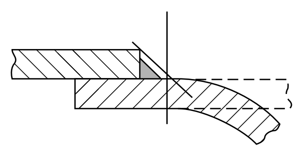
t_{s1} and t_{s2} may be different



(g)

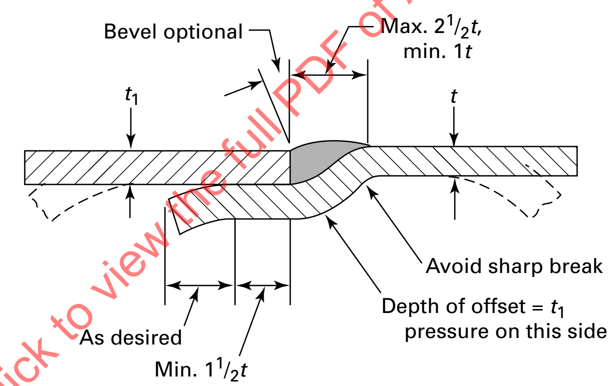


(h)



(i)

Sketches (g), (h), and (j) are not permissible



t or t_1 = $^5/_8$ in. (16 mm) max. [Note (1)]

(k) Butt Weld With One Plate Edge Offset

NOTE: (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.

NCD-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 NCD-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 NCD-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 $^1/_4$ in. (6 mm). The butt welds shall be made by applying a backing strip $^1/_8$ in. (3 mm) thick or heavier by tack welding to the underside of the plate [Figure NCD-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 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.

NCD-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 NCD-4246.1(a)-1] or, for tanks not exceeding 35 ft (11 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 neither less than 1.75t nor more than 3t.

NCD-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 NCD-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 $^3/_{16}$ in. (5 mm) or smaller.

NCD-4246.4 Roof Plates. Roof plates shall be attached at least by a continuous full fillet lap joint on the top side (Figure NCD-4246.3-1). The top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

NCD-4246.5 Nozzle, Manhole, and Outlet Joints. Nozzles, manholes, and outlets shall be attached by full fillet welds as shown in Figures NCD-4246.5-1 through NCD-4246.5-4.

NCD-4246.6 For Class 2 Only — Flanges to Roof Nozzles, Manholes, and Bottom Outlets. Flanges to roof nozzles, manholes, and bottom outlets shall be attached by fillet welds as shown in Figures NCD-4246.5-1, NCD-4246.5-2 and NCD-4246.5-4.

NCD-4246.7 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 $^3/_{16}$ in. (5 mm) thick, full fillet welds; plates over $^3/_{16}$ in. (5 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $^3/_{16}$ 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 $^1/_2$ 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 $^1/_8$ 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 NCD-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.

NCD-4246.8 Other Weld Joints. The fabrication requirements for weld joints not specifically covered by NCD-4246, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in NCD-4240 for Category A, B, and C weld joints for vessels.

NCD-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.

NCD-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.

NCD-4247.2 Bottom-to-Sidewall. All welds shall meet the design requirements of NCD-3933. Flat bottoms shall be attached to sidewalls by full penetration welds and fillet welds on each side as a minimum.

NCD-4247.3 Roof-to-Sidewall. Roof-to-sidewall joints shall be in accordance with the design requirements of NCD-3933. The joints shall have continuous full fillet welds as a minimum.