ASME BPVC.III.1.NF-2023

SECTION III

Rules for Construction of Nuclear Facility Components

2023 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NF

Supports

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AN INTERNATIONAL CODE

2023 ASME Boiler & Pressure Vessel Code

2023 Edition July 1, 2023

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NF

Supports

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

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FOREWORD*

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees: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.

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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.

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

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

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

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

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

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

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

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

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

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(23) # ASME Boiler and Pressure Vessel Standards Committees, Subgroups, and Working Groups

January 1, 2023

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CORRESPONDENCE WITH THE COMMITTEE

General

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

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

Revisions and Errata

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

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

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

Cases

(a) The most common applications for cases are

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

(2) to provide alternative requirements

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

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

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

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

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

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

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

(1) a statement of need and background information

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

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

(4) the edition(s) of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements.

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Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

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

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

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

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

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

Committee Meetings

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

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ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, Division 4, 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, by the letter "F" for Division 4, and by the letter “H” for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, 4, 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 4 — Fusion Energy Devices
  - Subsection FA — Fusion Energy Device Facilities
  - Subsection FB — Pressure Boundary Components
- 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

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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).

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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.

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(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.

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SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(23)**, placed next to the affected area. In addition, gender pronouns have been eliminated throughout this Subsection.

Page	*Location*	*Change*
viii	List of Sections	(1) Under Section III, Division 4 added (2) Title of Section XI and subtitle of Section XI, Division 2 revised (3) Information on interpretations and Code cases moved to "Correspondence With the Committee"
xii	Personnel	Updated
xxxiv	Correspondence With the Committee	Added (replaces "Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees")
xxxvi	Organization of Section III	In para. 1, Division 4 added
xlii	Cross-Referencing in the ASME BPVC	Updated
1	NF-1110	Subparagraph (e) revised
2	NF-1214	Subparagraph (g) added
8	Figure NF-1214-1	Last illustration added
10	NF-2130	In subpara. (a), cross-reference to NCA updated
14	NF-2321	Revised
24	NF-2432.2	In subpara. (c), cross-reference to NCA updated
25	NF-2530	Title and first line of paragraph revised
26	NF-2610	(1) Cross-references to NCA updated (2) Subparagraph (b) revised (3) Subparagraph (g) added
29	NF-3128	Title and first line of paragraph revised
30	Table NF-3131(a)-1	For Type "Standard," Class 2 entries under "Linear" column corrected by errata
33	Table NF-3221.2-1	Note (2) revised
38	NF-3250	Paragraph below heading deleted
38	NF-3251	(1) Paragraph below main heading added (2) Titles of NF-3251.1, NF-3251.2, and NF-3251.3 revised
42	Table NF-3251.2-1	Note (2) revised
47	NF-3313.1	In nomenclature, entry for F_e added
48	Table NF-3312.1(b)-1	Note (2) revised
50	NF-3322.1	(1) Subparagraphs (c), (c)(1), (c)(2), and (e)(1) revised (2) Duplicate equation numbers deleted
56	NF-3322.2	(1) Revised (2) Duplicate equation numbers deleted
57	Table NF-3322.2(d)-1	Added
69	Figure NF-3322.8-2	Below General Note, the dimensional requirements for a, b, and b_e, combined and corrected by errata to "$a \geq 1.33b_e$, where $b_e = 2t + \frac{5}{8}$ in. ($2t + 16$ mm) ≤ b"
74	NF-3324.6	Subparagraphs (a)(1) through (a)(4) revised
78	Table NF-3332.3-1	In first column, for "General Condition — Groove welds" and "General Condition — Attachments," cross-references revised
83	NF-3342.2	Duplicate equation numbers deleted
86	NF-3411.3	Subparagraphs (c) and (c)(2) revised
87	NF-3412.4	(1) In subpara. (a), last sentence added (2) Endnote 6 revised
88	NF-3412.5	Last sentence added
88	NF-3412.6	Added
93	NF-4121.1	First cross-reference updated

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Page	*Location*	*Change*
93	NF-4125	Sentence below heading corrected by errata
98	NF-4335	Second sentence revised
98	NF-4335.1	In subpara. (a), last sentence revised
102	NF-4451	Revised
105	Table NF-4622.1-1	Column heads revised
104	NF-4622.3	Revised
106	NF-4622.7	Subparagraph (b) revised
107	Table NF-4622.7(b)-1	Revised
109	Table NF-4622.7(b)-2	Deleted
109	NF-4721	In subpara. (e), cross-reference to "(d)" corrected by errata to "(b)"
110	NF-4725.1	Revised
114	NF-5321	Subparagraph (d) revised
116	NF-5510	Cross-references updated
116	NF-5521	In endnote 9, cross-reference updated
117	NF-5523	Cross-reference updated
117	NF-5540	Added
192	NF-B-5200	Revised
196	Article NF-C-4000	(1) Revised (2) Former Table NF-C-4000 redesignated as Table NF-C-4000-1 (3) Table NF-C-4000-2 added
202	Table NF-D-1330-1	For Items *II* and *VI* in first column, text following "C)" revised

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(23)

CROSS-REFERENCING IN THE ASME BPVC

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

(a) Hierarchy of Subparagraph Breakdowns

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

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

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

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

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

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

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

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

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

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

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

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ARTICLE NF-1000
INTRODUCTION

NF-1100 SCOPE AND GENERAL REQUIREMENTS

(23) NF-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NF contains rules for the material, design, fabrication, examination, installation, and preparation of certification documents (Certificate of Compliance and NS-1 Certificate of Conformance) for supports for components and piping which are intended to conform to the requirements for Class 1, 2, 3, and MC construction as set forth in Subsections NB, NCD, and NE, respectively, of this Section.

(b) They *do not* cover deterioration that may occur in service as a result of corrosion, erosion, radiation effects, or metallurgical instability of the materials (see NCA-1130).

(c) Nuclear power plant supports (see NCA-9200 provides the definitions of "support" and other terms) for which the rules are specified in this Subsection are those metal elements which transmit loads between components (see NCA-1210), including piping systems, and intervening elements and the building structure. However, the term *supports* does not encompass a structural element the sole function of which is to carry dynamic loads caused by a postulated loss of pressure-retaining integrity.

(d) The Owner shall be responsible for assuring the adequacy of the building structure and all intervening elements in the support load path in accordance with the requirements of NCA-3211.18 and NCA-3211.19(b). To the extent necessary, the support designer shall consider the structural interaction with intervening elements and the building structure.

(e) Except for the requirements listed in (1) through (11), the requirements of Subsection NF do not apply to bearings, bushings, gaskets, hydraulic fluids, seals, shims, slide plates, retaining rings, wear shoes, springs, washers, wire rope, compression spring end plates, thread locking devices, cotter pins, sight glass assemblies, spring hanger travel and hydro stops, nameplates, nameplate attachment devices, padding between piping and supports, or for compression dynamic stops used as stops (stops do not include snubbers, dampers, and energy absorbers; see NF-3412.4, NF-3412.5, and NF-3412.6) for seismic and other dynamic loads that are designed primarily for compressive loading and are not connected to the support or pressure boundary.

(1) The material of the exempt items shall be selected to tolerate the environmental conditions to which they will be exposed, such as temperature, fluids, humidity, and irradiation.

(2) The exempt item shall be designed for the loading conditions and other requirements identified in the Design Specification.

(3) Design Output Documents (see NCA-3211.40) shall indicate items that are exempt.

(4) Materials, fabrication, and installation of the exempt items shall comply with Design Output Documents.

(5) Class 1 springs shall be inspected in accordance with NF-2520.

(6) Washers shall comply with the requirements of NF-2128(b) and NF-4700.

(7) Wire rope shall comply with the requirements of NF-2530 and Article NF-3000.

(8) Compression spring end plates shall comply with the requirements of Articles NF-3000, NF-4000, NF-5000, and NF-8000.

(9) Compression dynamic stops shall comply with the requirements of Articles NF-3000, NF-4000, NF-5000, and NF-8000.

(10) Thread locking devices shall comply with the requirements of NF-4725.1.

(11) The means by which exempt items are attached to supports shall comply with the applicable requirements of this Subsection.

NF-1120 RULES FOR SUPPORTS AND THEIR CLASSIFICATION

NF-1121 Rules for Supports

The rules of Subsection NF provide requirements for new construction and include consideration of mechanical stresses and effects which result from the constraint of free-end displacements and anchor point motions defined in NF-3121.12 and NF-3121.13, but not thermal or peak stresses.

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NF-1122 Classification of Supports

Supports shall be constructed to the requirements of this Subsection that are applicable to the class of the component, including piping system, they are intended to support. Supports may be optionally classified as permitted in NCA-2134. When the components are optionally classified to a higher class as permitted in NCA-2134 (d), the support need not be classified to the higher class.

NF-1123 ALTERNATIVE RULES

NF-1123.1 Linear Piping Supports. See Section III Appendices, Nonmandatory Appendix CC for the alternative rules to the requirements of Division 1 Subsections NCA and NF for Linear Piping Supports.

NF-1130 BOUNDARIES OF JURISDICTION

NF-1131 Boundary Between Components and Supports

The jurisdictional boundary between components, including piping systems, and supports shall meet the requirements of NB-1132, NCD-1132, or NE-1132 as applicable to the class of component.

NF-1132 Boundary Between Supports and the Building Structure

(a) Supports may bear on or may be welded, bolted, pinned, or clamped to the building structure. Typical examples of jurisdictional boundaries defined between supports and building structures are shown in Figure NF-1132-1.

(b) The jurisdictional boundary between a support and the load carrying building structure is the surface of the building structure.

(c) For the purpose of defining the jurisdictional boundary between a support and the building structure, structural members shown on the civil/structural drawings of the plant and considered in the building structural analysis may be designated building structure even though located in the support load path. However, structural members, except as defined in (d), detailed on support drawings which are installed and used for the primary purpose of supporting piping or components shall be designated supports and be constructed to the rules of this Subsection.

(d) The Design Specification shall designate whether surface-mounted base plates intended to receive loads transmitted by supports are to be within the jurisdiction of Subsection NF or building structure. Fully or partially embedded steel elements intended to receive loads transmitted by supports; grout; concrete anchors; and hold-down bolts, nuts, and washers shall be designated building structure.

(e) If the means by which the support is connected to the building structure is a weld, the weld shall fall within the jurisdiction of this Subsection.

(f) If the means by which the support is connected to the building structure is a bolted joint to a building structural steel member, the bolts shall fall within the jurisdiction of this Subsection.

NF-1133 Boundary Between Supports and Intervening Elements

The jurisdictional boundary between supports and intervening elements in the support load path is the surface of the intervening elements. Supports may bear on or may be welded, bolted, pinned, or clamped to intervening elements. The means by which supports are connected to intervening elements shall fall within the jurisdiction of this Subsection.

NF-1200 TYPES OF SUPPORTS AND ATTACHMENTS

NF-1210 TYPES OF SUPPORTS

NF-1211 General Requirements

In this Subsection all supports are categorized into three separate types based on the general design procedure used for analysis of the support (see NF-3140). Requirements for materials, design, fabrication, and examination for each of the three types are provided in the following Articles of this Subsection. These support types are defined in NF-1212 through NF-1215.

NF-1212 Plate- and Shell-Type Supports

A *Plate- and Shell-Type Support* is a support such as a skirt or saddle which is fabricated from plate and shell elements and is normally subjected to a biaxial stress field.

NF-1213 Linear-Type Support

A *Linear-Type Support* is defined as acting under essentially a single component of direct stress. Such elements may also be subjected to shear stresses. Examples of such structural elements are tension and compression struts, beams and columns subjected to bending, trusses, frames, rings, arches, and cables. Energy-absorbing parts designed to dissipate energy by yielding and which are incorporated into a linear-type piping support shall be constructed in accordance with Mandatory Appendix NF-III.

NF-1214 Standard Supports (23)

Typical *Standard Supports* are described in MSS SP-58, *Pipe Hangers and Supports, Materials, Design, and Manufacture*, which was developed and approved by the Manufacturers Standardization Society of the Valve and Fittings

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Industry. Typical catalog items are shown in Figure NF-1214-1. The capacities of standard supports may be determined using plate and shell analysis or linear analysis or load rating. Examples of standard supports are

(a) rigid supports consisting of anchors, guides, restraints, rolling or sliding supports, and rod-type hangers

(b) constant and variable type spring hangers

(c) snubbers

(d) sway braces and vibration dampeners

(e) structural attachments such as ears, shoes, lugs, rings, clamps, slings, straps, and clevises

(f) dampers

(g) energy absorbers

NF-1215 Primary and Secondary Members

Support members are also categorized as primary or secondary according to function. These member types are defined in the following paragraphs.

(a) Primary Members. Primary members of supports are defined as those members designed to carry loads under any postulated load condition.

(b) Secondary Members. Secondary members are defined as those members typically used as bracing to maintain primary member system geometry, and which under all loading conditions, are not designed to sustain any significant stress. Significant stress is defined as being in excess of 50% of the allowable stress permitted by Article NF-3000.

NF-1230 WELDING BETWEEN TYPES OF SUPPORTS

NF-1231 Welded Joints Between Plate- and Shell-Type and Linear-Type Supports

Welded joints between Plate- and Shell-Type Supports (see NF-1212), and Linear-Type Supports (see NF-1213) shall meet the rules of either Plate- and Shell-Type or Linear-Type welded joints of this Subsection.

NF-1240 ATTACHMENTS

NF-1242 Attachments to Supports

Attachments to supports may be permanent or temporary, are nonstructural, and are not in the support load path.

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Figure NF-1132-1
Typical Examples of Jurisdictional Boundaries Between Supports and the Building Structure

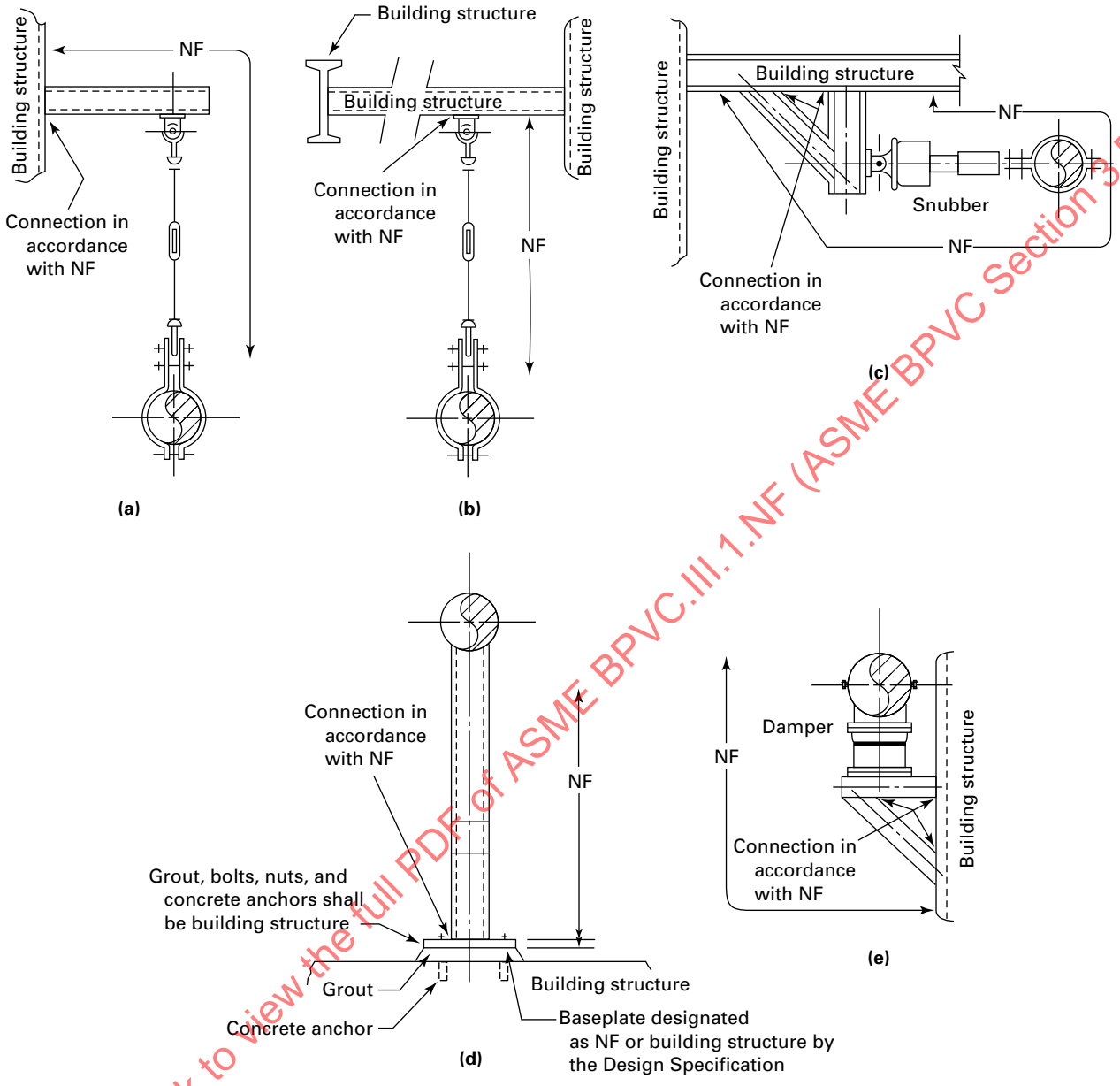

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Figure NF-1132-1
Typical Examples of Jurisdictional Boundaries Between Supports and the Building Structure (Cont'd)

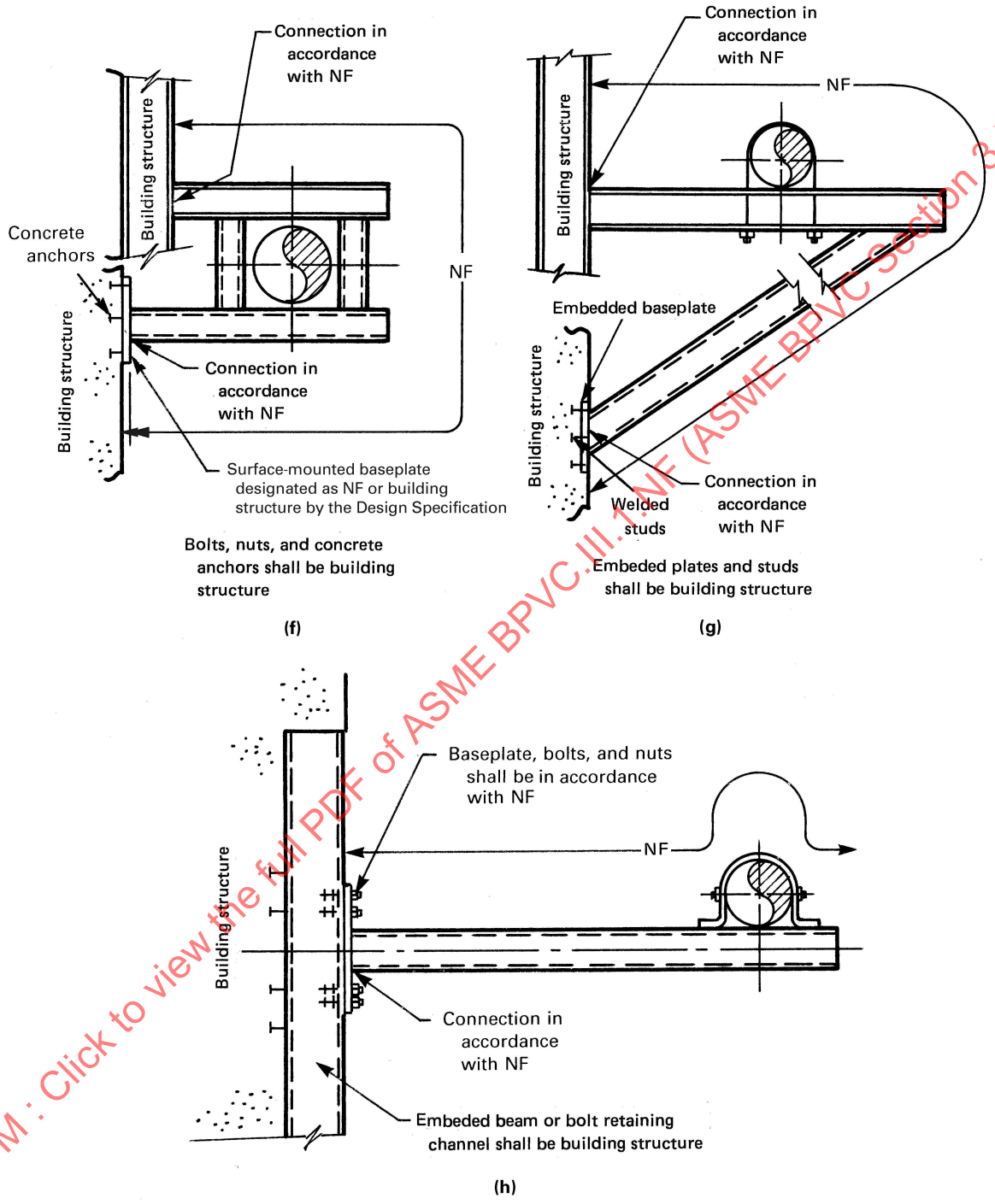

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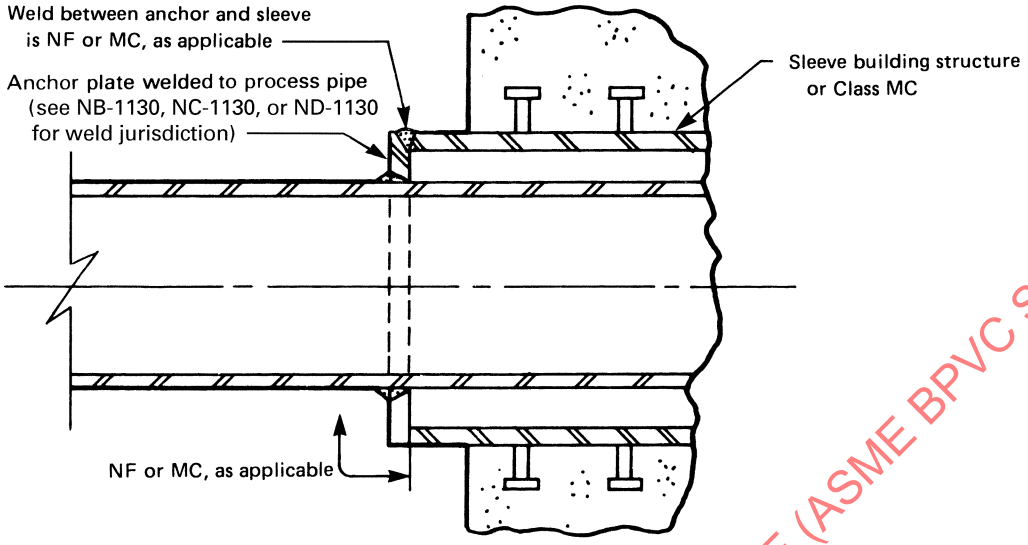
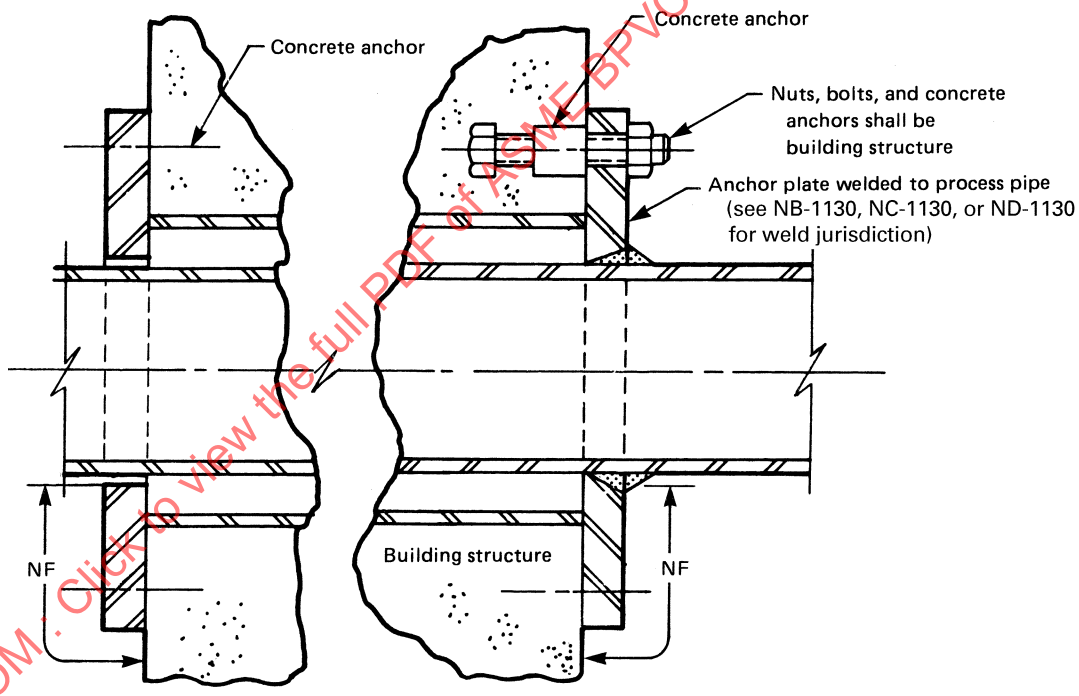
Figure NF-1132-1
Typical Examples of Jurisdictional Boundaries Between Supports and the Building Structure (Cont'd)



(i)



(j)

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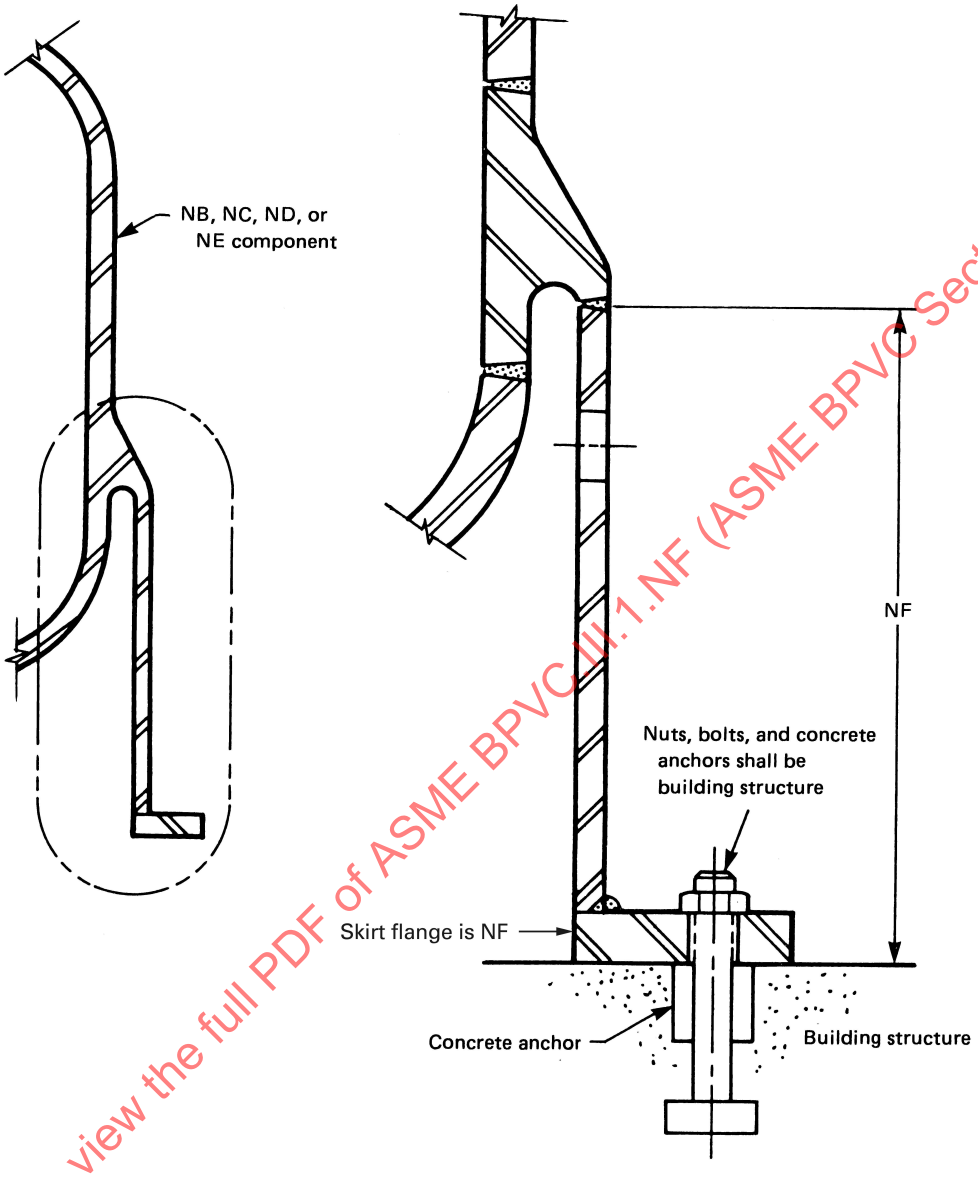
Figure NF-1132-1
Typical Examples of Jurisdictional Boundaries Between Supports and the Building Structure (Cont'd)



(k)

GENERAL NOTE: Sketches (a) through (k) are intended to show jurisdictional concepts and should not be considered as recommended configurations.

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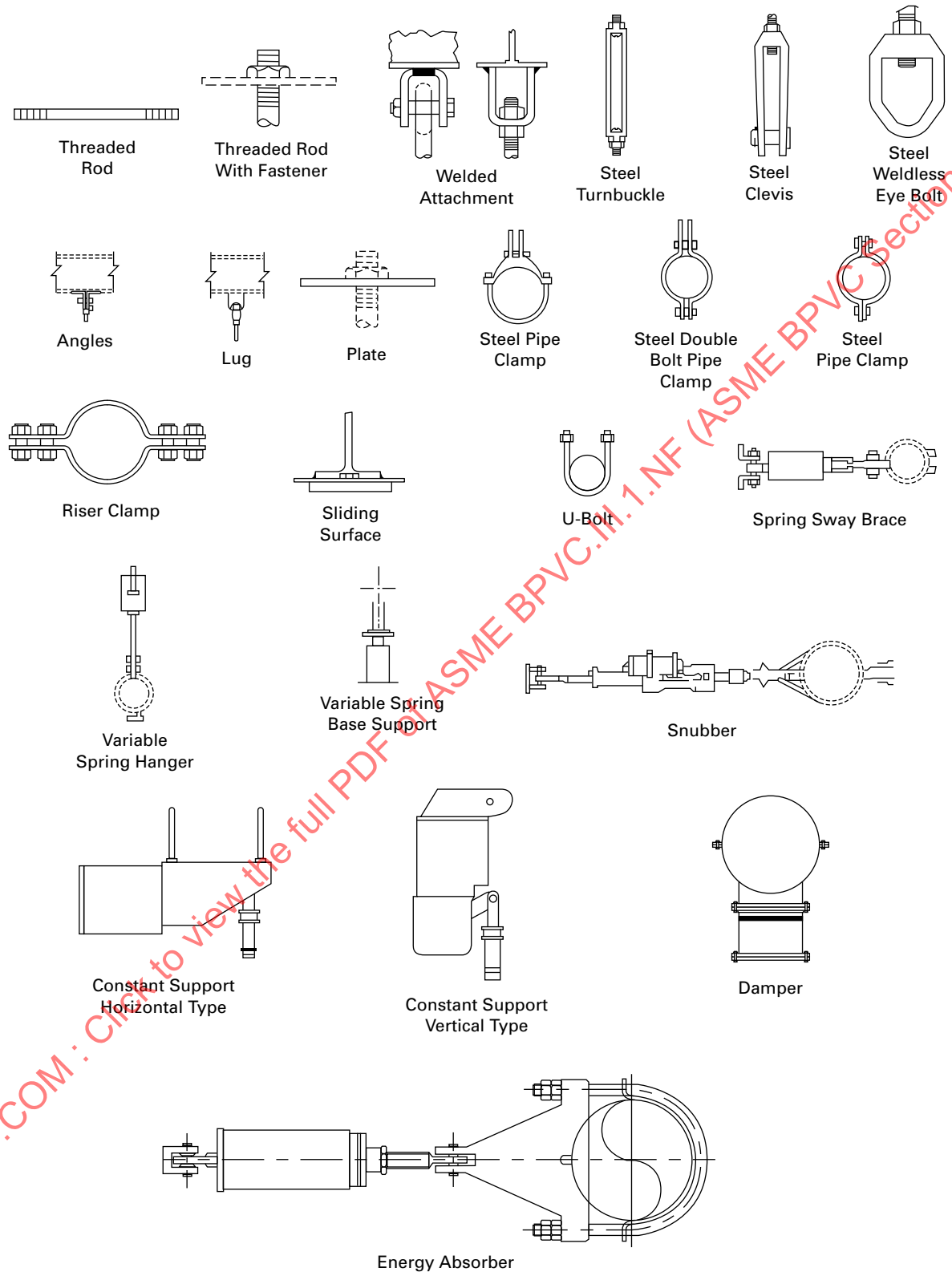
Figure NF-1214-1
Typical Standard Support Units



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ARTICLE NF-2000
MATERIAL

NF-2100 GENERAL REQUIREMENTS FOR MATERIAL

NF-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

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

(b) 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: thickness, *t*, is defined as the largest nominal thickness of the load carrying portion of the casting.

NF-2120 SUPPORT MATERIAL

NF-2121 Permitted Material Specifications

(a) Except as provided in (b) or NF-2128, material for supports shall conform to the requirements of the specifications for material listed in the tables of Section II, Part D, including all applicable footnotes in the table, applicable to the Class of construction, as indicated in Table NF-2121(a)-1.

(b) The requirements of Article NF-2000 do not apply to exempt items as indicated in NF-1110(e). Certificates of Compliance (see NF-2130) are not required for exempt items.

(c) Welding and brazing material 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.

NF-2122 Special Requirements Conflicting With Permitted Material Specifications

(a) 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 [see NCA-4256.3(d)]. 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 NF-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 NF-4121.1. Pipe or tube material used under the rules of this Subsection need not be hydrostatically or pneumatically tested, provided these materials are not used in a pressure-retaining function.

(b) Copper and copper-based alloys shall not be used for structural members.

(c) 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.

NF-2124 Size Ranges

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 the rules for construction. 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 [see NCA-4256.3(d)].

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Table NF-2121(a)-1
Material Tables Required for Supports

Type and Class	Section II, Part D, Subpart 1, Tables 2A and 2B, Design Stress Intensity Values, S_m	Section II, Part D, Subpart 1, Tables 1A and 1B, Allowable Stress Values, S	Section II, Part D, Subpart 1, Table Y-1, Yield Strength Values, S_y	Section II, Part D, Subpart 1, Table U, Tensile Strength Values, S_u
Plate and shell				
Class 1	x	...	x	x
Class 2 and MC	...	x	x	x
Class 3	...	x	x	x
Bolting (all classes)	...	...	x	x
Linear				
Class 1	...	...	x	x
Class 2 and MC	...	...	x	x
Class 3	...	...	x	x
Bolting (all classes)	...	...	x	x
Standard support				
Class 1	x (plate and shell)	...	x (linear)	x (All Types)
Class 2	...	x (plate and shell)	x (linear)	x (All Types)
Class 3	...	x (plate and shell)	x (linear)	x (All Types)
Bolting (all classes)	...	...	x (linear)	x (All Types)
Applicable Class	Cl. 1	Cl. 2, Cl. 3, and MC	All Classes	All Classes

GENERAL NOTES:
(a) Section II, Part D, Subpart 1, Table Y-2 provides permanent strain limiting factor for plate- and shell-type supports.
(b) Section II, Part D, Subpart 2, Tables TE and TM provide values of the coefficient of thermal expansion and modulus of elasticity, respectively.

NF-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 or Table 4. Materials listed in Section II, Part D, Subpart 1, Table 3 may be used for Class 2 and Class 3 supports and for Class 1 Standard Supports. Materials listed in Section II, Part D, Subpart 1, Table 4 may be used for Class 1 supports. Material for nuts shall conform to SA-194, SA-563, or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Tables 3 and 4. Material for nuts may also conform to the specification for suitable nuts identified in a permitted bolting specification. Table NF-2121(a)-1 provides the source for the yield and tensile strength values required for design.

(b) Unless required by NF-4720, 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.

(23) **NF-2130 CERTIFICATION OF MATERIAL**

(a) Material used in the construction of supports shall be certified. Certified Material Test Reports in accordance with NCA-1224 and NCA-1225 shall be provided for material used for primary members for Class 1 Plate- and Shell-Type Supports, and Class 1 Linear-Type Supports. Material for other Classes of supports and all Classes of Standard Supports shall be provided with Certified Material Test Reports when impact testing is required (see NF-2311). Copies of these certificates shall be provided with the support.

(b) Certificates of Compliance with the material specification, grade, class, and heat-treated condition, as applicable, or Certified Material Test Reports shall be provided by the Material Organization for material for all other supports, Standard Supports, and secondary members of all types and Classes of supports.

(c) When Design Documents, such as the Design Report or Load Capacity Data Sheet, permit the use of alternative materials for which certificates of compliance are permitted, the alternative materials may be documented in the Design Documents or the documentation for the support in lieu of documenting the specific material used. The requirements of NF-2150 for identification of materials shall apply.

(d) When material Certificates of Compliance are permitted, the support manufacturer shall transmit copies of the material Certificates of Compliance applicable to each support. Alternatively, it shall execute and furnish a single document certifying a listing of all material specifications involved in the shipment. When a single document is furnished, its quality program shall provide for its retention of the material Certificates of

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Compliance for each of the materials incorporated into the supports.

NF-2140 WELDING MATERIAL

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

NF-2150 MATERIAL IDENTIFICATION

The identification of material requiring Certified Material Test Reports shall meet the requirements of NCA-4256. Material furnished by a Material Organization with Certificates of Compliance shall be identified by a controlled system meeting the requirements of the applicable material specification, grade, and class. Identification of the material to the Material Organization's Certificate of Compliance is not required after the support manufacturer has verified that the material meets the requirements of this Section. Material for small items shall be controlled during the manufacture of the supports so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of supports so that it is identifiable as acceptable material until the material is actually consumed in the process (see NF-4122).

NF-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 [see NCA-3211.19(b)], with specific attention being given to the effect of Service Conditions upon the properties of the material.

NF-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steel, 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 support at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

NF-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 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.

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

NF-2210 HEAT TREATMENT REQUIREMENTS

NF-2211 Test Coupon Heat Treatment for Ferritic Material[1]

If ferritic steel material is subjected to heat treatment during construction of a support, the material used for the impact test specimens shall be heat treated in the same manner as the support, 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. The support manufacturer 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.

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

NF-2212.1 Cooling Rates. When ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (see NF-2223.3 and NF-2226.4). 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 NF-2212.2 or one of the specific procedures described in NF-2220 shall be used for each product form.

NF-2212.2 General Procedures. One of the general procedures in (a), (b), and (c) 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 NF-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

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within 25°F (14°C) and 20 sec at all temperatures after cooling begins.

(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) are met.

(c) When any of the specific procedures described in NF-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).

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

NF-2221 General Requirements

The procedure for obtaining impact 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.

NF-2222 Plates

NF-2222.1 Number of Tension Test Coupons. The number of tension test coupons required shall be in accordance with the material specification and with SA-20, except that from carbon steel plates weighing 42,000 lb (19 000 kg) and over and alloy steel plates weighing 40,000 lb (18 000 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NF-2222.2 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. The orientation of the coupons shall be as specified in the material specification.

NF-2222.3 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the support 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 NF-2212.2(b), the dimensions of the coupon shall not be less than $3t \times 3t \times t$, where t is the nominal material thickness.

NF-2223 Forgings

NF-2223.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat-treated thickness. A thermal buffer as described in NF-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NF-2212.2.

NF-2223.2 Very Thick and Complex Forgings. Test coupons for forgings that are both very thick and complex, such as trunnions, support forgings, flanges, 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.

NF-2223.3 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).

(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.

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(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 to 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 forgings.

(e) Test coupons for complex forgings shall be taken in accordance with NF-2223.2.

NF-2224 Bars and Bolting Material

NF-2224.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat-treated end, where t is either the bar diameter or thickness.

NF-2224.2 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.

NF-2225 Tubular Products and Fittings

NF-2225.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat-treated end, where t is the nominal wall thickness of the tubular product.

NF-2225.2 Separately Produced Coupons Representing Fittings. Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NF-2223.3 shall be met.

NF-2226 Castings

NF-2226.1 Castings With 2 in. (50 mm) Maximum Thickness and Less. For castings with a maximum thickness of 2 in. (50 mm) and less, the specimens shall be taken from either the standard separately cast coupons or the casting, in accordance with the material specification.

NF-2226.2 Castings With Thicknesses Exceeding 2 in. (50 mm) Maximum Thickness. For castings exceeding a thickness of 2 in. (50 mm), the coupons shall be taken from the casting (or an extension of it) 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. A thermal buffer may be used [see NF-2212.2(c)(3)].

NF-2226.3 Separately Cast Test Coupons for Castings With Thicknesses Exceeding 2 in. (50 mm). In lieu of the requirements of NF-2226.2, separately cast test coupons may be used under the conditions of (a) through (c).

(a) The separate test coupon representing castings from one heat and one heat-treated lot shall be of the same heat of material and shall be subjected to substantially the same foundry practices as the production casting it represents.

(b) The separate test coupon shall be heat treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with NF-2212.2.

(c) The separate test coupon shall not be less than $3t \times 3t \times t$, where t equals the nominal thickness of the casting. Test specimens shall be taken with 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 casting thickness.

NF-2226.4 Castings Machined or Cast to Finished Configuration Before Heat Treatment. In lieu of the requirements of NF-2226.1, NF-2226.2, or NF-2226.3, test coupons may be removed from prolongations or other stock provided on the product. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface equivalent at least to 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 be at least $\frac{3}{4}$ in. (19 mm) from any heat-treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any second heat-treated surface. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service.

NF-2227 Rolled Shapes

For rolled shapes, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickest element of the shape and with the midlength of the specimen at least t from a heat-treated end.

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Table NF-2311(b)-1
Exemptions From Impact Testing Under NF-2311(b)(9) and NF-2311(b)(10) for Material Thickness to 2½ in. (64 mm), Inclusive

Material [Note (1)]	Material Condition [Note (1)]	T_{NDT}, °F (°C) [Notes (2), (3)]
SA-537, Class 1	N	−30 (−35)
SA-516, Grade 70	Q & T	−10 (−25)
SA-516, Grade 70	N	0 (−18)
SA-508, Class 1	Q & T	+10 (−10)
SA-533, Grade B	Q & T	+10 (−10)
SA-299 [Note (4)]	N	+20 (−7)
SA-216, Grades WCB, WCC	Q & T	+30 (0)
SA-36 (Plate)	HR	+40 (5)
SA-508, Class 2	Q & T	+40 (5)

NOTES:
(1) Material Condition letters refer to:
N = Normalize
Q & T = Quench and Temper
HR = Hot Rolled
(2) These values for T_{NDT} were established from data on heavy section steel [thickness greater than 2½ in. (64 mm)]. Values for sections less than 2½ in. (64 mm) thick are held constant until additional data are obtained.
(3) T_{NDT} = temperature at or above nil-ductility transition temperature (ASTM E208); T_{NDT} is 10°F (5.6°C) below the temperature at which at least two specimens show no-break performance.
(4) Materials made to a fine grain melting practice.

NF-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NF-2310 MATERIAL TO BE IMPACT TESTED

NF-2311 Supports for Which Impact Testing of Material Is Required

When impact testing is required, the methods of Section III Appendices, Nonmandatory Appendix G may be used as an alternative design procedure for assuring protection against nonductile failure.

(a) Support materials shall be impact tested in accordance with the requirements listed below.

(1) Attachments to the component or piping shall meet the requirements for impact testing stipulated in the applicable Subsection.

(2) Class 1, 2, 3, and MC component supports shall meet the requirements of NF-2300.

(3) For Class 1, 2, and 3 piping supports, Class 1, 2, and 3 Standard Supports, and all other types and Classes of supports, the Design Specification (see NCA-3211.19) shall state whether or not impact testing is required for the material of which the support is constructed. When impact testing is required, the tests shall meet the requirements of NF-2300 for Class 1, 2, 3, or MC, respectively, and shall become a requirement of this Subsection.

(b) The requirements for supports shall be as specified in NF-2300, except that the materials described in (1) through (13) are not to be impact tested as a requirement of this Subsection.

(1) Material with a nominal section thickness of ⅝ in. (16 mm) and less.

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

(3) Bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less.

(4) Material for fittings with all pipe connections of ⅝ in. (16 mm) nominal wall thickness and less.

(5) Austenitic stainless steels, including precipitation-hardened austenitic Grade 660 (UNS S66286).

(6) Nonferrous materials.

(7) Material for supports when the maximum stress does not exceed 6,000 psi (40 MPa) tension or is compressive.

(8) Rolled structural shapes, when the thickness of a flange is ⅝ in. (16 mm) or less.

(9) Materials for Class 1, 2, or MC supports, listed in Table NF-2311(b)-1, for thicknesses 2½ in. (64 mm) and less when the Lowest Service Temperature[2] is at least 30°F (15°C) above the tabulated temperature. This exemption from impact testing does not apply to either the weld metal (NF-2430) or the weld procedure qualification (NF-4335).

(10) Materials for Class 3 supports, listed in Table NF-2311(b)-1, for thicknesses 2½ in. (64 mm) and less, when the Lowest Service Temperature is equal to or greater than the tabulated temperature. This exemption from impact testing does not apply to either the weld metal (see NF-2430) or the weld procedure qualification (see NF-4335).

(11) Materials for Class 2 and MC supports for which the Lowest Service Temperature exceeds 150°F (65°C).

(12) Materials for Class 3 supports for which the Lowest Service Temperature exceeds 100°F (38°C).

(13) Materials for Class 2, 3, and MC supports for which the Lowest Service Temperature (LST) is equal or above the Minimum Design Metal Temperature of Figure NF-2311(b)-1 for the materials listed and the applicable material thicknesses.

(c) The Design Specification [see NCA-3211.19(b)] shall state the Lowest Service Temperature (LST) for the support and the designated impact test temperature, when required.

NF-2320 IMPACT TEST PROCEDURES

NF-2321 Charpy V-Notch Tests (23)

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

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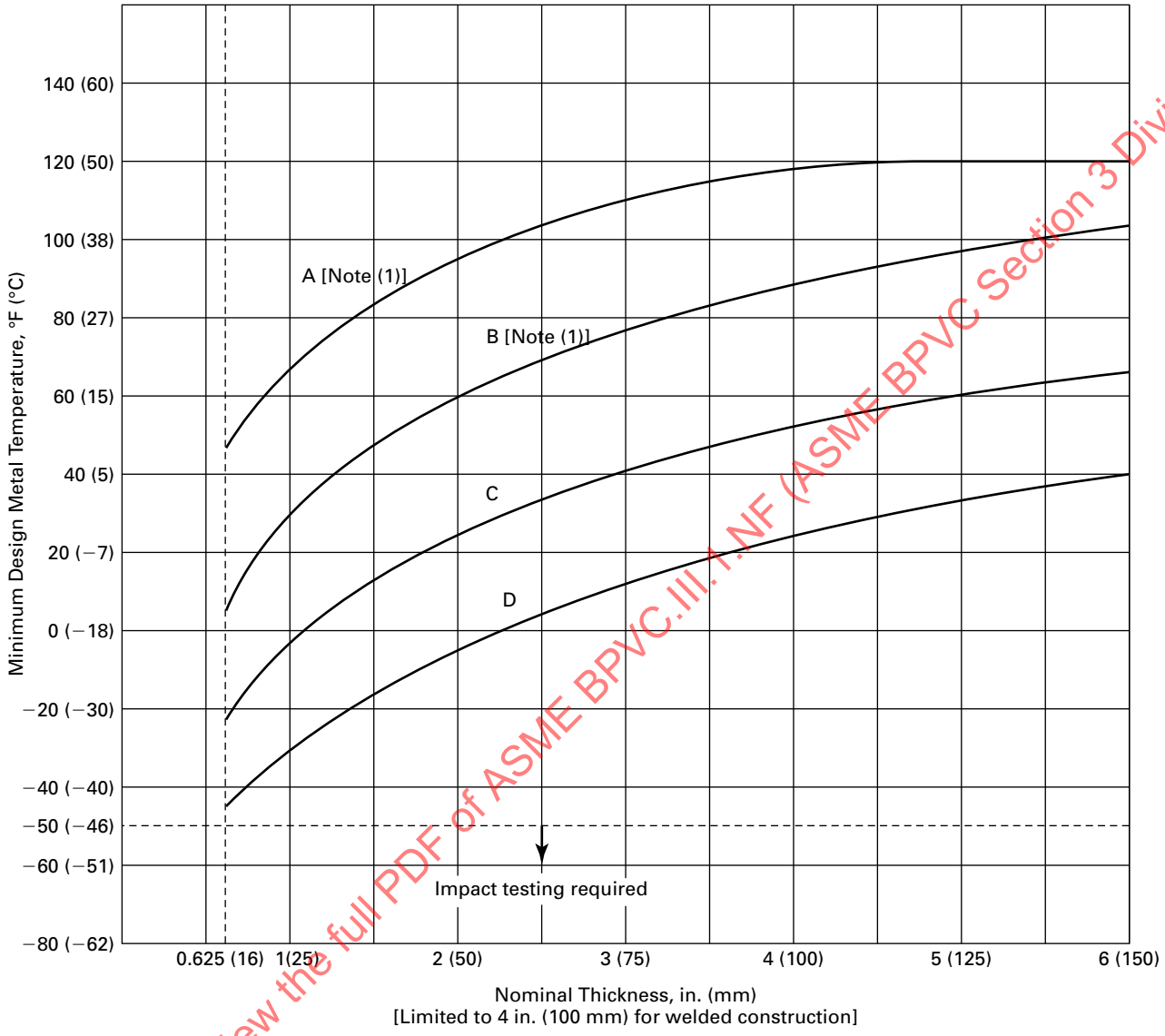
Figure NF-2311(b)-1
Impact Test Exemption Curves for Materials for Class 2, 3, and MC Supports



GENERAL NOTES:

(a) Curve A — all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(b) Curve B

(1) SA-285 Grades A and B
(a) SA-414 Grade A
(b) SA-442 Grade 55 > 1 in. (25 mm) if not to fine grain practice and normalized
(c) SA-442 Grade 60 if not to fine grain practice and normalized
(d) SA-515 Grades 55 and 60
(e) SA-516 Grades 65 and 70 if not normalized
(f) SA-612 if not normalized
(g) SA-662 Grade B if not normalized
(h) SA-724 if not normalized

(2) all materials of Curve A if produced to fine grain practice and normalized which are not listed for Curves C and D below;

(3) except for bolting [see (e) below], plates, structural shapes, and bars, all other product forms (such as pipe, fittings, and tubing) not listed for Curves C and D below

(c) Curve C

(1) SA-182 Grades 21 and 22 if normalized and tempered
(a) SA-302 Grades C and D
(b) SA-336 Grades F21 and F22 if normalized and tempered

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Figure NF-2311(b)-1
Impact Test Exemption Curves for Materials for Class 2, 3, and MC Supports (Cont'd)

GENERAL NOTES (Cont'd)

(c) SA-387 Grades 21 and 22 if normalized and tempered
(d) SA-442 Grade 55 ≤ 1 in. (25 mm) if not to fine grain practice and normalized
(e) SA-516 Grades 55 and 60 if not normalized
(f) SA-533 Grades B and C
(g) SA-662 Grade A;

(2) all material of Curve B if produced to fine grain practice and normalized and not listed for Curve D below

(d) Curve D

(1) SA-203
(2) SA-442 if to fine grain practice and normalized
(3) SA-508 Class 1
(4) SA-516 if normalized
(5) SA-524 Classes 1 and 2
(6) SA-537 Classes 1 and 2
(7) SA-612 if normalized
(8) SA-662 if normalized
(9) SA-724 if normalized

(e) For bolting the following impact test exemption temperature shall apply:

Spec. No.	Grade	Impact Test Exemption Temperature, °F (°C)
SA-193	B5	−20 (−30)
	B7	−40 (−40)
	B7M	−50 (−45)
	B16	−20 (−30)
SA-307	B	−20 (−30)
SA-320	L7, L43	Impact tested
SA-325	1	−20 (−30)
SA-354	BB	−20 (−30)
	BC	0 (−18)
	BD	+20 (−7)
SA-449	...	−20 (−30)

NOTE: (1) See NF-2311(b)(12) for Class 3 lowest service temperature limit.

consist of a set of three full-size 10 mm × 10 mm specimens and meet the requirements of NF-2330. When the material being tested is expected to exceed 80% of the testing machine's full-scale capacity, standard subsize specimens may be used as permitted in SA-370. When subsize specimens are used, the average lateral expansion and absorbed energy results shall be a minimum of 50 mils (1.27 mm) and 75 ft-lb (100 J), respectively.

The test location, orientation, size, test temperature, lateral expansion, and absorbed energy shall be reported in the Certified Material Test Report.

NF-2322 Location and Orientation of Test Specimens

Impact test specimens for quenched and tempered material shall be removed from the locations and orientation specified for tensile test specimens in each product form in NF-2220 except that for plates the orientation of the impact test specimens shall be longitudinal. For material in other heat-treated conditions, impact test specimens shall be removed from the locations and orientations specified for tensile test specimens in the material specification except that for plates the orientation of the impact specimens shall be longitudinal, and for structural shapes the location and orientation of the impact test specimens shall be as specified in ASTM A673. Alternatively, the orientation may be in the direction of maximum stress regardless of heat treatment. For bolting, the C_v impact test specimens shall be prepared 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

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Table NF-2331(a)-1
Required C_v Lateral Expansion Values for Class 1 Support Material Other Than Bolting

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils (mm)
$\frac{5}{8}$ (16) or less	No test required
Over $\frac{5}{8}$ to 1 (16 to 25), incl.	15 (0.38)
Over 1 (25)	25 (0.64)

length of the represented studs, nuts, or bolts. For all material, the number of tests shall be in accordance with NF-2340.

NF-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NF-2331 Material (Excluding Bolting)

When impact testing is required, material (other than bolting) shall be tested as required by (a) and (b).

(a) Test three C_v specimens at the designated temperature (see NF-2311). All three specimens shall meet one of the acceptance standards applicable to the specific test method.

(1) 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 NF-2331(a)-1 for Class 1, of Table NF-2331(a)-2 for Class 2 and MC, and of Table NF-2331(a)-3 for Class 3 supports.

(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 NF-2331(a)-4 for Class 1, of Figure NF-2331(a)-1 for Classes 2 and MC, and of Figure NF-2331(a)-2 for Class 3 supports.

(b) Apply the procedures of (a) to

(1) base material[3]

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests of NF-4330

(3) the weld metal of NF-2431

Table NF-2331(a)-2
Required C_v Lateral Expansion Values for Class 2 and MC Support Material Other Than Bolting

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils (mm)
$\frac{5}{8}$ (16) or less	No test required
Over $\frac{5}{8}$ to 1 (16 to 25), incl.	15 (0.38)
Over 1 (25)	20 (0.50)

NF-2333 Bolting Material

When impact testing is required, for bolting material including studs, nuts, and bolts, test three C_v specimens at the designated temperature. All three specimens shall meet the requirements of Table NF-2333-1.

NF-2340 NUMBER OF IMPACT TESTS REQUIRED

NF-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the unheat-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.

NF-2342 Forgings and Castings

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

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

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

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

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

(f) As an alternative to (e) for static castings, a separately cast test coupon (see NF-2226.3) may be used; one test shall be made for Charpy V-notch.

Table NF-2331(a)-3
Required C_v Lateral Expansion Values for Class 3 Support Material Other Than Bolting

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils (mm)
$\frac{5}{8}$ (16) or less	No test required
Over $\frac{5}{8}$ (16)	15 (0.38)

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Table NF-2331(a)-4
Required C_v Energy Values for Class 1 Support Material Other Than Bolting

Customary Units						
	Energy, ft-lb for Base Materials of Specified Minimum Yield Strength, ksi					
	55 ksi or Below		Over 55 ksi to 75 ksi, Incl.		Over 75 ksi to 105 ksi, Incl.	
Nominal Wall Thickness, in.	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
5/8 or less [Note (1)]	...	...	...	...	...	...
Over 5/8 to 1, incl. [Note (2)]	15	10	20	15	25	20
Over 1 [Note (2)]	25	20	30	25	35	30
SI Units						
	Energy, J for Base Materials of Specified Minimum Yield Strength, MPa					
	380 MPa or Below		Over 380 MPa to 515 MPa, Incl.		Over 515 MPa to 725 MPa, Incl.	
Nominal Wall Thickness, mm	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
16 or less [Note (1)]	...	...	...	...	...	...
Over 16 to 25, incl. [Note (2)]	20	14	27	20	34	27
Over 25 [Note (2)]	34	27	41	34	47	41

NOTES:
(1) No test required.
(2) Where weld metal tests of NF-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NF-2343 Bars and Rolled Shapes

(a) For bars, one test shall be made for each diameter or size greater than 1 in. (25 mm) in each lot, where a lot is defined as one heat of material

(1) as-rolled in one continuous operation or

(2) heat treated in one charge, or each 6,000 lb (2 700 kg) or less from one continuous operation.

(b) For rolled shapes, the frequency of testing shall be one test (a set of three specimens) for at least each 15 tons (14 000 kg) or each single length of 15 tons (14 000 kg) or more, of the same nominal shape size, excluding length, for each heat in the as-rolled condition. If the shapes are heat treated, one test shall be taken from each heat of each nominal shape size, excluding length, in each furnace lot. For shapes heat treated in a continuous furnace, a lot shall not exceed 15 tons (14 000 kg).

NF-2344 Tubular Products and Fittings

On products that are seamless or welded without filler metal, one test shall be made from each lot. On products 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.

NF-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 the following (in weight):

Diameter, in. (mm)	Weight, lb (kg)
1 3/4 (44) and less	1,500 (700)
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)

NF-2350 RETESTS

NF-2351 Retests for Class 1, 2, 3, and MC Material Other Than Bolting

(a) For Charpy V-notch tests required by NF-2331 to meet the acceptance standards of Tables NF-2331(a)-1, NF-2331(a)-2, and NF-2331(a)-3, respectively, one retest at the same temperature may be conducted, provided

(1) the average value of the test results meets the minimum requirements,

(2) not more than one specimen per test is below the minimum requirements, and

(3) the specimens not meeting the minimum requirements are not lower than 5 mils (0.13 mm) below the specified requirements.

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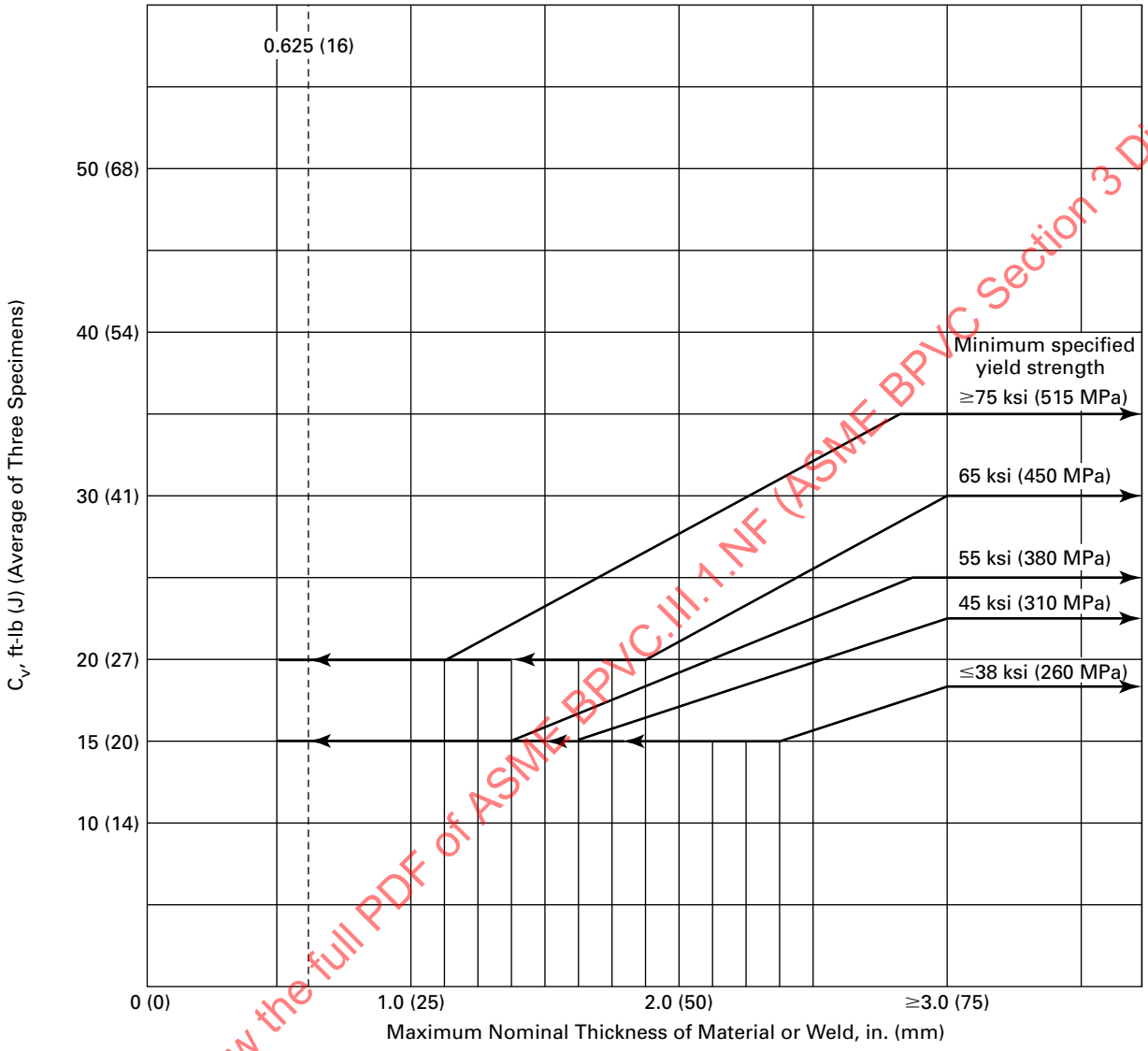
Figure NF-2331(a)-1
Required C_v Energy Values for Class 2 and MC Support Material Other Than Bolting



GENERAL NOTES:
(a) Interpolation between yield strengths shown is permitted.
(b) The lowest of three specimens tested shall not be less than 5 ft-lbf (7 J) below the average value required.

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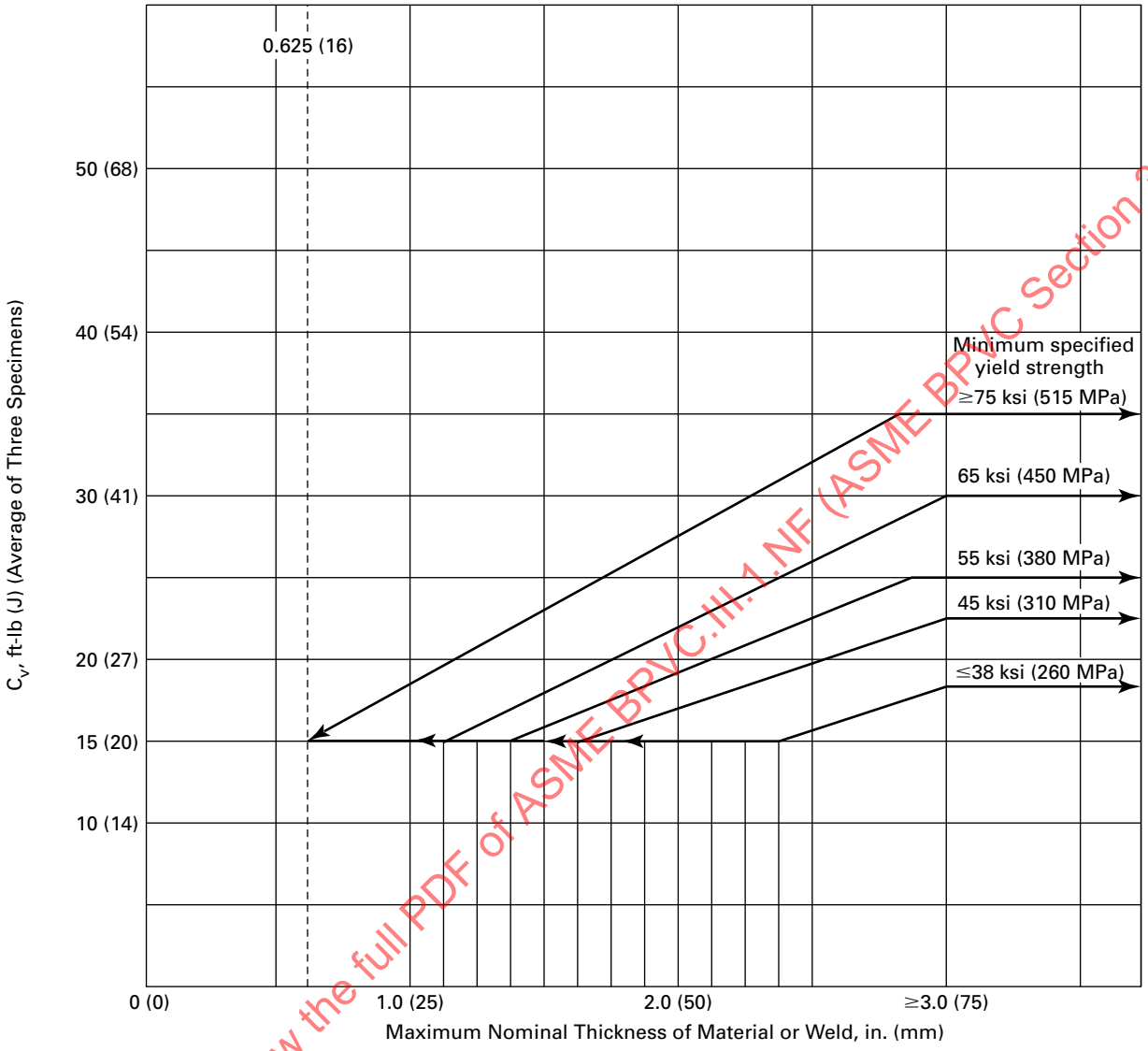
Figure NF-2331(a)-2
Required C_v Energy Values for Class 3 Support Material Other Than Bolting



GENERAL NOTES:
(a) Interpolation between yield strengths shown is permitted.
(b) The lowest of three specimens tested shall not be less than 5 ft-lbf (7 J) below the average value required.

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

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)
1 (25) or less	No test required
Over 1 (25)	25 (0.64)

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 minimum requirements.

(b) For Charpy V-notch tests required by NF-2331 to meet the acceptance standards of Table NF-2331(a)-4, one retest at the same temperature may be conducted provided

(1) the average value of the test results meets the "Average of 3" requirements specified.

(2) not more than one specimen per test is below the "Lowest 1 of 3" requirements specified.

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (7 J) below the "Lowest 1 of 3" requirements specified.

(4) 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 3" requirements specified.

NF-2352 Retests for Bolting for Charpy V-Notch Tests

For Charpy V-notch tests of bolting required by NF-2333 to meet the acceptance standards of Table NF-2333-1, one retest at the same temperature may be conducted, provided

(a) the average value of the test results meets the minimum requirements.

(b) not more than one specimen per test is below the minimum requirements.

(c) the specimens not meeting the minimum requirements are not lower than 5 mils (0.13 mm) below the specified requirements.

(d) 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 minimum requirements.

NF-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).

(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).

NF-2400 WELDING MATERIAL

NF-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of supports 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 NF-2150.

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

(1) welding process

(2) SFA Specification and classification

(3) other identification if no SFA Specification applies

(4) minimum tensile strength [see NF-2431.1(e)] in either the as-welded or heat-treated condition, or both [see NF-2431.1(c)]

(5) Charpy V-notch test for material as-welded or heat treated, or both (see NF-2331); the test temperature, and the lateral expansion or the absorbed energy, shall be provided

(6) the preheat and interpass temperatures to be used during welding of the test coupon [see NF-2431.1(c)]

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

(8) elements for which chemical analysis is required per the SFA Specification or WPS and NF-2432

(9) minimum delta ferrite (see NF-2433)

NF-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

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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 NF-4000 and this subarticle are made and the results conform to the requirements of this Article.

NF-2430 WELD METAL TESTS

NF-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).

(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 NF-2311(b)(1) through NF-2311(b)(8) and NF-2311(b)(11) and NF-2311(b)(12) shall likewise be exempted from the impact testing required by this paragraph

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

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

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform with 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 which 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[1] 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 support. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table NF-4622.1-1 or Table NF-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 NF-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 where required, shall be located and prepared in accordance with the requirements of SFA-5.1, or the applicable SFA specification. For impact specimen preparation and testing, the applicable parts of NF-2321 shall apply. The longitudinal axis of the specimen shall be at a minimum

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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. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements 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 requirements of NF-2331(a), applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NF-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NF-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 NF-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f).

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

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

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat-treated condition. The postweld heat treatment temperatures shall be in accordance with Table NF-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies 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 above, the general test of NF-2431.1 shall be used.

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

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

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

NF-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NF-2420 and as required by NF-2432.1 and NF-2432.2.

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

(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). The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c). As an alternative, the deposit shall be made in accordance with (d) 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 either the filler metal analysis or the undiluted weld deposit analysis or for *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[4] 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 Specification 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

Table NF-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

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Table NF-2432.2(a)-1
Welding Material Chemical Analysis

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

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 NF-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NF-2431.1(c) do not apply.

(d) The alternate method provided in (b) 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.

(23) **NF-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) through (c).

(a) Welding material of ferrous alloy A-No. 8 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table NF-2432.2(a)-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 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-1225.1. Elements listed in Table NF-2432.2(a)-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

NF-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (see 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.

NF-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). Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NF-2432 in conjunction with Figure NF-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 NF-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).

NF-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 NF-2130 or NF-4120.

NF-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.

NF-2500 EXAMINATION AND REPAIR OF MATERIAL

NF-2510 EXAMINATION AND REPAIR OF MATERIAL OTHER THAN BOLTING

Material for supports shall be examined in accordance with the material specification. Defects may be repaired as permitted by the material specification.

NF-2520 REQUIRED EXAMINATION AND ACCEPTANCE STANDARDS FOR CLASS 1 SPRINGS

Spring coils for Class 1 variable, constant, and sway brace standard supports shall be examined after coiling by either the magnetic particle or liquid penetrant method. Linear indications shall be removed by grinding and blending. If the depth of the ground area exceeds 3% of the bar diameter or thickness, the spring coil shall be rejected.

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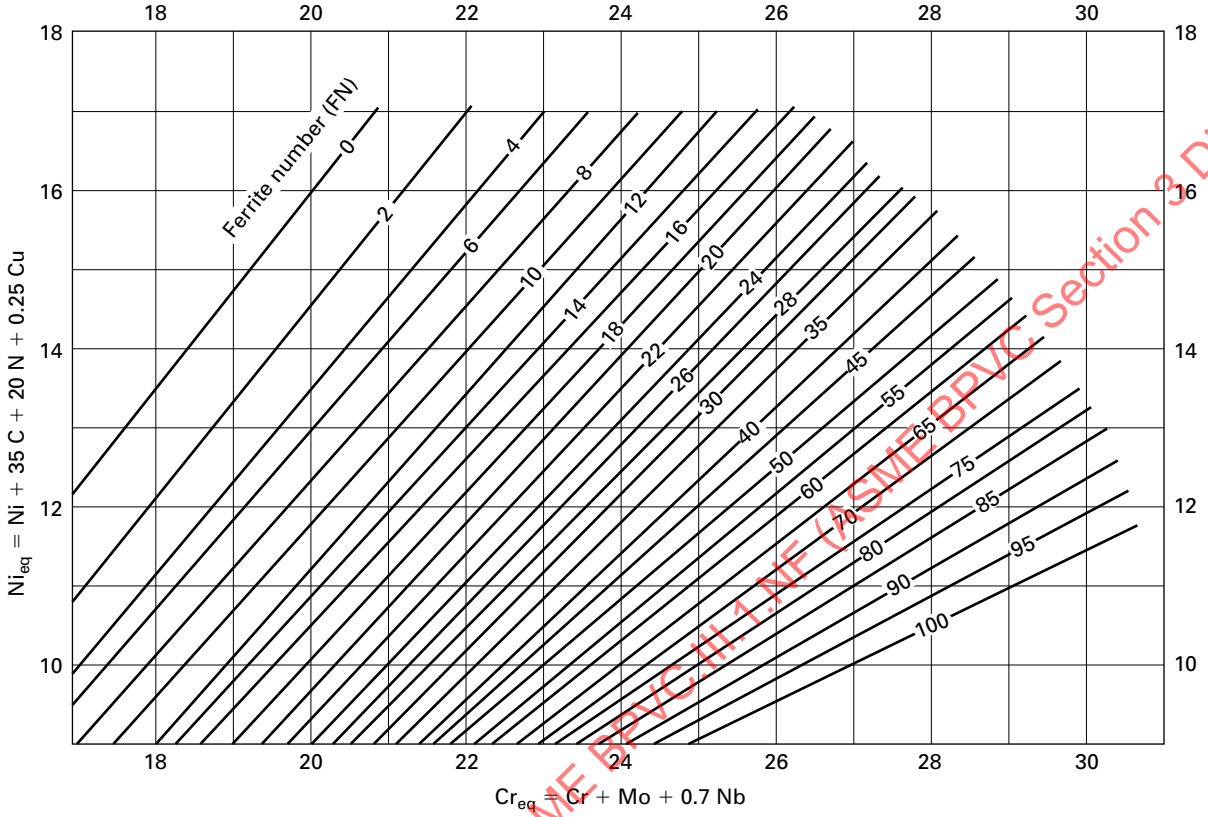
Figure NF-2433.1-1
Delta Ferrite Content



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

(23) **NF-2530 REQUIRED EXAMINATION AND ACCEPTANCE STANDARDS FOR COILED WIRE ROPE**

Coiled wire rope shall be visually examined after coiling and shall be free from kinks, loose strands, loose wires, or broken protruding wires.

NF-2580 EXAMINATION OF BOLTING MATERIAL AND RODS

The word *rods* as used in this subarticle is intended to cover rods that are threaded. It also includes forged piston rods if they are threaded for a portion of their length. It does not apply to unthreaded bar stock.

NF-2581 Required Examinations

NF-2581.1 Class 1 Supports. All bolting material and rods shall be visually examined in accordance with NF-2582. In addition, nominal sizes greater than 2 in. (50 mm) shall be examined by either the magnetic particle or liquid penetrant method in accordance with NF-2583. In addition, nominal sizes greater than 4 in. (100 mm) shall be ultrasonically examined in accordance with NF-2584.

NF-2581.2 Class 2, 3, and MC Supports. Bolts, studs, and nuts shall be examined in accordance with the requirements of the material specification and NF-2582.

NF-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

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to NF-5100 or by personnel qualified in accordance with NF-5500.

NF-2583 Magnetic Particle or Liquid Penetrant Examination

All bolting material and rods greater than 2 in. (50 mm) nominal size for Class 1 supports shall be examined by a magnetic particle method or a liquid penetrant method. Such examination shall be performed on the finished bolting material after threading or on the material stock at approximately the finished diameter before threading and after heading (if involved). Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

NF-2584 Ultrasonic Examination for Sizes Greater Than 4 in. (100 mm)

All bolting material and rods greater than 4 in. (100 mm) nominal size for Class 1 supports shall be ultrasonically examined over the entire cylindrical surface prior to threading in accordance with the requirements of the following subparagraphs.

NF-2584.1 Ultrasonic Method. Examination shall be carried out by the straight beam, radial scan method.

NF-2584.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to ensure adequate penetration or better resolution. The search unit area shall not exceed 1 in.^{2} (650 mm^2).

NF-2584.3 Calibration of Equipment. Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full screen height.

NF-2584.4 Acceptance Standards. Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NF-2586 Repair by Welding

Weld repairs of bolting material and rods are not permitted.

NF-2600 MATERIAL MANUFACTURERS' QUALITY SYSTEM PROGRAMS

(23) NF-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b), Material Organizations shall have a Quality System Program that meets the requirements of NCA-3300.

(b) The requirements of NCA-1224 and NCA-1225 shall be met as required by NF-2130. The other requirements of NCA-3300 and NCA-4200 need not be used by Material Organizations for small products, as defined in (c), for material used in items commensurate with their contribution to safety or risk, as defined in (g) below; for brazing material; and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (see NCA-4100) shall include measures to provide assurance that the material is furnished in accordance with the material specification and the requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (3)

(1) pipe, tube, pipe fittings, and flanges of 2 in. (50 mm) nominal size and less

(2) bolting material, including studs, nuts, and bolts of 2 in. (50 mm) nominal diameter and less

(3) structural material with a nominal cross-sectional area of 2 in.^{2} (1 300 mm^2) and less

(d) When impact testing is required in accordance with NF-2300, the material not exempted by NF-2311 shall be furnished with Certified Material Test Reports in accordance with NCA-1225.

(e) Structural materials, which are permitted by this Section to be furnished with a Certificate of Compliance, may be repaired by welding using welders, documentation, and examination requirements specified in SA-6 and need not meet the requirements of NCA-4257.3.

(f) Materials manufactured to a Material Specification prohibiting weld repair without user approval do not require documentation to indicate that weld repairs have not been performed.

(g) For the purpose of this paragraph, items commensurate with their contribution to safety or risk are defined as given in (1) and (2) below.

(1) The Owner or the Owner's designee has established that the exemption is consistent with the safety or risk significance of the item. The determination of the safety or risk significance of the item to design and operations is beyond the scope of this Section. Appropriate guidance for the safety or risk significance of the item shall be derived from system criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory and enforcement authorities having jurisdiction at the site

(2) The Owner or the Owner's designee has permitted the exemption in the Design Specification and shall specify to which items this exemption applies.

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ARTICLE NF-3000
DESIGN

NF-3100 GENERAL DESIGN REQUIREMENTS

NF-3110 LOADING CRITERIA

NF-3111 Loading Conditions

The loadings that shall be taken into account in designing a support include, but are not limited to, those in the following:

(a) weight of the piping or component and normal contents under plant and system operating and test conditions, including loads due to static and dynamic head and fluid flow effects

(b) weight of the support

(c) superimposed static and thermal loads and reactions induced by the supported system components

(d) dynamic loads, including loads caused by earthquake and vibration

(e) effects from piping thermal expansion

(f) anchor and support movement effects

(g) environmental loads such as wind and snow loads

(h) expansion or contraction of a component produced by internal or external pressure

Guidelines for classification of these loadings into primary, secondary, or peak are listed in NF-3120 and NF-3220.

NF-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and NF-3112.1 through NF-3112.3.

NF-3112.1 Design Temperature. The specified Design Temperature shall be established in accordance with NCA-2142.1(b). The metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under plant and system equivalent operating conditions. In lieu of heat transfer analysis or measurements, the component or piping Design Temperature may be used. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in Section II, Part D, Subpart 1, Tables 1A, 1B, 2A, 2B, 3, 4, and Y-1, or exceed the maximum temperature limitations specified elsewhere in this Subsection.

NF-3112.2 Design Mechanical Loads. The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c), and shall include all loads from the component or piping acting on the support.

NF-3112.3 Design Stress Intensity and Allowable Stress Values. When the procedures of design by analysis (see NF-3220) are employed, the applicable design stress intensity values S_m listed in Section II, Part D, Subpart 1, Table 2A, 2B, and 4 shall be used. When the procedures of linear elastic analysis (see NF-3320) are employed, the allowable stress values shall be the applicable yield strength values S_y listed in Section II, Part D, Subpart 1, Table Y-1 as modified by the design factors given in NF-3322. The material 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 listed. The values in the tables may be interpolated for intermediate temperatures.

NF-3113 Service Conditions

Each Service Condition to which the piping or component may be subjected shall be categorized in accordance with NCA-2142.2, and Service Limits [see NCA-2142.4(b)] shall be designated in the Design Specification in such detail as will provide a complete basis for design in accordance with this Article.

NF-3114 Test Conditions

The component and piping support loadings resulting from test conditions shall be identified (see NCA-2142).

NF-3115 Design Interface

The design interface between the support and the component shall be established in the Design Specifications [see NCA-3211.19(c)]. In order to establish the interface loads, a system analysis is performed (see Section III Appendices, Mandatory Appendix XXVII, XXVII-1410). In some cases, the design procedures or service limits permitted for supports in this Article could result in support behavior different from that utilized in the system analysis. If necessary, the support Design Specification shall restrict the design procedure or establish more restrictive limits to reflect those utilized in the system analysis.

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NF-3120 DESIGN CONSIDERATIONS

NF-3121 Terms Relating to Design by Analysis

NF-3121.1 General Considerations.

(a) Terms that are common to the design by stress analysis of Plate- and Shell-Type, Linear-Type, and Standard Supports are defined in NF-3121.2 through NF-3121.17.

(b) Terms unique to the design by stress analysis of Plate- and Shell-Type Supports are defined in NF-3212.

(c) Terms unique to the design by stress analysis of Linear-Type Supports are defined in NF-3313.

NF-3121.2 Primary Stress. Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the support that no redistribution of load occurs in the support as a result of yielding. Examples of primary stress are

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads

(b) bending stress in a cantilever beam due to a normal end load

For evaluation purposes, stresses induced in the support by restraint of free end displacement [see NF-3111(e)] and anchor motion [see NF-3111(f)] of piping are considered primary stresses.

NF-3121.3 Secondary Stress. Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur, and failure from one application of the stress is not to be expected.

Examples of secondary stress are

(a) general thermal stress [see NF-3121.11]

(b) bending stress at a gross structural discontinuity

NF-3121.4 Peak Stress. Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress (see NF-3121.11), including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Evaluation of peak stresses in the support is not required by this Subsection.

NF-3121.5 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

NF-3121.6 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

NF-3121.7 Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

NF-3121.8 Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

NF-3121.9 Total Stress. Total stress is the sum of the primary and secondary stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NF-3121.10 Critical Buckling. Critical buckling occurs when a support is loaded to a state at which an infinitesimal additional load or disturbance causes the support to change from an equilibrium condition to one of instability.

NF-3121.11 Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. Evaluation of thermal stresses in the support is not required by this Subsection.

NF-3121.12 Free End Displacement. Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated and permitted to move.

NF-3121.13 Anchor Point Motion Stress. Anchor point motion stresses are those stresses resulting from the differential motion of support points. An example is differential building settlement.

NF-3121.14 Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire thickness of the member. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the thickness.

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Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between parts of different diameters or thicknesses.

NF-3121.15 Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the collapse load.

NF-3121.16 Collapse Load — Lower Bound. If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium and nowhere exceeds the material yield strength, using shape factors associated with the cross section under consideration, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NF-3121.17 Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NF-3122 Piping or Component Deformation Limits

Deformation limits for the supported piping or component shall be stipulated in the Design Specifications, if required.

NF-3123 Functional Requirements

When a support is to be designed to perform a specific function during any Service Condition, the functional requirements shall be designated in the Design Specifications.

NF-3124 Rolling and Sliding Supports

(a) Rolling and sliding supports shall permit free movement of the piping or component, or the piping or component shall be designed to include the imposed load and frictional resistance of these types of supports; their dimensions shall provide for the designed movement of the supported piping or component.

(b) Sliding supports (or shoes) and brackets shall be designed to accommodate the forces caused by friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the design movement of the supported piping or component. Material and lubricants used in sliding supports shall be suitable for the environment of the metal at the point of sliding contact and shall be specified in the Design Documents.

NF-3125 Sway Braces and Vibration Dampeners

Sway braces and vibration dampeners may be used to limit the effects of vibration and may be of the rigid strut (linear type) tension–compression type. If employed in the design or added as a result of observation under startup or initial operating conditions, the effect of sway braces shall be included in the stress analysis of the piping or component for all of the specified conditions.

NF-3127 Provisions for Movement of Supported Piping or Component

Consideration shall be given to the relative motion of the supported piping or component and the support. When clearances or travel ranges or both are required to accommodate piping or component movements, sufficient design margins shall be introduced to allow for variations due to fabrication and installation. Care shall be taken to ensure that design clearances and travel ranges are based on the maximum range that might occur between two operating conditions and not necessarily on the maximum cold to hot range. All parts of the support shall be fabricated and assembled so that they will not be disengaged by movement of the supported piping or component. Supports needed only to provide stability during Level C or Level D Service Conditions shall be designed and installed so as not to overstress the piping or component during Level A or Level B Service Conditions.

NF-3128 Snubbers, Dampers, and Energy Absorbers (23)

The end connections of snubbers and energy absorbers shall be designed to accommodate vertical and horizontal movement of the piping or component, as required. Dampers shall be properly oriented and installed in accordance with manufacturer's requirements.

NF-3130 GENERAL DESIGN REQUIREMENTS

NF-3131 Requirements for Acceptability

The requirements for acceptability of support design are given in (a) through (e).

(a) The design shall be such that the stress intensity values or the stress values (whichever are applicable) will not exceed the limits given in this subarticle. Table NF-3131(a)-1 indicates the rules and limits to be used for the various classes and types of design procedures. The applicable tables of allowable stress values for materials to be used with a specific design procedure are referenced in Table NF-2121(a)-1.

(b) The design procedure shall be one of those given in Table NF-3131(a)-1 as being applicable to supports.

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Table NF-3131(a)-1
Reference Paragraphs for Procedures for Design of Component Supports, Piping Supports, and Standard Supports

Type and Class of Support	Plate and Shell					Linear				
	Design by Analysis	Bolting	Weld Joint	Experimental Analysis	Load Rating	Design by Analysis	Bolting	Weld Joints	Experimental Analysis	Load Rating
Component										
Class 1	NF-3220, NF-3522	NF-3225, NF-3525	NF-3226, NF-3526	NF-3270	NF-3280	NF-3320, NF-3523	NF-3324, NF-3525	NF-3324, NF-3526	NF-3370	NF-3380
Class 2 and MC [Note (1)]	NF-3250, NF-3552	NF-3255, NF-3555	NF-3256, NF-3556	NF-3270	NF-3280	NF-3350, NF-3553	NF-3324, NF-3555	NF-3324, NF-3556	NF-3370	NF-3380
Class 3	NF-3260, NF-3552	NF-3265, NF-3555	NF-3266, NF-3556	NF-3270	NF-3280	NF-3360, NF-3553	NF-3324, NF-3555	NF-3324, NF-3556	NF-3370	NF-3380
Piping										
Class 1	NF-3220, NF-3622	NF-3225, NF-3625	NF-3226, NF-3626	NF-3270	NF-3280	NF-3320, NF-3623	NF-3324, NF-3625	NF-3324, NF-3626	NF-3370	NF-3380
Class 2	NF-3250, NF-3652	NF-3255, NF-3655	NF-3256, NF-3656	NF-3270	NF-3280	NF-3350, NF-3653	NF-3324, NF-3655	NF-3324, NF-3656	NF-3370	NF-3380
Class 3	NF-3260, NF-3652	NF-3265, NF-3655	NF-3266, NF-3656	NF-3270	NF-3280	NF-3360, NF-3653	NF-3324, NF-3655	NF-3324, NF-3656	NF-3370	NF-3380
Standard										
Class 1 [Note (1)]	NF-3220, NF-3422	NF-3225, NF-3425	NF-3226, NF-3426	NF-3270	NF-3280	NF-3320, NF-3423	NF-3324, NF-3425	NF-3324, NF-3426	NF-3370	NF-3380
Class 2 [Note (1)]	NF-3250, NF-3452	NF-3255, NF-3455	NF-3256, NF-3456	NF-3270	NF-3280	NF-3350, NF-3453	NF-3324, NF-3455	NF-3324, NF-3456	NF-3370	NF-3380
Class 3	NF-3260, NF-3452	NF-3265, NF-3455	NF-3266, NF-3456	NF-3270	NF-3280	NF-3360, NF-3453	NF-3324, NF-3455	NF-3324, NF-3456	NF-3370	NF-3380

NOTE: (1) Supports for Class 2 vessels designed to NCD-3200 shall be designed in accordance with Class 1 requirements.

(c) The design details shall conform to the rules of this subarticle or to those referenced herein.

(d) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account in addition to the requirements of (a), (b), and (c).

(e) For Class 1 supports, protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

NF-3132 Dimensional Standards

Dimensions of supports may comply with the standards and specifications listed in Table NCA-7100-1 but are not mandatory. Compliance with these standards does not replace or eliminate the requirements for stress analysis or load rating.

NF-3133 Stress Analysis

A detailed stress analysis or Design Report, as required by NCA-3211.40(e) for all supports, shall be prepared in sufficient detail to show that each of the stress limits of NF-3200 or NF-3300 is satisfied when the support is subjected to the loadings of NF-3110.

NF-3134 Support Tolerances

(a) Tolerances shall be specified by the designer in the design output documents. Fabrication tolerances and local installation tolerances as contained in Nonmandatory Appendix NF-D are only mandatory when invoked by the designer.

(b) When specifying the support tolerances, the support designer shall consider the piping support location/orientation tolerances specified by the piping designer (Section III Appendices, Nonmandatory Appendix T, T-1230).

NF-3140 GENERAL DESIGN PROCEDURES

NF-3141 Types of Procedures

(a) The design procedure which may be used is dependent on the type of support being designed and the Class of construction involved. Three design procedures are recognized, namely

(1) design by analysis

(-a) maximum shear stress theory

(-b) maximum stress theory

(2) experimental stress analysis (Section III Appendices, Mandatory Appendix II)

(3) load rating

(b) Unless either the experimental stress analysis procedure or the load rating procedure is used, the requirements of the following paragraphs apply.

NF-3142 Plate- and Shell-Type Supports — Analysis Procedure

NF-3142.1 Elastic Analysis.

(a) Elastic analysis used in the design of Plate- and Shell-Type Supports of Class 1 construction shall be based on maximum shear stress theory in accordance with the rules of NF-3200.

(b) Elastic analysis used in the design of Plate- and Shell-Type Supports of Class 2, 3, and MC construction shall be based on maximum stress theory. Supports for Class 2 vessels designed to NCD-3200 shall be designed in accordance with Class 1 requirements.

NF-3142.2 Limit Analysis.

(a) Limit analysis used in the design of Plate- and Shell-Type Supports of Class 1 construction shall be in accordance with the procedures of NF-3221.4.

(b) Limit analysis used in the design of Plate- and Shell-Type Supports of Class 2, 3, and MC construction shall be in accordance with the procedures of NF-3251.4.

NF-3143 Linear-Type Supports — Analysis Procedure

(a) The analysis procedure shall comply with (1) or (2).

(1) Elastic analysis based on maximum stress theory in accordance with the rules of NF-3300 shall be used for the design of Linear-Type Supports for Class 1, 2, 3, and MC construction.

(2) Limit analysis in accordance with the procedures of NF-3340 shall be used in the design of Linear-Type Supports for Class 1, 2, 3, and MC construction.

(b) High cycle fatigue analysis in accordance with procedures of NF-3330 shall be used in the design of Linear-Type Supports for Class 1 construction when members and their connections are subject to high cycle fatigue as defined in NF-3331.

NF-3144 Standard Supports — Analysis Procedure

Standard Supports designed by analysis shall be designed to either the requirements of NF-3142 or NF-3143, according to whether they are Plate- and Shell-Type or Linear-Type Standard Supports.

NF-3200 DESIGN RULES FOR PLATE- AND SHELL-TYPE SUPPORTS

NF-3210 GENERAL REQUIREMENTS

NF-3211 Basis for Determining Stresses in Design by Analysis

The theory of failure used in the rules of this Subsection for combining stresses for the design of Class 1 Plate- and Shell-Type Supports is the maximum shear stress theory;

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for Class 2, 3, and MC Plate- and Shell-Type Supports, it is the maximum stress theory.

NF-3212 Definitions

Terms used in the design of Plate- and Shell-Type Supports by stress analysis are defined in NF-3121 and in NF-3212.1 below.

NF-3212.1 Stress Intensity. *Stress intensity* is defined as twice the maximum shear stress which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

This definition of *stress intensity* is not related to the definition of stress intensity applied in the field of fracture mechanics.

NF-3220 DESIGN BY ANALYSIS FOR CLASS 1

NF-3221 Stress Limits

Stress limits for elements of Class 1 supports are given in this paragraph. Stress limits for bolts and welds are given in NF-3225 and NF-3226. General requirements concerning stress determinations, definitions, derivations of stress intensities, and classification of stresses are given in NF-3210.

Plate- and Shell-Type Supports may be designed by either elastic or limit analysis, stress intensity limits for which are given in NF-3221.1 through NF-3221.4.

NF-3221.1 Design Limits. The stress intensity limits which must be satisfied for the Design Loadings stated in the Design Specification are the two limits of this paragraph and the Special Stress Limits of NF-3223. The design stress intensity values S_m are given in NF-3224.

(a) General primary membrane stress intensity P_m is derived from the average value across the thickness of a section of the general primary stresses produced by specified Design Mechanical Loads, but excluding all secondary stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is S_m at the Design Temperature.

(b) Primary membrane plus primary bending stress intensity $P_m + P_b$ is derived from the highest value across the thickness of a section of the general membrane stresses plus primary bending stresses produced by the specified Design Mechanical Loads, but excluding all secondary stresses. The allowable value of this stress intensity is $1.5S_m$.

NF-3221.2 Service Level A Through D Service Limits. The rules and stress limits which must be satisfied in an elastic analysis for any Level A through D Service Loadings stated in the Design Specification are those given in NF-3221.1 and NF-3223 multiplied by the appropriate stress intensity limit factor from Table NF-3221.2-1 for the particular loading and stress categories.

NF-3221.3 Test Limits. The rules and stress limits which must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3221.1 and NF-3223 multiplied by the appropriate stress intensity limit factor in Table NF-3221.2-1 under Test Loadings.

NF-3221.4 Limit Analysis. The limits on primary membrane plus primary bending stress intensity [see NF-3221.1(b)] need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load for Design Loadings and Service Level A and B Loadings, and do not exceed 0.8 times the lower bound collapse load for Service Level C Loadings. Service Level D Loadings shall not exceed 0.9 times the lower bound collapse load. For Service Level D, the lower bound collapse load may be determined using a yield stress in the analysis that is the greater of $1.2S_y$ and $1.5S_m$, but not larger than $0.7S_u$. For materials in Section II, Part D, Subpart 1 for which allowable stresses, or stress intensities, may reach 90% of the yield strength S_y at temperature, the specified loading shall not exceed the product of the applicable permanent strain limiting factor of Section II, Part D, Subpart 1, Table Y-2 times the lower bound collapse load.

NF-3222 Derivation of Stress Intensities

One requirement for the acceptability of a design (see NF-3130) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e).

(a) At the point on the support which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t, l, and r. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses and T_{lt}, T_{lr}, and T_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the item will be subjected and assign each set of stress values to one or a group of the following categories:

(1) general primary membrane stress P_m (see NF-3121.7)

(2) primary bending stress P_b (see NF-3121.8)

(3) secondary stress Q (see NF-3121.3)

(c) For each category, calculate the algebraic sum of the values of σ_t that result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

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Table NF-3221.2-1
Elastic Analysis Stress Categories and Stress Limit Factors for Class 1 Plate- and Shell-Type Supports Designed by Analysis

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	Stress Limit Factors for Loading Categories [Note (1)]					
Stress Category	**Design**	**Service Level A**	**Service Level B [Note (2)]**	**Service Level C [Note (3)]**	**Service Level D**	**Test Loadings**
Primary stresses [Notes (4), (5)]	K_m = 1.0	K_m = 1.0	K_m = 1.33	K_m = 1.5	K_m = greater of 1.5 or $1.2S_y/S_m$ [Note (6)]	K_m = 1.33
	K_v = 1.0	K_v = 1.0	K_v = 1.33	K_v = 1.5	K_v = greater of 1.5 or $1.2S_y/S_m$ [Note (7)]	K_v = 1.33
	K_{bk} = 1.0	K_{bk} = 1.0	K_{bk} = 1.33	K_{bk} = 1.5	K_{bk} = greater of 1.5 or $1.2S_y/S_m$	K_{bk} = 1.33
	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress [Note (8)]	but stress ≤ ½ of critical buckling stress
Primary plus secondary stresses [Notes (5), (9)]	Evaluation is required for critical buckling for all loading categories. The requirements of this subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTE:

K_{bk} = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (compression only)

K_m = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (see NF-3221.1 and NF-3221.2)

K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3223.2)

NOTES:

(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_m, K_v, and K_{bk} = 1.0 for design of snubbers, dampers, and energy absorbers.

(3) Stress shall not exceed $0.7S_u$.

(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.

(6) Primary membrane stress intensity shall not exceed $0.7S_u$.

(7) Shear stress shall not exceed $0.42S_u$.

(8) Two-thirds of the critical buckling stress may be used, provided the critical buckling stress is determined by one of the following methods:

(a) comprehensive analysis that considers effects such as geometric imperfections, deformations due to existing loading conditions, nonlinearities, large deformations, residual stresses, and inertial forces

(b) tests of physical models under conditions of restraint and loading the same as those to which the configuration is expected to be subjected

(9) Service Levels A and B, primary plus secondary stresses shall be limited to a range of $2S_y$ or S_u at temperature, whichever is less for component supports only.

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(d) Translate the stress components for the t, l, and r directions into principal stresses σ_1, σ_2, and σ_3.

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the following equations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12}, S_{23}, and S_{31}.

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component stress level in (b) or (c).

NF-3223 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of this paragraph take precedence for the particular situations to which they apply.

NF-3223.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted.

(b) When bearing loads are applied near 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 primary stress (see NF-3121.2) and $0.5S_y$ in the case of primary stress plus secondary stress (see NF-3121.9).

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

(d) Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits apply.

NF-3223.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated, shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings except those for which Level D Limits are designated, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) Primary plus secondary shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of Table NF-3221.2-1.

NF-3223.3 Triaxial Stresses. The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m.

NF-3223.4 Applications of Elastic Analysis for Stresses Beyond the Yield Strength. Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material.

NF-3223.5 Buckling. Plate- and shell-type support structures are typically composed of rectangular plates, shells, and tubular structural members. Care should be used when using open cross-sections (angles, channels, I-beams, etc.) because these items are susceptible to torsional and lateral-torsional buckling.

The allowable compressive stress values for plates and shells for all loadings associated with Design, Level A, Level B, and Level C Service Limits shall be determined by one of the following:

- classical buckling analysis (a) or (b) reduced by margins that reflect the difference between the theoretical and actual load capacities
- inelastic buckling analysis (d)
- detailed stability analysis, such as by the finite element method

For all loadings associated with Level D Service Limits (c), the same limitations on methodology (d) used for Design and Level A Service Limit loads shall be followed, but the allowable compressive stress values shall be adjusted per the requirements of Table NF-3221.2-1.

The material properties used in calculating compressive stresses and critical buckling stresses shall be those at temperature coincident with the loading.

For thin elements such as shells with a diameter-to-thickness ratio of greater than 70 and plates with a length-to-thickness ratio of greater than 60, determination of the critical buckling stress shall give additional consideration to the influence of tolerances and the differences between theoretical results and actual test results. Appropriate knockdown factors shall be used and the justification of the value used shall be included in the Design Report.

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(a) Cylindrical Shells Under Axial Compression. The 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 (1) or (2) below.

(1) The S_m value for the applicable material at Design Temperature (or the temperature under consideration for operating loadings associated with Level A, B, C, or D Service Limits) given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 in the manner given in Steps 1 through 5

Step 1. Calculate the value of factor A using the following equation:

$$A = 0.125/(R/T)$$

where

R = inside radius of the cylindrical shell or tubular product, in. (mm)

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in. (mm)

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 (or the temperature under consideration for operating loadings associated with Level A, B, C, or D Service Limits). 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 (where E is the modulus of elasticity at Design Temperature or the temperature under consideration for operating loadings associated with Level A, B, C, or D Service Limits):

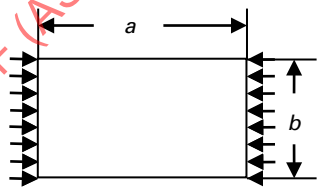
$$B = AE/2$$

This is the maximum allowable compressive stress for the values of T and R used in Step 1.

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 shall be selected and the design procedure repeated until a value of B is obtained (the allowable compressive stress) that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

(b) Rectangular Plates Under Compressive Loading. The support members that are subjected to compressive loading shall be designed based on the performance of the individual members rather than the entire structure. The elastic stress analysis of the support shall be performed to determine the axial forces and moments on individual members. These forces and moments shall be used to size the members in accordance with the allowable compressive stress provided in (3).

(1) Rectangular Plate Under Uniaxial Compression. The critical buckling stress σ_{cr} for a plate of dimension a by b and thickness t shall be calculated using the following equation:



$$\sigma_{cr} = K\frac{E}{1-\nu^2}\left(\frac{t}{b}\right)^2 \quad (1)$$

In the above equation, E is the elastic modulus of the plate material at operating temperature, ν is Poisson's ratio, and K is the plate buckling coefficient, which is a function of the boundary conditions of the plate. The smaller plate width should be greater than 10 times the thickness of the plate.

The plate geometry, the values of K for various boundary conditions, and a/b ratios are given in Table NF-3223.5-1. Values of K are provided for various combinations of simply supported, clamped, and free edge constraints. Values not provided in the table shall be justified in the Design Report. K values for other combinations of edge constraints shall be justified in the Design Report.

(2) Rectangular Plate Under Biaxial Compression. The critical buckling stress shall be calculated using the following equations for a plate under biaxial compression that has all edges simply supported when the smaller plate width is greater than 10 times the thickness of the plate:

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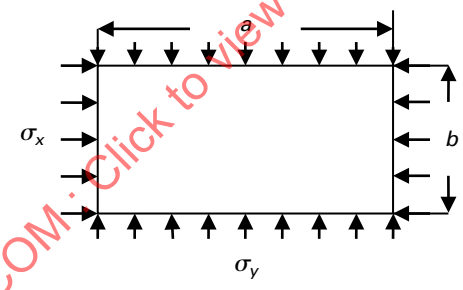
Table NF-3223.5-1
Values of *K* for Various Boundary Conditions and *a*/*b* Ratios

	K					
a/*b*	All Edges Simply Supported	Edges *b* Simply Supported, Edges *a* Clamped	Edges *b* Simply Supported, One Edge *a* Simply Supported and Other Free	Edges *b* Simply Supported, One Edge *a* Clamped and Other Free	Edges *b* Clamped, Edges *a* Simply Supported	All Edges Clamped
0.2	22.2	...	...	...	...	...
0.3	10.9	...	...	...	...	...
0.4	6.92	7.76	...	...	...	...
0.5	...	6.32	3.62	...	...	...
0.6	4.23	5.80	...	...	11.0	...
0.7	...	5.76	...	...	...	...
0.8	3.45	6.00	...	...	7.18	...
1.0	3.29	6.32	1.18	1.40	5.54	7.70
1.1	...	...	...	1.28	...	...
1.2	3.40	5.80	0.934	1.21	4.80	...
1.3	...	...	...	1.16	...	...
1.4	3.68	5.76	0.784	1.12	4.48	...
1.5	...	...	...	1.10	...	...
1.6	3.45	6.00	0.687	1.09	4.39	...
1.7	...	...	...	1.09	4.39	...
1.8	3.32	5.80	0.622	1.10	4.26	...
1.9	...	...	...	1.12	...	...
2.0	3.29	...	0.574	1.14	3.99	6.70
2.1	...	5.76	...	...	...	...
2.2	3.32	...	...	1.19	...	...
2.4	3.40	...	...	1.21	...	...
2.5	...	...	0.502	...	3.72	...
2.7	3.32	...	...	...	...	...
3.0	3.29	...	0.464	...	3.63	6.40
4.0	...	...	0.425	...	...	...
5.0	...	...	0.416	...	...	...
∞	3.29	5.73	...	...	...	5.73



$$\sigma_{x(cr)}\frac{m^2}{a^2} + \sigma_{y(cr)}\frac{n^2}{b^2} = 0.823\frac{E}{1-\nu^2}t^2\left(\frac{m^2}{a^2} + \frac{n^2}{b^2}\right)^2 \quad (2)$$

Here m and n are integers and denote the number of half waves in which a plate buckles in the x and y directions, respectively. The positive values of the σ_x and σ_y indicate compressive stresses. Equations (2) through (6) provide the values of σ_x and σ_y at which buckling may occur. For a given σ_x , $\sigma_{y(cr)}$ shall be determined from the above equation taking m = 1 and n = 1, if the following inequality is satisfied:

$$C\left(1 - 4\frac{a^4}{b^4}\right) < \sigma_x < C\left(5 + 2\frac{a^2}{b^2}\right) \quad (3)$$

where

$$C = \frac{0.823Et^2}{\left(1-\nu^2\right)a^2} \quad (4)$$

If σ_x is too large to satisfy the inequality in eq. (3), taking n = 1, the value of m shall be determined that satisfies the inequality in eq. (5)

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$$C\left(2m^2 - 2m + 1 + 2\frac{a^2}{b^2}\right) < \sigma_x < C\left(2m^2 + 2m + 1 + 2\frac{a^2}{b^2}\right) \quad (5)$$

Using the calculated value of m and $n = 1$, eq. (2) shall be used to provide the critical buckling stress, $\sigma_{y(cr)}$.

If σ_x is too small to satisfy eq. (3), taking $m = 1$, the value of n shall be determined that satisfies the inequality in eq. (6).

$$C\left(1 - n^2(n-1)^2\frac{a^4}{b^4}\right) > \sigma_x > C\left(1 - n^2(n+1)^2\frac{a^4}{b^4}\right) \quad (6)$$

Using the calculated value of n and $m = 1$, eq. (2) shall be used to calculate the critical buckling stress $\sigma_{y(cr)}$.

(3) Allowable Compressive Stress. For Design Loadings and loadings for which Design and Level A and Level B and Level C Service Limits, respectively, are designated, the allowable compressive stress shall be one-half of the critical buckling stress as calculated in (1) or (2) above but shall not exceed S_m for compressive primary membrane stress and $1.5S_m$ for compressive primary membrane plus primary bending stress.

(c) Allowable Elastic Compressive Stress for Level D Service Limits. For loadings for which Level D Service Limits are designated, the allowable compressive stress values shall be adjusted per the requirements of Table NF-3221.2-1.

(d) Inelastic Buckling. An inelastic buckling analysis of plates and shells subject to compressive loadings for which Design, Level A, Level B, Level C, or Level D Service Limits are designated shall be performed when the actual compressive stress exceeds $0.375S_m$ and the calculated elastic critical buckling stress (σ_{cr}) exceeds $0.75S_m$.

Alternatively, when the actual compressive stress exceeds $0.375S_m$ but is less than $0.60S_m$ and the calculated elastic critical buckling stress (σ_{cr}) exceeds $0.75S_m$ but is less than $1.2S_m$, an elastic buckling analysis may be used provided the allowable compressive stresses of (a) and (b) are reduced by 20%.

Finite element methods and testing are recommended for stability analysis of plates in the inelastic region. If finite element analyses are used, the methods and margins shall be justified in the Design Report.

NF-3224 Design Stress Values

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 for support material. Values for intermediate temperatures may be found by interpolation. Values of yield strength and ultimate tensile strength are given in Section II, Part D, Subpart 1, Tables Y-1 and U, respectively. Values of the coefficient of thermal expansion and of the modulus of elasticity are given in Section II, Part D, Subpart 2, Tables TE and TM.

NF-3225 Design of Bolting

NF-3225.1 Design Limits. The rules and stress limits that must be satisfied for any Design Loading stated in the Design Specification are those given in NF-3324.6.

NF-3225.2 Service Limits, Level A Through D. The rules and stress limits which must be satisfied for any Level A through D Service Loading stated in the Design Specification are those given in NF-3324.6 multiplied by the appropriate stress limit factor for the particular service loading level and stress category specified in Table NF-3225.2-1. Table NF-3225.2-1 establishes additional stress limits based on the yield and tensile strength of the material at temperature.

NF-3225.3 Test Limits. The rules and stress limits that must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3324.6 multiplied by the appropriate stress limit factor for the particular Service Loading Level and stress category specified in Table NF-3225.2-1.

NF-3225.4 Friction-Type Joints. Multiplying factors normally used to increase the allowable limits for Service Level B, C, and D are not applicable to friction-type joints [see NF-3324.6(a)(4)].

NF-3226 Design of Welded Joints

NF-3226.1 Permissible Types of Welded Joints in Plate- and Shell-Type Supports. All welded joints in Plate- and Shell-Type Supports shall be continuous and shall be of one of the types listed in (a) through (c). Typical examples of those permitted types are shown in Figure NF-3226.1-1. Fillet and partial penetration welds shall meet the requirements of NF-3324.5(d), except that NF-3324.5(d)(7) does not apply.

(a) Butt Joints. Butt joints shall be one of the following:

(1) full penetration, single or double welded [see Figure NF-3226.1-1, sketches (a-1) and (a-2)].

(2) partial penetration, double welded [see Figure NF-3226.1-1, sketch (b)].

(3) the applicable welds may be either square groove, V groove, bevel groove, J groove, U groove, flare V groove, or flare bevel groove [see Figure NF-3226.1(a)-1].

(4) when angle joints are used for connecting a transition in diameter to a cylinder, the angle α of Figure NF-3226.1-1, sketch (f) shall not exceed 30 deg.

(5) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Figure NF-3226.1(a)-2, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3 mm),

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Table NF-3225.2-1
Stress Limit Factors for Class 1, 2, 3, and MC Bolt Design by Analysis

Stress Category	Stress Limit Factors for Loading Levels Stated in Design Specification [Notes (1), (2)]					
	Design	Service Level A	Service Level B	Service Level C	Service Level D	Test Loading
Tension and shear	K_{bo} = 1.0	K_{bo} = 1.0	K_{bo} = 1.15	K_{bo} = 1.25	K_{bo} = 1.5	K_{bo} = 1.25

GENERAL NOTE:
K_{bo} = stress limit factor applicable to the Design allowable tensile and shear stresses

NOTES:
(1) Not to be used for friction type connections.
(2) Average tensile stress shall not exceed $0.7S_u$ and S_y, and average bolt shear stress shall not exceed $0.42S_u$ and $0.6S_y$.

whichever is less. 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, or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell, or cylindrical course or plate.

(6) When the use of backing rings will result in undesirable conditions such as severe stress or corrosion, the requirements of NF-4240 shall be met.

(b) Corner Joints. Corner joints shall be one of the following:

(1) full penetration, as shown in Figure NF-3226.1-1, sketch (d-1)

(2) partial penetration with a fillet weld as shown in Figure NF-3226.1-1, sketches (d-2) and (d-3)

(3) the applicable welds are fillet, square groove, V groove, bevel groove, U groove, J groove, flare V groove and flare bevel groove

(c) Tee Joints. Tee joints shall be one of the following:

(1) full penetration, Figure NF-3226.1-1, sketches (c) and (g)

(2) partial penetration, double welded with or without additional fillet welds, Figure NF-3226.1-1, sketch (e)

(3) partial penetration, single welded between the end surface of a closed tubular section or a closed formed section, Figure NF-3226.1-1, sketch (h)

(4) the applicable welds may be square groove, bevel groove, J groove, flare V groove or flare bevel groove

NF-3226.2 Stress Intensities and Stress Limits for Welded Joints in Plate- and Shell-Type Supports.

(a) Design Limits. The stress intensity and allowable stress limits which must be satisfied for welds for the Design Loadings stated in the Design Specification shall be the following:

(1) Full Penetration Groove Welds. The stress intensity limits for full penetration groove welds shall not exceed the applicable stress intensity value for the base metal being joined, as specified in NF-3221.1 and Table NF-3324.5(a)-1. See NF-3111.

(2) Partial Penetration Groove Welds

(-a) Compression Normal to Effective Throat. The stress intensity and stress limits shall be the same as those for the base metal as required in NF-3221.1.

(-b) Tension Normal to the Axis on the Effective Throat or Shear on the Effective Throat. The stress limits shall be as specified in Table NF-3324.5(a)-1.

(3) Fillet Welds. The allowable stress limits for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(b) Service Limits Levels A, B, C, and D, and Test. The rules and stress limits that must be satisfied for welds for any Level A, B, C, and D Service and Test Loadings stated in the Design Specification are those given in (a) multiplied by the appropriate base material stress limit factor given in Table NF-3251.2-1.

(c) The effective sizes of welds shall be as given in NF-3324.5(d) and NF-3324.5(f).

NF-3226.3 Consideration of Lamellar Tearing. Welded joint configurations causing significant through-thickness tensile stress [as defined in NF-1215(b)] during fabrication and/or service on rolled product forms should be avoided. However, if this type of construction is used, the designer should consider one or several of the following factors that may reduce the susceptibility of the joint to experience lamellar tearing and provide documentation, including fabrication requirements, in the Design Output Documents:

(a) Reduce volume of weld metal to the extent practical.

(b) Select materials that are resistant to lamellar tearing.

(c) Invoke any of the special fabrication requirements of NF-4441.

NF-3250 DESIGN BY ANALYSIS FOR CLASS 2 AND MC (23)

NF-3251 Stress Limits (23)

Stress limits for elements of Class 2 Plate and Shell-Type Supports are given in this paragraph. Stress limits for bolts and welds are given in NF-3255 and NF-3256. General requirements concerning stress determinations, definitions, and classification of stresses are given in NF-3210. Plate and Shell-Type Supports may be designed

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Figure NF-3226.1-1
Permissible Welded Joints for Class 1 Plate- and Shell-Type Supports

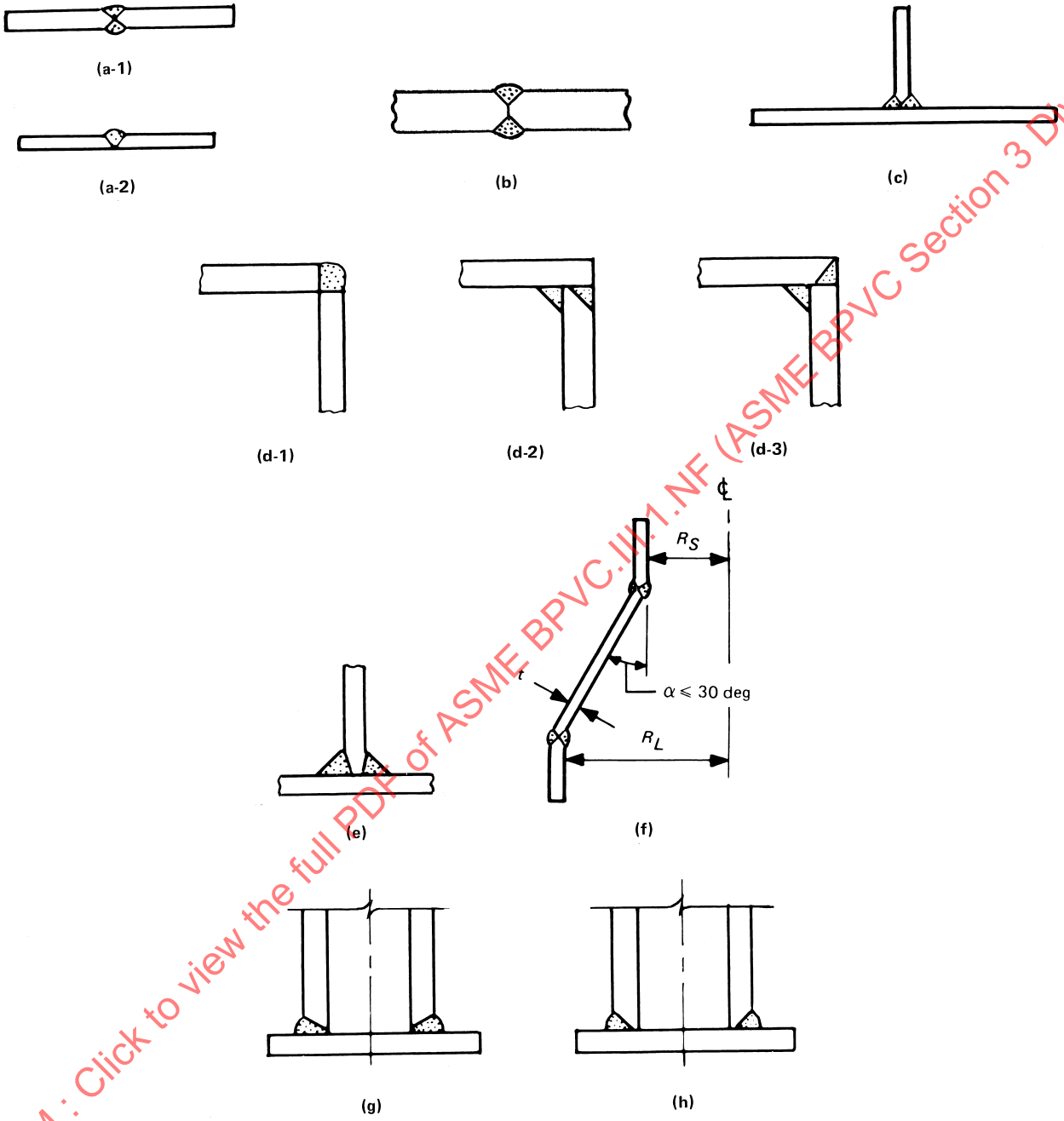

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Figure NF-3226.1(a)-1
Typical Weld Details Referenced

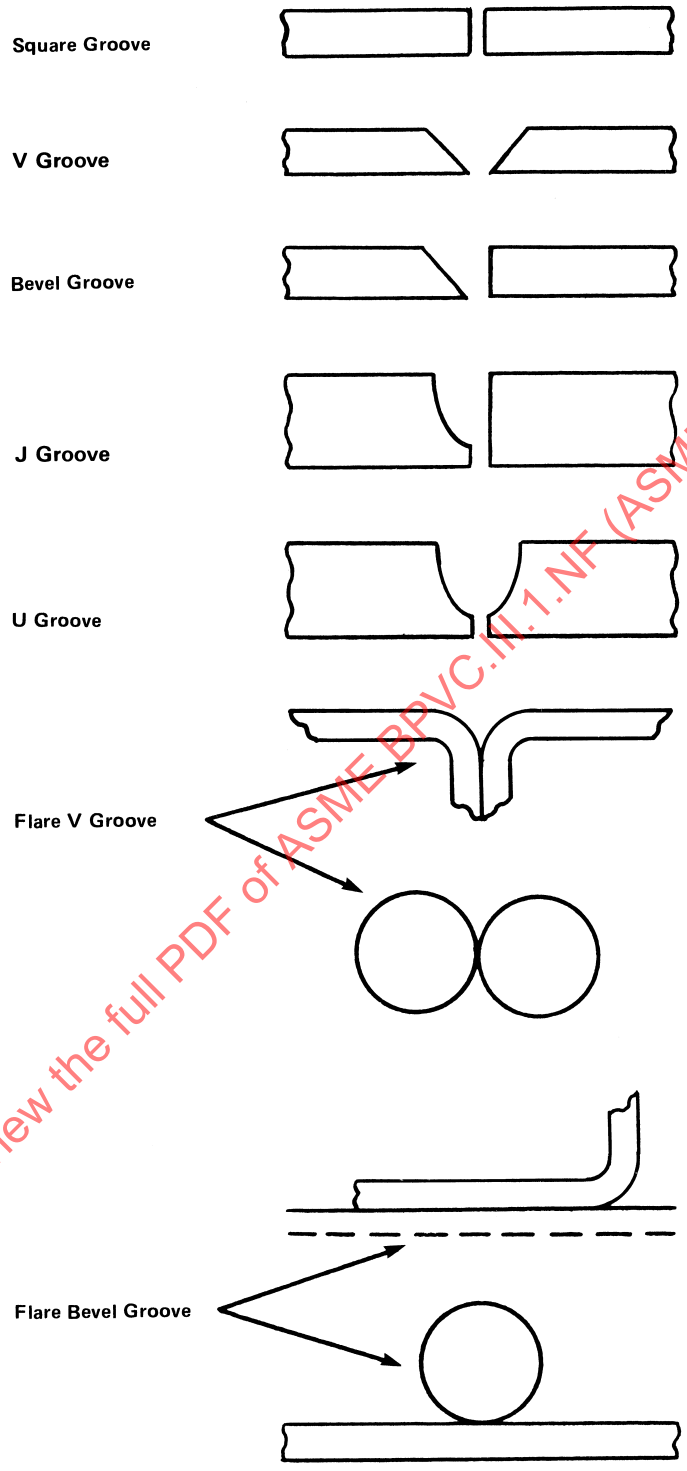

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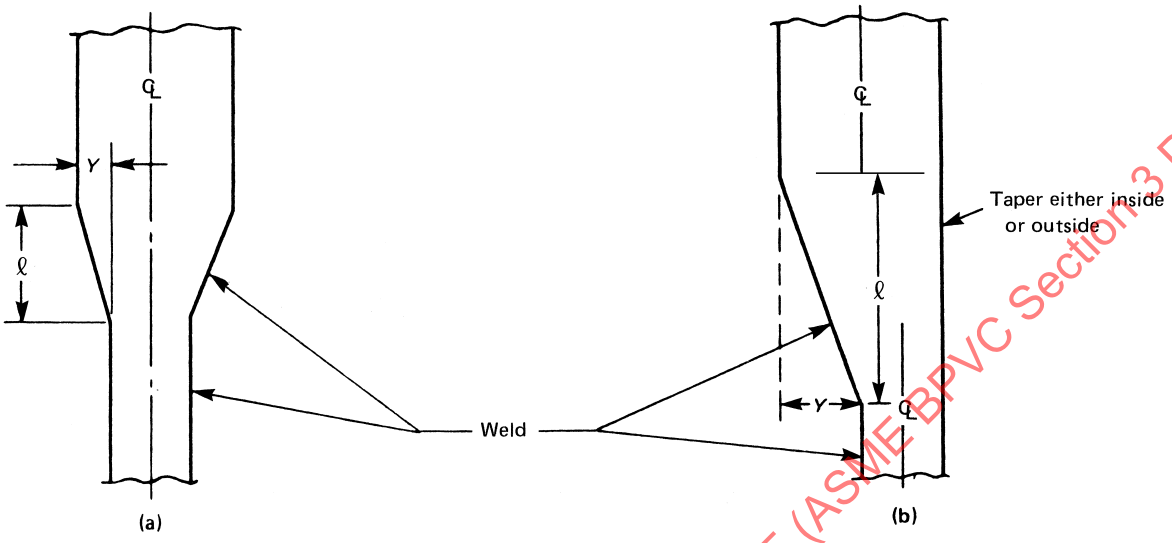
Figure NF-3226.1(a)-2
Butt Welding of Plates of Unequal Thickness



GENERAL NOTES:
(a) $\ell \geq 3y$, where ℓ is required length of taper and y is the C sections.
(b) Length of required taper ℓ may include the width of the weld.
(c) In all cases ℓ shall not be less than $3y$.

by either elastic or limit analysis, stress limits for which are given in NF-3251.1 through NF-3251.4.

NF-3251.1 Design Limits. The stress (maximum normal stress, also referred to as *principal stress*) limits are satisfied for the Design Loadings (NCA-2142.1) stated in the Design Specifications if the requirements of eqs. (1) and (2) are met.

$$\sigma_m \leq 1.0S \quad (1)$$

$$\sigma_m + \sigma_b \leq 1.5S \quad (2)$$

where

S = allowable stress value, ksi (MPa), from the applicable table of Section II, Part D, Subpart 1, as referenced in Table NF-2121(a)-1
σ_b = bending stress, ksi (MPa) (see NF-3121.8)
σ_m = membrane stress, ksi (MPa) (see NF-3121.7)

NF-3251.2 Service Limits — Service Level A Through D. The rules and stress limits that must be satisfied in an elastic analysis for any Level A through D Service Loading stated in the Design Specification are those given for Design Loadings in NF-3251.1 multiplied by the appropriate stress limit factor specified in Table NF-3251.2-1.

NF-3251.3 Test Limits. The rules and stress limits that must be satisfied for any Test Loadings stated in the Design Specification are those given for Design Loadings in NF-3251.1 multiplied by the appropriate stress limit factor specified in Table NF-3251.2-1.

NF-3251.4 Limit Analysis. The limits for Class 1 Plate- and Shell-Type Supports designed by limit analysis apply.

NF-3252 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of this paragraph take precedence for the particular situations to which they apply.

NF-3252.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load controlled

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Table NF-3251.2-1
(23) **Elastic Analysis Stress Categories and Stress Limit Factors for Class 2, 3, and MC Plate- and Shell-Type Supports Designed by Analysis**

	Stress Limit Factors for Loading Categories [Note (1)]					
Stress Category	**Design**	**Service Level A**	**Service Level B [Note (2)]**	**Service Level C [Note (3)]**	**Service Level D**	**Test Loadings**
Primary stresses [Notes (4), (5)]	K_m = 1.0	K_m = 1.0	K_m = 1.33	K_m = 1.5	K_m = greater of 1.5 or $1.2S_y/S$ [Note (6)]	K_m = 1.33
	K_v = 1.0	K_v = 1.0	K_v = 1.33 [Note (7)]	K_v = 1.5 [Note (7)]	K_v = greater of 1.5 or $1.2S_y/S$ [Note (7)]	K_v = 1.33 [Note (7)]
	K_{bk} = 1.0	K_{bk} = 1.0	K_{bk} = 1.33	K_{bk} = 1.5	K_{bk} = greater of 1.5 or $1.2S_y/S$	K_{bk} = 1.33
	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress [Note (8)]	but stress ≤ ½ of critical buckling stress

GENERAL NOTE:
K_{bk} = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stress (compression only)
K_m = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stress (see NF-3251.1 and NF-3261)
K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3252.2 and NF-3261)

NOTES:
(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.
(2) K_m and K_{bk} = 1.0 for design of snubbers, dampers, and energy absorbers.
(3) Stress shall not exceed $0.7S_u$.
(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.
(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.
(6) Primary membrane stress intensity shall not exceed $0.7S_u$.
(7) Shear stress shall not exceed $0.42S_u$.
(8) Two-thirds of the critical buckling stress may be used, provided the critical buckling stress is determined by one of the following methods:
(a) comprehensive analysis that considers effects such as geometric imperfections, deformations due to existing loading conditions, nonlinearities, large deformations, residual stresses, and inertial forces
(b) tests of physical models under conditions of restraint and loading the same as those to which the configuration is expected to be subjected

stress only, the average shear stress shall be limited to 0.6S in the case of primary stress (see NF-3121.2).

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

(d) Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits apply.

NF-3252.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, shall be limited to 0.6S.

(b) The maximum primary shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to 0.8S.

NF-3252.3 Buckling. The allowable compressive stress values for plates and shells shall be determined in accordance with NF-3223.5, except that Table NF-3251.2-1 shall be used instead of Table NF-3221.2-1. The material properties used in calculating compressive stresses and critical buckling stresses shall be those at temperature coincident with the loading.

NF-3255 Design of Bolting

The provisions of NF-3225 apply.

NF-3256 Design of Welded Joints

NF-3256.1 Permissible Types of Welded Joints in Plate- and Shell-Type Supports. All welded joints in Plate- and Shell-Type Supports shall be continuous and shall be of one of the types listed in (a) through (d). Typical examples of those permitted types are shown in Figure NF-3256.1-1. Fillet and partial penetration welds shall meet the requirements of NF-3324.5(d), except that NF-3324.5(d)(7) does not apply. Plug and slot welds shall meet the requirements of

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NF-3324.5(e). Lap joints shall meet the requirements of NF-3324.3.

(a) Butt Joints. Butt joints shall be one of the following:

(1) full penetration, single and double welded, Figure NF-3256.1-1, sketches (a-1) and (a-2).

(2) partial penetration, double welded, Figure NF-3256.1-1, sketch (b).

(3) when angle joints are used for connecting a transition in diameter to a cylinder, the angle α of Figure NF-3256.1-1, sketch (n) shall not exceed 30 deg.

(4) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Figure NF-3226.1(a)-2, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section or adjacent to it.

(5) When the use of backing rings will result in undesirable conditions such as severe stress or corrosion, the requirements of NF-4240 shall be met.

(b) Corner Joints. Corner joints shall be one of the following:

(1) full penetration, as shown in Figure NF-3256.1-1, sketch (c)

(2) partial penetration with a fillet weld as shown in Figure NF-3256.1-1, sketches (d) and (e)

(c) Tee Joints. Tee joints shall be one of the following:

(1) full penetration, single or double welded, Figure NF-3256.1-1, sketches (f-1), (f-2), and (h)

(2) partial penetration, with or without additional fillet welds, Figure NF-3256.1-1, sketch (g)

(3) partial penetration, single welded between a plate and the end surface of a closed tubular section or a closed formed section, Figure NF-3256.1-1, sketch (j)

(4) fillet, double welded, Figure NF-3256.1-1, sketch (k-1); single welded when double members are used, Figure NF-3256.1-1, sketch (k-2)

(5) fillet, single welded between a flat surface and the end surface of a closed tubular section or a closed formed section, Figure NF-3256.1-1, sketch (l)

(d) Lap Joints. Lap joints shall be fillet, double welded, Figure NF-3256.1-1, sketch (m).

(e) The applicable welds for the joints permitted in (a) through (d) are

(1) square groove, bevel groove, J groove, flare bevel groove, U groove and V groove

(2) plug and slot welds are permitted in (c) and (d) only

(3) fillet welds are permitted in (c)(4), (c)(5), and (d) only

NF-3256.2 Allowable Stress Limits.

(a) Design Limits. The allowable stress limits which must be satisfied for the Design Loadings stated in the Design Specification shall be the following:

(1) Full Penetration Groove Welds. The allowable stress limits for full penetration groove welds shall not exceed the applicable allowable stress value for the base metal being jointed, as specified in NF-3251.1 and Table NF-3324.5(a)-1.

(2) Partial Penetration Groove Welds

(-a) Compression Normal to Effective Throat. The allowable stress limits shall be as specified in Table NF-3324.5(a)-1.

(-b) Tension Normal to the Axis on the Effective Throat or Shear on the Effective Throat. The stress limits shall be as specified in Table NF-3324.5(a)-1.

(3) Fillet Welds. The allowable stress limit for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(b) Service Limits, Level A Through D, and Test. The rules and stress limits which must be satisfied for welds for any Level A through D Service and Test Loading stated in the Design Specification are those given in (a) multiplied by the appropriate base material stress limit factor given in Table NF-3251.2-1.

NF-3256.3 Effective Size. The effective sizes of welds shall be as given in NF-3324.5(d) through NF-3324.5(f).

NF-3256.4 Consideration of Lamellar Tearing. Welded joint configurations causing significant through-thickness tensile stress [as defined in NF-1215(b)] during fabrication and/or service on rolled product forms should be avoided. However, if this type of construction is used, the designer should consider one or several of the following factors that may reduce the susceptibility of the joint to experience lamellar tearing and provide documentation, including fabrication requirements, in the Design Output Documents:

(a) Reduce volume of weld metal to the extent practical.

(b) Select materials that are resistant to lamellar tearing.

(c) Invoke any of the special fabrication requirements of NF-4441.

NF-3260 DESIGN BY ANALYSIS FOR CLASS 3

NF-3261 Stress Limits

The design of Class 3 supports shall be in accordance with the requirements of NF-3250 using one of the design procedures indicated in Table NF-3131(a)-1 for Class 3 construction.

NF-3265 Design of Bolting

The provisions of NF-3225 apply.

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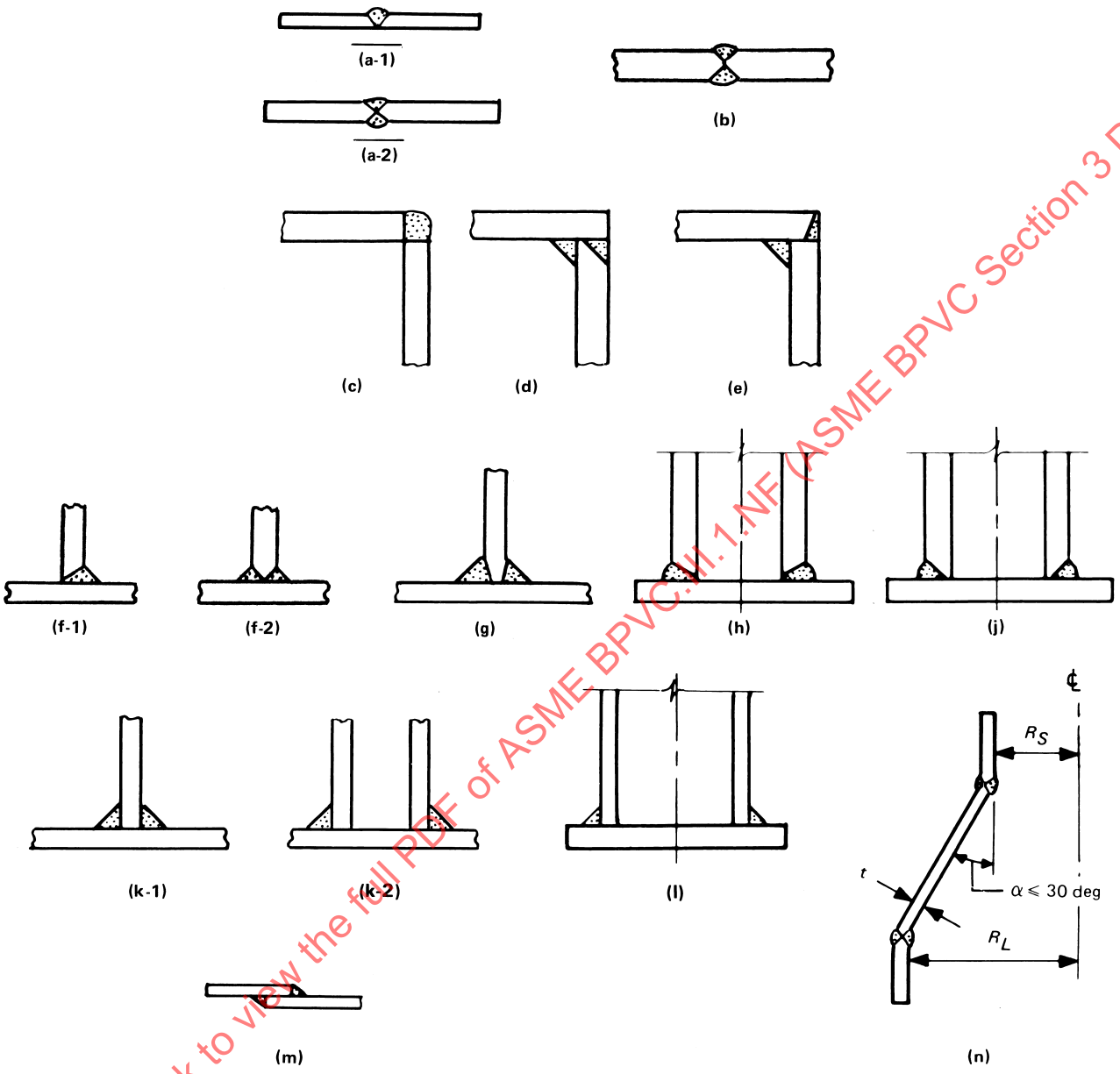
Figure NF-3256.1-1
Permissible Welded Joints for Class 2, 3, and MC Plate- and Shell-Type Supports



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NF-3266 Design of Welded Joints

The types of welded joints shall be as stipulated in NF-3256 for Class 2 and MC supports, except that for groove welded T-joints, groove welded corner joints, and fillet welded T-joints, as shown in Figure NF-3256.1-1, sketches (c), (d), (e), (f-1), (f-2), (g), (k-1), and (k-2), the welds may be intermittent instead of continuous. Intermittent fillet welds shall meet the requirements of NF-3324.5(d)(7). The allowable stress limits shall be as stipulated in NF-3256.2.

NF-3270 EXPERIMENTAL STRESS ANALYSIS

Supports may be designed by experimental stress analysis in accordance with Section III Appendices, Mandatory Appendix II. The test collapse load may be determined by Section III Appendices, Mandatory Appendix II, II-1430. Supports designed by experimental stress analysis for Level A and Level B Service Conditions shall not exceed the test collapse load divided by 1.7. Supports designed by experimental stress analysis for Level C Service Condition shall not exceed the test collapse load divided by 1.3. Supports designed by experimental stress analysis for Level D Service Condition shall not exceed the test collapse load.

NF-3280 DESIGN BY LOAD RATING

NF-3281 Procedure for Load Rating

The procedure for load rating shall consist of imposing a total load on one or more duplicate full-size samples of a support equal to or less than the load under which the support fails to perform its required function. Full-size samples composed of various parts may have each part or a number of parts load rated, provided that all parts in the load path are either load rated or otherwise qualified per NF-3200, or by experimental stress analysis. When parts are connected by bolting or welding, the connection shall be either load rated or qualified per NF-3225 or NF-3226. Should more than one part be load rated in a single load test, then the load rating equations of NF-3280 shall be evaluated for each part using the part's $S_{y(act)}$ and $S_{u(act)}$ values. The part having the lowest load rating shall establish the load rating for the combination of parts. A single test sample is permitted but, in that case, the load ratings shall be reduced by 10%. Otherwise, tests shall be run on a statistically significant number of samples. The permissible types of welded joints shall be as permitted for the specific class of construction in NF-3226.1, NF-3256.1, and NF-3266. The full-size sample shall be fabricated for testing using welds not exceeding weld sizes stipulated in the Design Drawings. Bolted joints in the test sample shall be made up using the lowest strength bolt material and minimum edge distance allowed by the specification.

NF-3282 Load Ratings in Relation to Design Service and Test Loadings

The load rating for Design Loadings shall be determined in accordance with the requirements for Service Level A limits. The load ratings for Service Loadings for which Level A through Level D Limits have been designated shall be determined by means of the equations in the following subparagraphs. The load rating for Test Loadings shall be determined in accordance with the requirements for Service Level B limits.

NF-3282.1 Nomenclature. The symbols used in this paragraph are defined as follows:

Kl = load rating coefficient for support in compression
S = allowable stress value at the Design Temperature (see NF-3112.1) from the applicable tables of Section II, Part D, Subpart 1, ksi (MPa)
S_T = specified minimum tensile strength of the material used in the support as given in the applicable tables of Section II, Part D, Subpart 1, ksi (MPa)
S_u = see NF-3313.1
$S_{u(act)}$ = actual tensile strength of the material used in the part or support which had reached ultimate capacity during the test, ksi (MPa)
S_Y = specified minimum yield strength of the material used in the support as given in the applicable tables of Section II, Part D, Subpart 1, ksi (MPa)
S_y = see NF-3313.1
$S_{y(act)}$ = actual yield strength of the material used in the part or support which yielded during the test, ksi (MPa)
TL_u = support test load at which a substantial increase in load displacement results in zero or negative increase in actual support load
TL_y = support test load at or below yield

NF-3282.2 Plate- and Shell-Type Supports. The load ratings for Plate- and Shell-Type Supports for the Service Loadings shall be determined by the following equations:

Design and Level A Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.0\frac{S}{S_{y(\text{act})}} \quad (1)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.0\frac{S}{S_{u(\text{act})}} \quad (2)$$

Test and Level B Limits (lower of the two values)

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$$\text{load rating}_{(\text{yield})} = TL_y \times 1.33\frac{S}{S_{y(\text{act})}} \quad (3)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.33\frac{S}{S_{u(\text{act})}} \quad (4)$$

Level C Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.5\frac{S}{S_{y(\text{act})}} \quad (5)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.5\frac{S}{S_{u(\text{act})}} \quad (6)$$

Level D Limits (lowest of the three values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 2.0\frac{S}{S_{y(\text{act})}} \quad (7)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 0.7\frac{S_u}{S_{u(\text{act})}} \quad (8)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 0.7 \quad (9)$$

NF-3282.3 Supports Loaded in Compression. The load rating for supports loaded in compression shall be determined for Service Levels A through D by the methods of NF-3282.2. In addition, for cases where buckling governs, TL_u shall be corrected for the ratio of Young's Modulus at the Design Temperature to Young's Modulus at the test temperature. The load rating shall be determined by the following equations:

Design and Level A Limits

$$\text{load rating} = 0.50\ Kl \times TL_u \quad (10)$$

Test and Level B Limits

$$\text{load rating} = 0.50\ Kl \times TL_u \quad (11)$$

Level C Limits

$$\text{load rating} = 0.50\ Kl \times TL_u \quad (12)$$

Kl = 1.0 for elastic buckling

$$Kl = \frac{S_y}{S_{y(\text{act})}} \text{ for inelastic buckling}$$

Level D Limits

$$\text{load reading} = 0.50\ Kl \times TL_u \quad (13)$$

NF-3282.4 Alternative Load Rating Method Using TL_y or TL_u Test Results Only. Either TL_y or TL_u test results may be used to establish a support load rating, provided the load rating as determined by the method of NF-3282.2 or NF-3282.3 is modified as follows:

(a) For load rating based on TL_y test results only

(1) for supports constructed of materials having definitely determinable yield points and specified minimum S_Y/S_T ratios not greater than 0.625, the load rating shall be multiplied by 0.83. If $S_{y(\text{act})}$ of the material is not known, 0.67 shall be used in place of multiplier 0.83.

(2) for supports constructed of carbon steel with specified minimum tensile strengths of not over 70,000 psi (485 MPa), $S_{y(\text{act})}$ shall be increased by 5,000 psi (34 MPa) prior to determining the load rating.

(3) for all other materials the determined load rating shall be multiplied by 0.67

For supports loaded in compression, a TL_u test shall be performed with the compressive load rating determined in accordance with NF-3282.3.

(b) For load rating based on TL_u test results, the determined load rating shall be multiplied by 0.50.

NF-3300 DESIGN RULES FOR LINEAR-TYPE SUPPORTS

NF-3310 GENERAL REQUIREMENTS

This subarticle provides rules for the design of Linear-Type Supports by either linear elastic analysis (see NF-3320) or plastic (limit) analysis (see NF-3340). Linear elastic analytical procedures are also provided (see NF-3330) for the design of members and connections which will be subjected to high cycle fatigue conditions in service.

NF-3311 Design Considerations

NF-3311.1 Linear Elastic Analysis. The rules for linear elastic analysis are based on the yield strength values at temperature of the materials used in constructing linear-type supports that are set forth in Section II, Part D, Subpart 1, Table Y-1. The allowable stresses are determined in NF-3320 by applying factors of safety dependent on the structural member involved to these yield strength values.

NF-3311.2 High Cycle Fatigue Analysis. The rules for designing Linear-Type Supports given in NF-3330 are essentially the same as those given in NF-3320 for linear elastic analysis, except that the maximum range of stress, namely, the difference between the minimum and maximum value of the stress throughout each cycle and the frequency with which the support will be subjected to this range of stress, shall be taken into consideration when so stipulated by the Design Specification [NCA-3211.19(b)].

NF-3311.3 Limit Analysis. The rules for limit (plastic) analysis given in NF-3340 may be used as an alternative to the linear elastic analysis method. These rules permit

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proportioning Linear-Type Supports on the basis of limit design by determining their lower bound collapse loads. The requirements set forth in NF-3320 governing allowable stresses to be used in designing Linear-Type Supports are waived when the limit design procedure is employed, but all other pertinent provisions of NF-3320 shall apply.

NF-3311.4 Basis for Determining Stress in Design by Analysis. The theory of failure used in the rules for the design of Linear-Type Supports is the maximum stress theory. In the maximum stress theory, the controlling stress is the maximum principal stress.

NF-3311.5 Terms Relating to Design by Analysis. Terms used in the design of Linear-Type Supports by stress analysis are defined in NF-3313.

NF-3312 Analysis Methods

Linear-Type Supports may be designed by either elastic or limit analysis, limits for which are given in NF-3312.1.

NF-3312.1 Elastic Analysis. In elastic analysis it is assumed that all component and support stiffnesses remain constant.

(a) Design Limits. The rules and stress limits that must be satisfied in an elastic analysis for any Design Loading shall be stated in the Design Specification.

(b) Service Limits, Level A Through D. The rules and stress limits which must be satisfied in an elastic analysis for any Level A through D Service Loading stated in the Design Specification are those given in NF-3321 multiplied by the appropriate stress limit factor from Table NF-3312.1(b)-1.

(c) Test Limits. The rules and stress limits that must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3321 multiplied by the appropriate stress limit factor in Table NF-3312.1(b)-1 under Test Loadings.

NF-3313 Nomenclature and Numbering of Equations

(23) **NF-3313.1 Nomenclature.** Except where symbols are used in the text of the paragraphs that follow to represent the value of complex algebraic expressions, or where nomenclature is specifically defined in figures, the nomenclature adopted in NF-3300 is defined as follows:

A = gross area of an axially loaded compression member, in.^{2} (mm^2)
a = clear distance between transverse stiffeners; dimension parallel to the direction of stress, Table NF-3332.3-1, in. (mm)
A_b = nominal body area of a fastener, in.^{2} (mm^2); area of an upset rod based upon the major diameter of its threads, i.e., the diameter of a coaxial cylinder that would bound the crests of the upset threads, in.^{2} (mm^2)
A_e = effective net area of an axially loaded tension member, in.^{2} (mm^2)
A_f = area of compression flange, in.^{2} (mm^2)
A_n = net area of an axially loaded tension member, in.^{2} (mm^2)
A_{st} = cross-sectional area of stiffener or pair of stiffeners, in.^{2} (mm^2)
A_w = area of girder web, in.^{2} (mm^2)
a' = distance required at ends of welded partial length cover plate to develop stress, in. (mm)
b = actual width of stiffened and unstiffened compression elements, in. (mm)
= dimensions normal to the direction of stress, Table NF-3332.3-1, in. (mm)
b_e = effective width of stiffened compression element, in. (mm)
b_f = flange width of rolled beam or plate girder, in. (mm)
C = ratio of bolt tensile strength to tensile strength of connected part
C_1 = increment used in computing minimum spacing of oversized and slotted holes
C_2 = increment used in computing minimum edge distance for oversized and slotted holes
C_b = bending coefficient dependent upon moment gradient
C_c = slenderness ratio separating elastic and inelastic buckling
C_m = coefficient applied to bending term in interaction equation and dependent upon column curvature caused by applied moments
C_t = reduction coefficient in computing effective net area of an axially loaded tension member
C_v = ratio of critical web stress, according to the linear buckling theory, to the shear yield stress of web material
C'_c = effective column slenderness ratio
D = factor dependent upon type of transverse stiffeners
= outside diameter of tubular members, in. (mm)
d = depth of beam or girder, in. (mm)
= diameter of roller or rocker bearing, in. (mm)
= nominal diameter of fastener, in. (mm)
d_c = column web depth clear of fillets, in. (mm)
E = modulus of elasticity of steel at temperature, ksi (MPa)
e = horizontal displacement, in the direction of the span, between top and bottom of simply supported beam at its ends, in. (mm)
f = axial compression stress on member based on effective area, ksi (MPa)
F_a = axial compressive stress permitted in the absence of bending moment, ksi (MPa)
f_a = computed axial stress, ksi (MPa)
F_b = bending stress permitted in the absence of axial force, ksi (MPa)

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Table NF-3312.1(b)-1

(23) **Elastic Analysis Stress Categories and Stress Limit Factors for Class 1, 2, 3, and MC Linear-Type Supports Designed by Analysis**

	Stress Limit Factors for Loading Categories [Note (1)]					
Stress Category	**Design**	**Service Level A**	**Service Level B [Notes (2), (3)]**	**Service Level C [Note (3)]**	**Service Level D [Note (4)]**	**Test Loadings**
Primary stresses [Notes (5), (6)]	K_s = 1.0	K_s = 1.0	K_s = 1.33	K_s = 1.5	K_s = lesser of 2.0 or $1.167S_u/S_y$ [Note (8)]	K_s = 1.33
	K_v = 1.0	K_v = 1.0	K_v = 1.33 [Note (7)]	K_v = 1.5 [Note (7)]	K_v = 2.0 [Notes (7), (9)]	K_v = 1.33 [Note (7)]
	K_{bk} = 1.0	K_{bk} = 1.0	K_{bk} = 1.33	K_{bk} = 1.5	K_{bk} = 1.5 [Note (10)]	K_{bk} = 1.33
	...	...	but stress ≤ ⅔ of critical buckling stress	but stress ≤ ⅔ of critical buckling stress	but stress ≤ ⅔ of critical buckling stress	but stress ≤ ⅔ of critical buckling stress
Primary plus secondary stresses [Notes (6), (11)]	Evaluation is required for critical buckling for all loading categories. The requirements of this subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTE:
K_{bk} = stress limit factor applicable to the Design allowable compressive axial and bending stresses to determine buckling limit
K_s = stress limit factor applicable to the Design allowable tensile and bending stresses (see NF-3321.1, NF-3322.1, NF-3350, and NF-3360)
K_v = stress limit factor applicable to the Design allowable shear stresses (see NF-3321.1, NF-3322.1, NF-3350, and NF-3360)

NOTES:
(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.
(2) K_s, K_v, and K_{bk} = 1.0 for design of snubbers, dampers, and energy absorbers.
(3) Stress shall not exceed $0.7S_u$ and $1.2S_y$.
(4) Tensile stress on the net section, except at pin holes and the through-plate thickness direction, shall not exceed the lesser of $0.7S_u$ and $1.2S_y$.
(5) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.
(6) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.
(7) Shear stress shall not exceed $0.42S_u$ and $0.72S_y$.
(8) If $S_u \le 1.2S_y$, K_s = 1.4.
(9) For fillet welds, K_v = 1.7 and shear stress shall not exceed $0.5S_u$.
(10) Except as required by NF-3322.1(c)(4).
(11) Service Levels A and B, primary plus secondary stresses, shall be limited to a range of $2S_y$ or S_u at temperature, whichever is less for component supports only.

f_b = computed bending stress, ksi (MPa)
F_e = elastic buckling stress, ksi (MPa)
F_p = allowable bearing stress on the projected area of bolts or pins, or on contact area of milled surfaces and ends of rollers, rockers, or fitted bearing stiffeners at temperature, ksi (MPa)
f_p = computed bearing stress, ksi (MPa)
F_{sr} = stress range, ksi (MPa)
F_t = allowable tensile stress, ksi (MPa)
f_t = computed tensile stress, ksi (MPa)
F_{tb} = allowable tensile stress at temperature, ksi (MPa)
F_v = allowable shear stress, ksi (MPa)
f_v = computed shear stress, ksi (MPa)
F_{vb} = allowable shear stress at temperature, ksi (MPa)
f_{vs} = shear between girder web and transverse stiffeners, kips/linear in. (N/mm) of single stiffener or pair of stiffeners
F_{yc} = column yield stress, ksi (MPa)
F_{yst} = stiffener yield stress, ksi (MPa)
F'_b = allowable bending stress in compression flange of plate girders as reduced for hybrid girders or because of large web depth–thickness ratio, ksi (MPa)
f'_c = specified compression strength of concrete, ksi (MPa)
F'_e = Euler stress divided by factor of safety, ksi (MPa)
g = transverse center to center spacing (gage) between successive holes in line of stress, in. (mm)

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h = clear distance between flanges of a beam or girder at the section under investigation, in. (mm)
K = effective length factor
k = coefficient relating linear buckling strength of a plate to its dimensions and condition of edge support
= also distance between outer face of column flange and web toe of its fillet if column is a rolled shape, or equivalent distance if column is a welded shape, in. (mm)
k_s = slip coefficient for the particular surface condition taken from Table NF-3324.6(a)(4)-1
L = span length
= distance from center of bolt hole to edge of connected part, in. (mm)
l = for beams, distance between cross section braced against twist or lateral displacement of the compression flange, in. (mm)
= for columns, actual unbraced length of member or unsupported length of lacing bar, in. (mm)
l_b = actual unbraced length in plane of bending, in. (mm)
l_{cr} = critical unbraced length adjacent to plastic hinge, in. (mm)
M = moment, in-kip (N·mm) (see NF-3320); factored bending moment, in-kip (N·mm) (see NF-3340)
m = number of shear planes per bolt
M_1 = smaller moment at end of unbraced length of beam column, in-kip (N·mm)
M_2 = larger moment at end of unbraced length of beam column, in-kip (N·mm)
M_m = critical moment that can be resisted by a plastically designed member in the absence of axial load, in-kip (N·mm)
M_p = plastic moment, in-kip (N·mm)
M' = lesser of the factored moments at the ends of unbraced segment, in-kip (N·mm)
N = length of bearing of applied load, in. (mm)
n = number of bolts in the joint
P = force transmitted by a fastener, kips (N) (see NF-3320); factored axial load, kips (N) (see NF-3340); axial load, kips (N) (see NF-3340)
P_{bf} = factored beam flange or connection plate force in a restrained connection
= the computed force delivered by the flange or moment connection plate, multiplied by five-thirds for Level A loads and multiplied by four-thirds for Level B, C, and D loads, kips (N)
P_{cr} = maximum strength of axially loaded compression member or beam, kips (N)
P_e = Euler buckling load, kips (N)
P_s = maximum slip resistance of the joint, lb (N)
P_y = axial plastic load, equal to member area times specified minimum yield stress, kips (N)
Q_a = ratio of effective area of an axially loaded member to its total area
Q_s = axial stress reduction factor
R = reaction or concentrated transverse load applied to beam or girder, kips (N); radius, in. (mm)
r = governing radius of gyration, in. (mm)
r_b = radius of gyration about axis of concurrent bending, in. (mm)
r_c = radius of gyration of a section comprising the compression flange plus one-third of the compression web area, taken about an axis in the plane of the web, in. (mm)
r_y = radius of gyration of a member about its weak axis, in. (mm)
s = longitudinal center-to-center spacing (pitch) of any two consecutive holes, in. (mm)
S_u = tabulated values of ultimate tensile strength of material at temperature (Section II, Part D, Subpart 1, Table U), ksi (MPa)
S_y = yield strength at temperature (Section II, Part D, Subpart 1, Table Y-1), ksi (MPa)
t = girder, beam, or column web thickness, in. (mm); thickness of a connected part, in. (mm)
= wall thickness of a tubular member, in. (mm)
T_b = specific pretension of a high-strength bolt, kips (N)
t_b = thickness of beam flange or moment connection plate at rigid beam to column connection, in. (mm)
t_f = flange thickness, in. (mm)
T_i = initial clamping force per bolt, lb (N)
t_l = thickness of thinner part joined by partial penetration groove weld, in. (mm)
V_u = shear produced by required factored loading, ultimate load, kips (N)
x = subscript relating to bending about the strong principal axis
Y = ratio of yield stress of web steel to yield stress of stiffener steel
y = subscript relating to bending about the weak principal axis
Z_x = plastic section modulus for axis of bending, in.^{3} (mm^3)
Δ = displacement of the neutral axis of a loaded member from its position when the member is not loaded, in. (mm)
α = ratio of hybrid girder web yield stress to flange yield stress

NF-3313.2 Numbering of Equations. A separate series of equation numbers is used for each paragraph and each series, beginning with NF-3322.1(a)(1), eq. (1).

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NF-3320 DESIGN BY LINEAR ELASTIC ANALYSIS FOR CLASS 1

NF-3321 General Design Requirements

NF-3321.1 Design and Service Conditions.

(a) Except as otherwise provided in this subarticle, all items of the structure shall be so proportioned that the stress, ksi (MPa), for Design and Level A Service Limits, shall not exceed the values of NF-3322. For Level B, C, and D Service Limits, allowable stresses may be increased by the factors shown in Table NF-3312.1(b)-1. Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

(b) To avoid column buckling in compression members, local instability associated with compression flange buckling in flexural members, and web buckling in plate girders, the allowable stress shall be limited to two-thirds of the critical buckling stress.

NF-3321.2 Design for High Cycle Fatigue Conditions. Design for high cycle fatigue conditions shall be in accordance with the requirements of NF-3330, using the allowable stresses of NF-3322 as modified by NF-3332.4.

NF-3322 Design Requirements for Structural Steel Members

(23) **NF-3322.1 Allowable Stresses.** Except where noted, the following are the allowable stresses for Design and Level A Service Conditions. See NF-3312.1 for other service condition allowable stresses.

(a) Stress in Tension. The allowable stress in tension shall be as given in (1) and (2)

(1) Except for threaded members used in bolting applications, F_t shall be the lesser of

$$F_t = 0.60S_y \tag{1}$$

on the gross area, and

$$F_t = 0.50S_u \tag{2}$$

on the effective net area (for determination of gross area and effective net area, see NF-3322.8).

(2) For threaded parts in tension used in bolting applications, see NF-3324.6(a)(1).

(b) Stress in Shear

(1) Except as provided in (2) and NF-3324.6(a)(2), on the cross-sectional area effective in resisting shear

$$F_v = 0.40S_y \tag{3a}$$

but not more than $0.33S_u$.

The effective area in resisting shear of rolled and fabricated shapes may be taken as the overall depth times the web thickness.

(2) At the beam end connections where the top flange is coped, and in similar situations where failure might occur by shear along a plane through the fasteners, or by a combination of shear along a plane through the fasteners plus tension along a perpendicular plane, on the effective area in resisting tearing failure shall be

$$F_v = 0.30S_u \tag{3b}$$

The effective area is the minimum net failure surface, bounded by the bolt holes.

(3) For pin-connected members, using the effective net area (for determination of effective net area, see NF-3322.8)

$$F_v = 0.30S_u \tag{3c}$$

(c) Stress in Compression. The allowable stress in compression shall be as required by (1) through (5). The allowable compressive stress for columns, except those fabricated from austenitic or duplex stainless steels, shall be as required by (1). The allowable compressive stress for columns fabricated from austenitic or duplex stainless steels shall be as required by (2). The allowable compressive stress for member elements other than columns constructed of any material, including austenitic or duplex stainless steels, shall be as required by (3). For Service Level D, the allowable compressive stress for columns fabricated from ferritic steel shall be as required by (4). For Service Level D, the allowable compressive stress for columns fabricated from austenitic or duplex stainless steel, except unequal leg angles, slender leg angles, and slender circular tubular members, shall be as required by (5).

(1) Gross Sections of Columns, Except Those Fabricated of Austenitic or Duplex Stainless Steels

(-a) Where Kl/r Is Less Than C_c. On the gross section of axially loaded compression members whose cross sections meet the provisions of NF-3322.2(d), when Kl/r(the largest effective slenderness ratio of any unbraced segment as defined in NF-3322.2) is less than C_c, the allowable stress in compression shall be

$$F_a = \frac{\left[1 - (Kl/r)^2/2C_c^{\,2}\right]S_y}{5/3 + \left[3(Kl/r)/8C_c\right] - \left[(Kl/r)^3/8C_c^{\,3}\right]} \tag{4}$$

where

$$C_c = \sqrt{2\pi^2 E/S_y}$$

(-b) Where Kl/r Is Greater Than C_c. On the gross section of axially loaded compression members when Kl/r exceeds C_c, the allowable stress in compression shall be

$$F_a = \frac{12\pi^2 E}{23\,(Kl/r)^2} \tag{5}$$

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(2) Gross Sections of Columns Fabricated From Austenitic or Duplex Stainless Steels, Except Unequal Leg Angles, Slender Leg Angles, and Slender Cirrcular Tubular Members. On the gross section of axially loaded compression members whose cross-sections meet the provisions of NF-3322.2(d), except for circular tubular members, the allowable stress in compression shall be as required by (-a) and (-b). The allowable stress in compression for circular tubular members whose cross-sections meet the provisions of NF-3322.2(d) shall be as required by (-c) and (-d).

(-a) Where $Kl/r \le 3.77\sqrt{E/S_y}$

$$F_a = \frac{\left(0.50\left(S_y/F_e\right)S_y\right)}{1.67} \tag{6a}$$

(-b) Where $Kl/r > 3.77\sqrt{E/S_y}$

$$F_a = \frac{0.531F_e}{1.67} \tag{6b}$$

(-c) Where $Kl/r \le 3.77\sqrt{E/S_y}$

$$F_a = \frac{\left(0.50\left(S_y/F_e\right)S_y\right)}{1.76} \tag{6c}$$

(-d) Where $Kl/r > 3.77\sqrt{E/S_y}$

$$F_a = \frac{0.531F_e}{1.76} \tag{6d}$$

(-e) For (-a) through (-d),

$$F_e = \frac{\pi^2 E}{(Kl/r)^2}$$

(3) Member Elements Other Than Columns

(-a) Plate Girder Stiffeners. On the gross area of plate girder stiffeners, the allowable stress in compression shall be

$$F_a = 0.60S_y \tag{7}$$

but not more than $0.50S_u$.

(-b) Webs of Rolled Shapes. On the web of rolled shapes at the toe of the fillet, the allowable stress in compression shall be

$$F_a = 0.75S_y \tag{8}$$

but not more than $0.63S_u$.

For the use of stiffeners to avoid web crippling, see NF-3322.6(a).

(4) Service Level D of Ferritic Steel Columns. The Service Level D maximum allowable load for ferritic steel columns shall be determined in accordance with the following, provided that the initial out-of-straightness does not exceed $^1/_{1000}$ of the unsupported length. Effects of deformations due to existing loads shall also be considered.

(-a) Except as noted in (-b), the following rules shall be applied:

For $0 \le \lambda \le 1$

$$\frac{P}{P_y} = \frac{1 - \lambda^2/4}{1.11 + 0.50\lambda + 0.17\lambda^2 - 0.28\lambda^3}$$

For $1 \le \lambda \le \sqrt{2}$

$$\frac{P}{P_y} = \frac{2}{3}\left(1 - \lambda^2/4\right)$$

For $\lambda > \sqrt{2}$

$$\frac{P}{P_y} = \frac{2}{3\lambda^2}$$

where

A_g = area of gross section
E = modulus of elasticity
K = effective length factor
L = unbraced length
P = maximum allowable load
$P_y = S_y A_g$
r = radius of gyration
$\lambda = \left(\frac{KL}{r}\right)\frac{1}{\pi}\sqrt{\frac{S_y}{E}}$

(-b) For nonstress-relieved heavy structural shapes [web or flange thickness greater than 1 in. (25 mm)] or for nonstress-relieved built-up members using universal mill plate, the following rules shall be applied:

For $0 < \lambda < 1$

$$\frac{P}{P_y} = \frac{1 - \lambda^2/4}{1.11 + 0.75\lambda + 0.83\lambda^2 - 0.81\lambda^3}$$

For $1 < \lambda < \sqrt{2}$

$$\frac{P}{P_y} = \frac{1 - \lambda^2/4}{1.88}$$

For $\lambda > \sqrt{2}$

$$\frac{P}{P_y} = \frac{1}{1.88\lambda^2}$$

(5) For Service Level D of Columns Fabricated From Austenitic or Duplex Stainless Steels, Except Unequal Leg Angles, Slender Leg Angles, and Slender Circular Tubular

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Members. On the gross section of axially loaded compression members whose cross sections meet the provisions of NF-3322.2(d), the allowable stress in compression shall be as required by (-a) and (-b), provided the initial out-of-straightness does not exceed 1/1,000 of the unsupported length. Effects of deformations due to existing loads shall also be considered.

(-a) Where $Kl/r \le 3.77\sqrt{E/S_y}$

$$F_a = \frac{\left[0.50\left(S_y/F_e\right)\right]S_y}{1.50}$$

(-b) Where $Kl/r > 3.77\sqrt{E/S_y}$

$$F_a = \frac{0.531F_e}{1.50}$$

For (-a) and (-b)

$$F_e = \frac{\pi^2 E}{(Kl/r)^2}$$

(d) Stress in Bending. The allowable bending stress resulting from tension and compression in structural members shall be as required by (1) through (6).

(1) Compact Sections

(-a) Tension and compression on extreme fibers of compact hot rolled or built-up members (except hybrid beams and members made from 65 ksi (450 MPa) or greater S_y material) symmetrical about and loaded in the plane of their minor axes and meeting the requirements of Subsection NF shall result in a maximum bending stress

$$F_b = 0.66S_y \tag{9}$$

but not more than $0.55S_u$.

In order to qualify, a member shall meet the requirements of (-1) through (-7).

(-1) The flanges shall be continuously connected to the web or webs.

(-2) The width–thickness ratio of unstiffened projecting elements of the compression flange [as defined in NF-3322.2(d)] shall not exceed $65/\sqrt{S_y}$ (for SI units, use $170/\sqrt{S_y}$).

(-3) The width–thickness ratio of stiffened elements of the compression flange [as defined in NF-3322.2(d)] shall not exceed $190/\sqrt{S_y}$ (for SI units, use $500/\sqrt{S_y}$).

(-4) The depth–thickness ratio of the web or webs shall not exceed the value given by eq. (10) or eq. (11), as applicable

(U.S. Customary Units)

$$d/t = \left(640/\sqrt{S_y}\right)\left[1 - 3.74\left(f_a/S_y\right)\right] \tag{10}$$

(SI Units)

$$d/t = \left(11\,680/\sqrt{S_y}\right)\left[1 - 3.74\left(f_a/S_y\right)\right]$$

when $f_a/S_y \le 0.16$;

(U.S. Customary Units)

$$d/t = 257/\sqrt{S_y} \tag{11}$$

(SI Units)

$$d/t = 673/\sqrt{S_y}$$

when $f_a/S_y > 0.16$.

(-5) The laterally unsupported length of the compression flange of members other than box-shaped members shall not exceed the value $76b_f/\sqrt{S_y}$ (for SI units, use $200b_f/\sqrt{S_y}$) nor $20{,}000/[(d/A_f)S_y]$ {for SI units, use $138\,000/[(d/A_f)\,S_y]$}.

(-6) The laterally unsupported length of the compression flange of a box-shaped member of rectangular cross section, whose depth is not more than six times the width and whose flange thickness is not more than two times the web thickness, shall not exceed the value

(U.S. Customary Units)

$$\left[1{,}950 + 1{,}200\left(M_1/M_2\right)\right]\left(b/S_y\right) \tag{12}$$

(SI Units)

$$\left[13\,400 + 8\,300\left(M_1/M_2\right)\right]\left(b/S_y\right)$$

except that it need not be less than 1,200 (b/S_y) [for SI units, use 8 300 (b/S_y)].

(-7) The diameter–thickness ratio of hollow circular sections shall not exceed $3{,}300/S_y$ (for SI units, use $23\,000/S_y$).

(-b) Beams and girders (except for hybrid girders and members made from 65 ksi (450 MPa) or greater S_y material) which meet the requirements of (-a)(-1) through (-a)(-7) and are continuous over supports or are rigidly framed to columns by means of high-strength bolts or welds may be proportioned for nine-tenths of the negative moments produced by gravity loading which are maximum at points of support, provided that for such members the maximum positive moment shall be increased by one-tenth of the average negative moments. This reduction shall not apply to moments produced by loading on cantilevers. If the negative

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moment is resisted by a column rigidly framed to the beam or girder, the one-tenth reduction may be used in proportioning the column for the combined axial and bending loading, provided that the stress f_a due to any concurrent axial load on the member does not exceed $0.15F_a$.

(2) Members With High Flange Width–Thickness Ratio. Members that meet the requirements of (1), except that $b_f/2t_f$ exceeds $65/\sqrt{S_y}$ (For SI units, use $170/\sqrt{S_y}$) but is less than $95/\sqrt{S_y}$ (For SI units, use $250/\sqrt{S_y}$), may be designed on the basis of an allowable bending stress

(U.S. Customary Units)

$$F_b = S_y\left[0.79 - 0.002\left(b_f/2t_f\right)\sqrt{S_y}\right] \quad (13)$$

(SI Units)

$$F_b = S_y\left[0.79 - 0.0008\left(b_f/2t_f\right)\sqrt{S_y}\right]$$

(3) Doubly Symmetrical Members With Bending About the Minor Axis. Tension and compression on extreme fibers of doubly symmetrical I- and H-shaped members [except for hybrid girders and members made from 65 ksi (450 MPa) or greater S_y material] which are bent about their minor axis, meeting the requirements of (1)(-a) and (1)(-b); solid round and square bars; and solid rectangular sections bent about their weaker axis shall not exceed a bending stress of

$$F_b = 0.75S_y \quad (14)$$

but not more than $0.63S_u$.

Doubly symmetrical I- and H-shaped members bent about their minor axis [except for hybrid girders and members made from 65 ksi (450 MPa) or greater S_y material], meeting the requirements of (1)(-a), except where $b_f/2t_f$ exceeds $65/\sqrt{S_y}$ (for SI units, use $170/\sqrt{S_y}$) but is less than $95/\sqrt{S_y}$ (for SI units, use $250/\sqrt{S_y}$), may be designed on the basis of an allowable bending stress

(U.S. Customary Units)

$$F_b = S_y\left[1.075 - 0.005\left(b_f/2t_f\right)\sqrt{S_y}\right] \quad (15a)$$

(SI Units)

$$F_b = S_y\left[1.075 - 0.002\left(b_f/2t_f\right)\sqrt{S_y}\right]$$

Rectangular tubular sections meeting the requirements of (1)(-a)(-1), (1)(-a)(-3), and (1)(-a)(-4), and bent about their minor axis, may be designed on the basis of an allowable bending stress

$$F_b = 0.66S_y \quad (15b)$$

but not more than $0.55S_u$.

(4) Box-Type Flexural Members. Tension and compression on extreme fibers of box-type flexural members whose compression flange or web width–thickness ratio does not meet the requirements of (1), but does conform to the requirements of NF-3322.2(d), shall not exceed a bending stress of

$$F_b = 0.60S_y \quad (16)$$

but not more than $0.50S_u$.

Lateral torsional buckling need not be investigated for a box section whose depth is less than six times its width. Lateral support requirements for box sections of larger depth–width ratios must be determined by special analysis.

(5) Miscellaneous Members

(-a) Tension on extreme fibers of flexural members not covered in (1) through (4), shall not exceed a bending stress as determined by using (4), eq. (16).

(-b) Compression on extreme fibers of flexural members included in (-a), meeting the requirements of NF-3322.2(d)(1)(-b), and having an axis of symmetry in and loaded in the plane of their web and compression on extreme fibers of channels [only eq. (19) is applicable to channels] bent about their major axis, shall have the larger value of bending stress computed by eqs. (17) through (19), as applicable, but not more than $0.60S_y$ (see NF-3322.3 for further limitations in plate girder flange stress).

When

(U.S. Customary Units)

$$\left[\left(102 \times 10^3 C_b\right)/S_y\right]^{1/2} \le l/r_c \le \left[\left(510 \times 10^3 C_b\right)/S_y\right]^{1/2}$$

(SI Units)

$$\left[\left(703.3 \times 10^3 C_b\right)/S_y\right]^{1/2} \le l/r_c \le \left[\left(3\,516 \times 10^3 C_b\right)/S_y\right]^{1/2}$$

then

(U.S. Customary Units)

$$F_b = \left\{2/3 - \left[S_y(l/r_c)^2/\left(1{,}530 \times 10^3 C_b\right)\right]\right\}S_y \quad (17)$$

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(SI Units)

$$F_b = \left\{ {}^{2}/_{3} - \left[S_y (l/r_c)^2 / \left(10\,550 \times 10^3 C_b \right) \right] \right\} S_y$$

When

(U.S. Customary Units)

$$l/r_c \geq \sqrt{\left(510 \times 10^3 C_b \right) / S_y}$$

(SI Units)

$$l/r_c \geq \sqrt{\left(3\,516 \times 10^3 C_b \right) / S_y}$$

then

(U.S. Customary Units)

$$F_b = \left(170 \times 10^3 C_b \right) / (l/r_c)^2 \qquad (18)$$

(SI Units)

$$F_b = \left(1\,172 \times 10^3 C_b \right) / (l/r_c)^2$$

When the compression flange is solid and approximately rectangular in cross section and its area is not less than that of the tension flange

(U.S. Customary Units)

$$F_b = \left(12 \times 10^3 C_b \right) / \left(ld/A_f \right) \qquad (19)$$

(SI Units)

$$F_b = (82\,740 C_b) / \left(ld/A_f \right)$$

where

C_b = $1.75 + 1.05(M_1/M_2) + 0.3\,(M_1/M_2)^2 \leq 2.3$, where M_1 is the smaller and M_2 is the larger bending moment at the ends of the unbraced length taken about the strong axis of the member, and where M_1/M_2 (the ratio of end moments) is positive when M_1 and M_2 have the same sign (reverse curvature bending) and is negative when they are of opposite signs (single curvature bending). When the bending moment at any point within an unbraced length is larger than that at both ends of this length, the value of C_b shall be taken as 1. When computing F_{bx} and F_{by} to be used in (e)(1), eq.(20), C_b may be computed by the equation given above for frames subject to joint translation. C_b may conservatively be taken as 1 for cantilever beams.[5]

For cantilevers braced against twist only at the support, l may be conservatively taken as the actual length.

(-c) For hybrid plate girders, S_y for (-b), eqs. (17) and (18) is the yield stress of the compression flange. Equation (19) of (-b) shall not apply to hybrid girders.

(6) Miscellaneous Members Braced Laterally. Compression in extreme fibers of flexural members meeting the requirements of NF-3322.2(d)(1)(-b), but not included in (5)(-b), shall result in a maximum bending stress as determined by using (4), eq. (16), provided that sections bent about their major axis are braced laterally in the region of compression stress at intervals not exceeding $76b_f/\sqrt{S_y}$ (for SI units, use $200b_f/\sqrt{S_y}$).

(e) Combined Stresses

(1) Axial Compression and Bending. For members subjected to both axial compression and bending, including bending moment resulting in secondary stress, stresses shall be proportioned to satisfy the requirements of eqs. (20) through (22)

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - f_a/F'_{ex}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - f_a/F'_{ey}\right) F_{by}} \leq 1.0 \qquad (20)$$

$$\frac{f_a}{0.60 S_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \qquad (21)$$

After evaluating primary stresses, the right-hand side of eq. (22) may be replaced by 1.5 when both primary and secondary bending stresses are considered. When $f_a/F_a \leq 0.15$, eq. (22) may be used in lieu of eqs. (20) and (21)

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \qquad (22)$$

In eqs. (20) through (22), the subscripts x and y indicate the axis of bending about which a particular stress or design property applies, and

$$F'_e = \frac{12\pi^2 E}{23(Kl_b/r_b)^2}$$

for all members except for those fabricated of austenitic and duplex stainless steels.

For all members fabricated of austenitic and duplex stainless steels:

$$F'_e = \frac{\pi^2 E}{1.67(Kl_b/r_b)^2}$$

for members except those for circular tubular members, or

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$$F'_e = \frac{\pi^2 E}{1.76(Kl_b/r_b)^2}$$

for circular members.

In the expression for F'_e, as in the case of F_a, F_b, and $0.60S_y$, F'_e may be multiplied by the appropriate stress limit factor from Table NF-3312.1(b)-1 for the particular stress category.

In equations 20 and 21, C_m is a coefficient whose value shall be as given in (-a) through (-c)

(-a) For compression members in frames subject to joint translation (sidesway), C_m = 0.85.

(-b) For rotationally restrained compression members in frames braced against joint translation and not subject to transverse loading between their supports in the plane of bending

$$C_m = 0.6 - 0.4(M_1/M_2)$$

where

M_1/M_2 = the ratio of the smaller to larger moments at the ends of that portion of the member unbraced in the plane of bending under consideration. M_1/M_2 is positive when the member is bent in reverse curvature and negative when it is bent in single curvature.

(-c) For compression members in frames braced against joint translation in the plane of loading and subjected to transverse loading between their supports, the value of C_m may be determined by rational analysis; however, in lieu of such analysis, the following values may be used:

(-1) for members whose ends are restrained against rotation in the plane of bending

$$C_m = 0.85$$

(-2) for members whose ends are unrestrained against rotation in the plane of bending

$$C_m = 1.0$$

(-d) For Level D, the allowable stresses in eqs. (20), (21), and (22) shall be defined as follows:

(-1) $F_a = P/A_g$, where P shall be determined in accordance with (c)

(-2) For all members except for those fabricated of austenitic or duplex stainless steels, the value of F'_e shall be taken as

$$F'_e = \frac{\pi^2 E}{1.30(Kl_b/r_b)^2}$$

For all members fabricated of austenitic or duplex stainless steels, the value of F'_e shall be taken as

$$F'_e = \frac{\pi^2 E}{1.50(Kl_b/r_b)^2}$$

(-3) F_b shall be determined using (2)(-b) or (2)(-c) as appropriate.

(-4) The $0.60S_y$ in eq. (21) shall be replaced with the smaller of $1.2S_y$ or $0.7S_u$.

(2) Axial Tension and Bending. Members subject to both axial tension and bending stresses shall be proportioned at all points along their length to satisfy the requirements of (1), eq. (21), where f_b is the computed bending tensile stress. However, the computed bending compressive stress, taken alone, shall not exceed the applicable value according to (d), "Stress in Bending."

For Level D

(-a) the $0.60S_y$ in (1), eq. (21) may be replaced with the smaller of $1.2S_y$ or $0.7S_u$

(-b) for members qualifying as compact sections under criteria of (d)(1), the maximum bending stress shall be given by

$$F_b = f \times S_y$$

where

f = plastic shape factor for the cross section

(-c) if members do not meet the compact section requirements, they shall be designed using one of the two methods below to determine F_b for use in the preceding equation.

(-1) Allowable values for F_b given in (d)(2) may be increased by a factor of 1.11 (to maintain a nominal factor of safety of 1.5 against instability).

(-2) Rigorous analysis of member stability may be used to determine critical bending stress. A factor of safety of 1.5 shall be used in determining allowable design bending stress.

(3) Shear and Tension. Bolts subject to combined shear and tension shall be proportioned in accordance with the requirements of NF-3324.

(f) Bearing on Contact Area

(1) Milled Surfaces. On contact area of milled surfaces and ends of fitted bearing stiffeners on projected area of pins in reamed, drilled, or bored holes, the maximum bearing stress shall be

$$F_p = 0.90S_y \quad (23)$$

NOTE: When parts in contact have different yield stresses, S_y shall be the smaller value.

(2) Rollers and Rockers. The maximum bearing stress, ksi (MPa), shall be

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$$F_p = \left(\frac{S_y - 13}{20}\right)0.66d \quad (24a)$$

(SI Units)

$$F_p = \left(\frac{S_y - 90}{20}\right)0.66d$$

(3) Bolts. The maximum bearing load on projected area of bolts in bearing connections shall be

$$F_p = 1.5S_u \quad (24b)$$

(4) Concrete Bearing. In the absence of any other Code rules governing bearing stresses on concrete, the maximum bearing stress values shall be as given in (-a) and (-b)

(-a) on the full area of a concrete support

$$F_p = 0.35f'_c \quad (25)$$

(-b) on less than the full area of a concrete support

$$F_p = 0.35f'_c\sqrt{A_2/A_1} \leq 0.7f'_c \quad (26)$$

where

A_1 = bearing area, in.^{2} (mm^2)
A_2 = full cross-sectional area of concrete support, in.^{2} (mm^2)

(5) Pinned or Bolted Joints. For Level C and Level D Service Loadings, the bearing stress for pinned joints or bolted joints shall not exceed $2.1S_u$.

(g) Single Angle Members. Single angle members shall be designed in accordance with Mandatory Appendix NF-II.

(23) **NF-3322.2 Stability and Slenderness and Width–Thickness Ratios.**

(a) General Requirements

(1) General stability shall be provided for the structure as a whole and for each compression element. Design consideration shall be given to significant load effects resulting from the deflected shape of the structure or of individual elements of the lateral load resisting system, including the effects on beams, columns, bracing, connections, and shear walls.

(2) In determining the slenderness ratio of an axially loaded compression member, except as provided in NF-3322.1(c)(3), the length shall be taken as its effective length Kl, and r shall be taken as the corresponding radius of gyration.

(b) Lateral Stability

(1) Braced Frames. In frames [where lateral stability is provided by adequate attachment to diagonal bracing (to shear walls), to an adjacent structure having adequate lateral stability, or to floor slabs (or roof decks) secured horizontally by walls or bracing systems parallel to the plane of the frame] and in trusses, the effective length factor K for the compression members shall be taken as 1.0, unless analysis shows that a smaller value may be used.

(2) Unbraced Frames. In frames where lateral stability is dependent upon the bending stiffness of rigidly connected beams and columns, the effective length Kl of compression members shall be determined by a rational method and shall not be less than the actual unbraced length.

(c) Maximum Slenderness Ratios

(1) The slenderness ratio Kl/r of compression members shall not exceed 200.

(2) The slenderness ratio l/r of tension members, other than rods, preferably should not exceed 240 for main members, and 300 for lateral bracing members and other secondary members.

(d) Width Ratios

(1) Unstiffened Elements Under Compression

(-a) Effective Width. Unstiffened (projecting) compression elements are those having one free edge parallel to the direction of compression stress. The width of unstiffened plates shall be taken from the free edge to the first row of fasteners or welds; the width of legs of angles, channel and zee flanges, and stems of tees shall be taken as the full nominal dimension; the width of flanges of I- and H-shaped members and tees shall be taken as one-half of the full nominal width. The thickness of a sloping flange shall be measured at a section halfway between a free edge and the corresponding face of the web.

(-b) Determination of Effective Width. Unstiffened elements subject to axial compression or compression due to bending shall be considered as fully effective when the width–thickness ratio is not greater than the following, except for those fabricated from austenitic or duplex stainless steels whose effective width meets the provisions of Table NF-3322.2(d)-1:

(-1) for single angle struts and double angle struts with separators, $76/\sqrt{S_y}$ (for SI units, use $200/\sqrt{S_y}$).

(-2) for struts comprising double angles in contact; angles or plates projecting from girders, columns, or other compression members; compression flanges of beams; and stiffeners on plate girders, $95/\sqrt{S_y}$ (for SI units, use $250/\sqrt{S_y}$).

(-3) for stems of tees, $127/\sqrt{S_y}$ (for SI units, use $333/\sqrt{S_y}$).

When the actual width–thickness ratio exceeds these values, the design stress shall be governed by the provisions of (e).

(2) Stiffened Elements Under Compression

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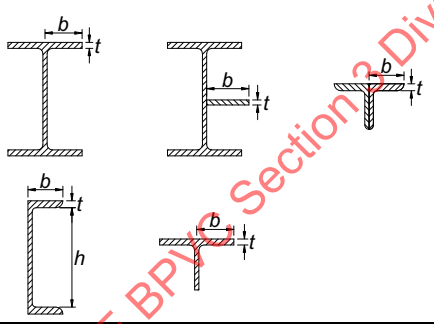
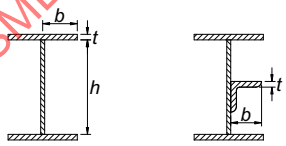
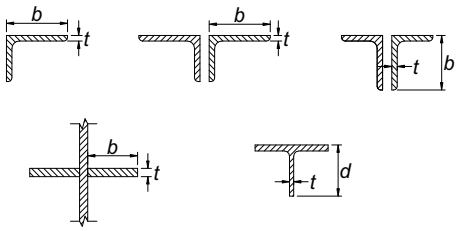
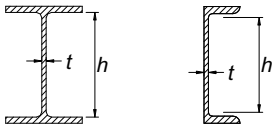
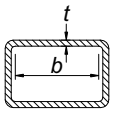
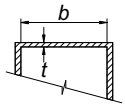
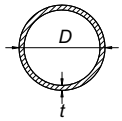
Table NF-3322.2(d)-1
Limiting Width-to-Thickness Ratios for Compression Elements in Members Subject to Axial Compression for Austenitic or Duplex Stainless Steels

(23)

Element Type	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio (nonslender/slender)	Example
Unstiffened elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.47\sqrt{E/S_y}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from builtup I-shaped sections	b/t	$0.47\sqrt{E/S_y}$	
	3	Legs of single angles, legs of double angles with separators, stems of tees and all other unstiffened elements	b/t	$0.38\sqrt{E/S_y}$	
Stiffened elements	4	Webs of doubly symmetric I-shaped sections and channels	h/t	$1.24\sqrt{E/S_y}$	
	5	Walls of rectangular tubular elements and boxes of uniform thickness	b/t	$1.24\sqrt{E/S_y}$	
	6	All other stiffened elements	b/t	$1.24\sqrt{E/S_y}$	
	7	Round tubular elements	D/t	$0.10E/S_y$	

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(-a) Effective Width. Stiffened compression elements are those having lateral support along both edges which are parallel to the direction of the compression stress. The width of such elements shall be taken as following, except for those fabricated from austenitic or duplex stainless steels whose effective width meets the provisions of Table NF-3322.2(d)-1:

(-1) For webs of rolled, built-up, or formed sections, h is the clear distance between flanges.

(-2) For webs of rolled, built-up, or formed sections, d is the full nominal depth.

(-3) For flange or diaphragm plates in built-up sections, the width b is the distance between adjacent lines of fasteners or lines of welds.

(-4) For flanges of rectangular hollow structural sections, the width b is the clear distance between webs less the inside corner radius on each side. If the corner radius is not known, the flat width may be taken as the total section width minus three times the thickness.

(-b) Determination of Effective Width. Stiffened elements subject to axial compression or to uniform compression due to bending, as in the case of the flange of a flexural member [webs of flexural members are covered by the provisions of NF-3322.6(a) and NF-3322.6(e)(2) and are not subject to the provisions of this paragraph], shall be considered as fully effective when the width–thickness ratio is not greater than the following, except for those fabricated from austenitic or duplex stainless steels whose effective width meets the provisions of Table NF-3322.2(d)-1:

(-1) for flanges of square and rectangular box sections of uniform thickness, $238/\sqrt{S_y}$ (for SI units, use $624/\sqrt{S_y}$).

(-2) for unsupported width of cover plates perforated with a succession of access holes, $317/\sqrt{S_y}$ (for SI units, use $831/\sqrt{S_y}$).

NOTE: Assumes net area of plate at widest hole as basis for computing compression stresses.

(-3) for all other uniformly compressed stiffened elements, $253/\sqrt{S_y}$ (for SI units, use $663/\sqrt{S_y}$).

Except in the case of perforated cover plates, when the actual width–thickness ratio exceeds these values, the design stress shall be governed by the provisions of (e).

(-c) Circular Tubular Elements. Circular tubular elements subject to axial compression, except for those fabricated from austenitic or duplex stainless steels whose effective width meets the provisions of Table NF-3322.2(d)-1, shall be considered as fully effective when the ratio of the outside diameter to the wall thickness is not greater than $3{,}300/S_y$ ($22\,700/S_y$). For diameter to thickness ratios greater than $3{,}300/S_y$ ($22\,700/S_y$) but less than $13{,}000/S_y$ ($89\,600/S_y$), the calculated stress shall be governed by the provisions of (e).

(e) Slender Compression Elements

(1) General Requirements. Axially loaded members and flexural members, containing elements subject to compression and having a width–thickness ratio in excess of the applicable limit given in (d)(1) and (d)(2), shall be proportioned to meet the requirements of the following subparagraphs:

(2) Unstiffened Compression Elements. Except as provided herein, stress on unstiffened compression elements, the width–thickness ratio of which exceeds the applicable limit given in (d)(1), shall be subject to a reduction of factor Q_s. The value of Q_s shall be determined by (-a), eq. (27) through (-e), eq. (35), as applicable, where b is the width of the unstiffened element as defined in (d)(1). When such elements comprise the compression flange of a flexural member, the maximum allowable bending stress shall not exceed $0.6S_yQ_s$, nor the applicable value as provided in (5) or (6). The allowable stress of axially loaded compression members shall be modified by the appropriate reduction factor Q_s as provided in (5).

(-a) For single angles, except for those fabricated from austenitic or duplex stainless steels, when

(U.S. Customary Units)

$$76/\sqrt{S_y} < b/t < 155/\sqrt{S_y}$$

(SI Units)

$$200/\sqrt{S_y} < b/t < 400/\sqrt{S_y}$$

then

(U.S. Customary Units)

$$Q_s = 1.340 - 0.00447(b/t)\sqrt{S_y} \qquad (27)$$

(SI Units)

$$Q_s = 1.340 - 0.00171(b/t)\sqrt{S_y}$$

when

(U.S. Customary Units)

$$b/t \geq 155/\sqrt{S_y}$$

(SI Units)

$$b/t \geq 400/\sqrt{S_y}$$

then

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(U.S. Customary Units)

$$Q_s = 15{,}500/\left[S_y(b/t)^2\right] \quad (28)$$

(SI Units)

$$Q_s = 106\,869/\left[S_y(b/t)^2\right]$$

(-b) For angles or plates projecting from columns or other compression members and for projecting elements of compression flanges of girders, except for those fabricated from austenitic or duplex stainless steels, when

(U.S. Customary Units)

$$95/\sqrt{S_y/k_c} < b/t < 195/\sqrt{S_y/k_c}$$

(SI Units)

$$250/\sqrt{S_y/k_c} < b/t < 510/\sqrt{S_y/k_c}$$

then

(U.S. Customary Units)

$$Q_s = 1.293 - 0.00309(b/t)\sqrt{S_y/k_c} \quad (29)$$

(SI Units)

$$Q_s = 1.293 - 0.00118(b/t)\sqrt{S_y/k_c}$$

when

(U.S. Customary Units)

$$b/t > 195/\sqrt{S_y/k_c}$$

(SI Units)

$$b/t > 510/\sqrt{S_y/k_c}$$

then

(U.S. Customary Units)

$$Q_s = 26{,}200\,k_c/\left[S_y(b/t)^2\right] \quad (30)$$

(SI Units)

$$Q_s = 180\,000\,k_c/\left[S_y(b/t)^2\right]$$

$$k_c = \frac{4.05}{(h/t)^{0.46}} \text{ if } \frac{h}{t} > 70, \text{ otherwise } k_c = 1.0.$$

(-c) For stems of tees, when

(U.S. Customary Units)

$$127/\sqrt{S_y} < b/t < 176/\sqrt{S_y}$$

(SI Units)

$$333/\sqrt{S_y} < b/t < 461/\sqrt{S_y}$$

then

(U.S. Customary Units)

$$Q_s = 1.908 - 0.00715\,(b/t)\sqrt{S_y} \quad (31)$$

(SI Units)

$$Q_s = 1.908 - 0.00273\,(b/t)\sqrt{S_y}$$

when

(U.S. Customary Units)

$$b/t \geq 176/\sqrt{S_y}$$

(SI Units)

$$b/t \geq 461/\sqrt{S_y}$$

then

(U.S. Customary Units)

$$Q_s = 20{,}000/\left[S_y(b/t)^2\right] \quad (32)$$

(SI Units)

$$Q_s = 138\,000/\left[S_y(b/t)^2\right]$$

(-d) However, unstiffened elements of channels and tees whose proportions exceed the limits of (d)(1) shall conform to the limits given in Table NF-3322.2(e)(2)-1.

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Table NF-3322.2(e)(2)-1
Limiting Proportions for Channels and Tees

Shape	Ratio of Flange Width to Profile Depth	Ratio of Flange Thickness to Web or Stem Thickness
Built-up or rolled channels	≤0.25	≤3.0
	≤0.50	≤2.0
Built-up tees	≥0.50	≥1.25
Rolled tees	≥0.50	≥1.10

(-e) For flanges, angles and plates projecting from rolled or built-up I-shaped columns or other compression members fabricated from austenitic or duplex stainless steels, when

$$b/t \le 0.47\sqrt{E/S_y}$$

then

$$Q_s = 1.0 \tag{33}$$

when

$$0.47\sqrt{E/S_y} < b/t \le 0.90\sqrt{E/S_y}$$

then

$$Q_s = 1.498 - 1.06\left(b/t\right)\sqrt{S_y/E} \tag{34}$$

when

$$b/t > 0.90\sqrt{E/S_y}$$

then

$$Q_s = \frac{0.44E}{S_y(b/t)^2} \tag{35}$$

(3) Stiffened Compression Elements

(-a) When the width–thickness ratio of uniformly compressed stiffened elements, except for perforated cover plates, exceeds the applicable limit given in (d)(2), a reduced effective width b_e shall be used in computing the flexural design properties of the section containing the element and the permissible axial stress, except that the ratio b_e/t need not be taken as less than the applicable value permitted in (d)(2).

(-1) For the flanges of square and rectangular sections of uniform thickness except for those fabricated from austenitic or duplex stainless steels:

(U.S. Customary Units)

$$b_e = \frac{253t}{\sqrt{f}}\left[1 - \left(\frac{50.3}{(b/t)\sqrt{f}}\right)\right] \le b \tag{36}$$

(SI Units)

$$b_e = \frac{663t}{\sqrt{f}}\left[1 - \left(\frac{132}{(b/t)\sqrt{f}}\right)\right] \le b$$

(-2) For other uniformly compressed elements except for those fabricated from austenitic or duplex stainless steels:

(U.S. Customary Units)

$$b_e = \frac{253t}{\sqrt{f}}\left[1 - \left(\frac{44.3}{(b/t)\sqrt{f}}\right)\right] \le b \tag{37}$$

(SI Units)

$$b_e = \frac{663t}{\sqrt{f}}\left[1 - \left(\frac{116}{(b/t)\sqrt{f}}\right)\right] \le b$$

(-3) For uniformly compressed elements including the flanges of square and rectangular sections fabricated from austenitic or duplex stainless steels with $b/t \ge 1.24\sqrt{E/f}$:

(U.S. Customary Units)

$$b_e = 1.468t\sqrt{E/f}\left[1 - \frac{0.194}{b/t}\sqrt{E/f}\right] \le b \tag{38}$$

(SI Units)

$$b_e = 1.468t\sqrt{E/f}\left[1 - \frac{0.194}{b/t}\sqrt{E/f}\right] \le b$$

where

b = the actual width, in. (mm), of a stiffened compression element as defined in (d)(2)

f = computed compressive stress, ksi (MPa), in the stiffened elements based on the design properties as specified in (4). If unstiffened elements are included in the total cross section for the stiffened element, f must be such that the maximum compressive stress in the unstiffened element does not exceed F_aQ_s or F_bQ_s, as applicable.

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(-b) The allowable stress for axially loaded circular tubular members not meeting the requirements of NF-3322.1(e), but having a diameter-to-thickness ratio of less than $13{,}000/S_y$ (for SI units, use $89\,000/S_y$), shall not exceed either the smaller value determined by NF-3322.1(e) or

(U.S. Customary Units)

$$F_a = \left[\frac{662}{D/t} + 0.4S_y\right]$$

(SI Units)

$$F_a = \left[\frac{4\,560}{D/t} + 0.4S_y\right]$$

(-c) When the allowable stresses are increased for Level C or Level D Service Limits, the effective width b_e shall be determined on the basis of 0.75 times the computed compressive stress, f, caused by Level C or Level D Service Loadings.

(4) Design Properties. Properties of sections shall be determined in accordance with conventional methods, using the full cross section of the member, except as required in (-a) and (-b).

(-a) In computing the moment of inertia and section modulus of flexural members with respect to the axis of bending under consideration, the effective width of stiffened compression elements parallel to the axis of bending and having a width–thickness ratio in excess of the applicable limit given in (d)(2), rather than the actual width, shall be used, and the axis of bending shall be located accordingly, except that for sections otherwise symmetrical, the properties may conservatively and more easily be computed using a corresponding effective area on the tension side of the neutral axis as well. That portion of the area that is neglected in arriving at the effective area shall be located at and symmetrical about the centerline of the stiffened element to which it applies.

(-b) The stress f_a due to axial loading, and the radius of gyration r, shall be computed on the basis of actual cross-sectional area. However, the allowable axial stress F_a, as provided in (5) shall be subject to the form factor

$$Q_a = \frac{\text{effective area}}{\text{actual area}}$$

where the effective area is equal to the actual area less $\sum(b - b_e)t$.

(5) Axially Loaded Compression Members. The allowable stress for axially loaded compression members, except for those fabricated from austenitic or duplex stainless steels containing unstiffened or stiffened elements shall not exceed

$$F_a = \frac{Q_s Q_a\left[1 - \frac{(Kl/r)^2}{2(C'_c)^2}\right]S_y}{\frac{5}{3} + \frac{3(Kl/r)}{8C'_c} - \frac{(Kl/r)^3}{8(C'_c)^3}} \qquad (39)$$

when the largest effective slenderness ratio of any unbraced segment is less than C'_c or the value given by NF-3322.1(c)(1)(-b), eq. (5) when Kl/r exceeds C'_c, where

$$C'_c = \sqrt{\frac{2\pi^2 E}{QS_y}}$$

and

$$Q = Q_s Q_a$$

The allowable stress for axially loaded compression members fabricated from austenitic or duplex stainless steels containing unstiffened or stiffened elements, except for circular tubular members, shall not exceed

$$F_a = \frac{Q_s Q_a\left(0.50^{QS_y/F_e}\right)S_y}{1.67} \qquad (40)$$

where

$$Kl/r \le 3.77\sqrt{E/QS_y}$$

and

$$F_a = \frac{0.531F_e}{1.67} \qquad (41)$$

where

$$Kl/r > 3.77\sqrt{E/QS_y}$$

where

$$Q = Q_s Q_a$$

(-a) Cross sections composed entirely of unstiffened elements

$$Q = Q_s \text{ (i. e., } Q_a = 1.0)$$

(-b) Cross sections composed entirely of stiffened elements

$$Q = Q_a \text{ (i. e., } Q_s = 1.0)$$

The allowable stress for axially loaded compression members fabricated from austenitic or duplex stainless steels containing unstiffened or stiffened elements for circular tubular members, shall not exceed

$$F_a = \frac{Q_s Q_a\left(0.50^{QS_y/F_e}\right)S_y}{1.76} \qquad (42)$$

where

$$Kl/r \le 3.77\sqrt{E/QS_y}$$

and

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$$F_a = \frac{0.531F_e}{1.76} \quad (43)$$

where

$$Kl/r > 3.77\sqrt{E/QS_y}$$

where

$$Q = Q_sQ_a$$

(-c) Cross sections composed of both stiffened and unstiffened elements

$$Q = Q_sQ_a$$

(6) Combined Axial and Flexural Stress. In applying the provisions of NF-3322.1(e) to members subject to combined axial and flexural stress and containing stiffened elements whose width–thickness ratio exceeds the applicable limit given in (d)(2), the stresses F_a, f_{bx}, and f_{by} shall be calculated on the basis of the section properties as provided in (4) and (5), as applicable. The allowable bending stress F_b for members containing unstiffened elements whose width–thickness ratio exceeds the applicable limit given in (d)(1) shall be the smaller value $0.6S_yQ_s$ or that provided in NF-3322.1(d)(5).

NF-3322.3 Plate Girders, Rolled Beams, and Built-Up Members.

(a) Girders and Rolled Beams. Rolled or welded shapes, plate girders, and cover-plated beams shall, in general, be proportioned by the moment of inertia of the gross section. No deduction shall be made for shop or field bolt or rivet holes in either flange provided that

$$0.5S_uA_{fn} \geq 0.6S_yA_{fg} \quad (44a)$$

where A_{fg} is the gross flange area and A_{fn} is the net flange area, calculated in accordance with the provisions of NF-3322.8.

If

$$0.5S_uA_{fn} < 0.6S_yA_{fg} \quad (44b)$$

the member flexural properties shall be based on an effective tension flange area A_{fe}

$$A_{fe} = \frac{5}{6}\frac{S_u}{S_y}A_{fn} \quad (44c)$$

(b) Hybrid Girders. Hybrid girders may be proportioned by the moment of inertia of their gross section, provided that they are not required to resist an axial force greater than $0.15S_y$ times the area of the gross section, where S_y is the yield stress of the flange material. To qualify as hybrid girders, the flanges at any given section shall have the same cross-sectional area and be made of the same grade of steel.

(c) Open Box-Type Beams and Grillages. When two or more rolled beams or channels are used side by side to form a flexural member, they shall be connected together at intervals of not more than 5 ft (1.5 m). Through-bolts and separators may be used, provided that in beams having a depth of 12 in. (300 mm) or more, no fewer than two bolts shall be used at each separator location. When concentrated loads are carried from one beam to the other or distributed between the beams, diaphragms having sufficient stiffness to distribute the load shall be bolted or welded between the beams.

NF-3322.4 Compression Members.

(a) Requirements for Fasteners

(1) Transverse Spacing of Fasteners. All parts of built-up compression members and the transverse spacing of their lines of fasteners shall meet the requirements of NF-3322.2.

(2) End Fasteners. At the ends of built-up compression members bearing on base plates or milled surfaces, all components in contact with one another shall be connected by bolts, spaced longitudinally not more than four diameters apart for a distance equal to $1\frac{1}{2}$ times the maximum width of the member, or by continuous welds having a length not less than the maximum width of the member.

(3) Intermediate Fasteners. The longitudinal spacing for intermediate bolts or intermittent welds in built-up members shall be adequate to provide for the transfer of calculated stress. The maximum longitudinal spacing of bolts or intermittent welds connecting two rolled shapes in contact with one another shall not exceed 24 in. (600 mm). In addition, for painted members and unpainted members not subject to corrosion where the outside component consists of a plate, the maximum longitudinal spacing shall not exceed:

(-a) $127/\sqrt{S_y}$ (for SI units, use $333/\sqrt{S_y}$) times the thickness of the outside plate nor 12 in. (300 mm) when fasteners are not staggered along adjacent gage lines;

(-b) $190/\sqrt{S_y}$ (for SI units, use $500/\sqrt{S_y}$) times the thickness of the outside plate nor 18 in. (450 mm) when fasteners are staggered along adjacent gage lines.

(b) Local Slenderness Ratio. Compression members composed of two or more rolled shapes separated by intermittent fillers shall be connected at these fillers at intervals such that the slenderness ratio Kl/r of either shape, between the fasteners, does not exceed $\frac{3}{4}$ times the governing slenderness ratio of the built-up member. The least radius of gyration r shall be used in computing the slenderness ratio of each component part. At least two intermediate connectors shall be used along the length of the built-up member.

(c) Tie Plates. Open sides of compression members built up from plates or shapes shall be provided with lacing having tie plates at each end and at intermediate points if the lacing is interrupted. Tie plates shall be as near to the ends as practicable. In main members carrying

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calculated stress, the end tie plates shall have a length of not less than the distance between the lines of bolts or welds connecting them to the elements of the member. Intermediate tie plates shall have a length not less than one-half of this distance. The thickness of tie plates shall be not less than one-fiftieth of the distance between the lines of bolts or welds connecting them to the segments of the members. In bolted construction, the spacing in the direction of stress in tie plates shall be not more than six diameters and the tie plates shall be connected to each segment by at least three fasteners. In welded construction, the welding on each line connecting a tie plate shall aggregate not less than one-third of the length of the plate.

(d) Lacing. Lacing, including flat bars, angles, channels, or other shapes employed as lacing, shall be so spaced that the ratio l/r of the flange included between their connections shall not exceed $^3/_4$ times the governing ratio for the member as a whole. Lacing shall be proportioned to resist a shearing stress normal to the axis of the member equal to 2% of the total compressive stress in the member. The ratio l/r for lacing bars arranged in single systems shall not exceed 140. For double lacing this ratio shall not exceed 200. Double lacing bars shall be joined at their intersections. For lacing bars in compression, the unsupported length of the lacing bar shall be taken as the distance between fasteners or welds connecting it to the components of the built-up member for single lacing, and 70% of that distance for double lacing. The inclination of lacing bars to the axis of the member shall preferably be not less than 60 deg for single lacing and 45 deg for double lacing. When the distance between the lines of fasteners or welds in the flanges is more than 15 in. (381 mm), the lacing preferably shall be double or be made of angles.

(e) Perforated Cover Plates. The function of tie plates and lacing may be performed by continuous cover plates perforated with a succession of access holes. The unsupported width of such plates at access holes, as defined in NF-3322.2(d)(2), is assumed to be available to resist axial stress, provided that

(1) the width-thickness ratio conforms to the limitations of NF-3322.2(d)(2)

(2) the ratio of length in direction of stress to width of hole shall not exceed 2

(3) the clear distance between holes in the direction of stress shall be not less than the transverse distance between nearest lines of connection bolts or welds

(4) the periphery of the holes at all points connecting shall have a minimum radius of $1^1/_2$ in. (38 mm)

NF-3322.5 Built-Up Tension Members.

(a) Longitudinal Spacing of Connectors. The longitudinal spacing of connectors between elements in continuous contact consisting of a plate and a shape or two plates shall not exceed

(1) 24 times the thickness of the thinner plate, or 12 in. (300 mm) for painted members or unpainted members not subject to corrosion

(2) 14 times the thickness of the thinner plate, or 7 in. (175 mm) for unpainted members of weathering steel subject to atmospheric corrosion

In a tension member the longitudinal spacing of fasteners and intermittent welds connecting two or more shapes in contact shall not exceed 24 in. (600 mm). Tension members composed of two or more shapes or plates separated by intermittent fillers shall be connected to one another at these fillers at intervals such that the slenderness ratio of either component between the fasteners does not exceed 300.

(b) Perforated Cover and Tie Plates. Either perforated cover plates or tie plates without lacing may be used on the open sides of built-up tension members. Tie plates shall have a length not less than two-thirds the distance between the lines of bolts or welds connecting them to the elements of the member. The thickness of such tie plates shall not be less than one-fiftieth of the distance between these lines. The longitudinal spacing of bolts or intermittent welds at tie plates shall not exceed 6 in. (150 mm). The spacing of tie plates shall be such that the slenderness ratio of any component in the length between tie plates shall not exceed 300.

NF-3322.6 Webs, Flanges, and Stiffeners.

(a) Webs. The ratio of the clear distance between flanges to the web thickness shall not exceed

(U.S. Customary Units)

$$14{,}000/\sqrt{S_y\left(S_y + 16.5\right)} \tag{45}$$

(SI Units)

$$96\,500/\sqrt{S_y\left(S_y + 114\right)}$$

except that when transverse stiffeners are provided, spaced not more than $1^1/_2$ times the girder depth, the limiting ratio may be $2{,}000/\sqrt{S_y}$ (for SI units, use $5\,300/\sqrt{S_y}$), where S_y is the yield stress of the compression flange.

(1) Combined Shear and Tension Stress. Plate girder webs which depend upon tension field action, as provided in (e)(2), eq.(54), shall be so proportioned that bending tensile stress due to moment in the plane of the girder web shall not exceed $0.6S_y$, or

$$\left(0.825 - 0.375\frac{f_v}{F_v}\right)S_y \tag{46}$$

where

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F_v = allowable web shear stress, ksi (MPa), according to (e)(2), eq. (54)

The allowable shear stress in the webs of girders having flanges and webs with yield values greater than 65 ksi (450 MPa) shall not exceed the values given by (e)(2), eq. (53) if the flexural stress in the flange f_b exceeds $0.75F_b$.

(2) Web Crippling

(-a) Local Web Yielding. Webs of beams and welded plate girders shall be so proportioned that the compressive stress at the web toe of the fillets, resulting from concentrated loads not supported by bearing stiffeners, shall not exceed the value of $0.66S_y$; otherwise, bearing stiffeners shall be provided. The governing equations shall be

(-1) for interior loads

$$\frac{R}{t(N + 5k)} \leq 0.66S_y \tag{47}$$

(-2) for end reactions

$$\frac{R}{t(N + 2.5k)} \leq 0.66S_y \tag{48}$$

where N is greater than or equal to k for end reactions.

(-b) Stress on Compression Edge of Web Plate. Bearing stiffeners shall be provided in the webs of members under concentrated loads, when the compressive force exceeds the following limits:

when the concentrated load is applied at a distance not less than $d/2$ from the end of the member

(U.S. Customary Units)

$$R = 67.5t_w^2\left[1 + 3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{S_y t_f/t_w} \tag{49}$$

(SI Units)

$$R = 177t_w^2\left[1 + 3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{S_y t_f/t_w}$$

when the concentrated load is applied less than a distance $d/2$ from the end of the member

(U.S. Customary Units)

$$R = 34t_w^2\left[1 + 3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{S_y t_f/t_w} \tag{50}$$

(SI Units)

$$R = 89t_w^2\left[1 + 3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{S_y t_f/t_w}$$

where

d = overall depth of the member, in. (mm)
S_y = specified minimum yield stress of beam web, ksi (MPa)
t_f = flange thickness, in. (mm)
t_w = web thickness, in. (mm)

If stiffeners are provided and extend at least one-half the web depth, eqs. (49) and (50) need not be checked.

Bearing stiffeners shall be provided in the webs of members with flanges not restrained against relative movement by stiffeners or lateral bracing and subject to concentrated compressive loads, when the compressive force exceeds the following limits:

If the loaded flange is restrained against rotation and $(d_c/t_w)/(l/b_f)$ is less than 2.3

(U.S. Customary Units)

$$R = \frac{6{,}800t_w^3}{h}\left[1 + 0.4\left(\frac{d_c/t_w}{l/b_f}\right)^3\right] \tag{50a}$$

(SI Units)

$$R = \frac{4646\,882t_w^3}{h}\left[1 + 0.4\left(\frac{d_c/t_w}{l/b_f}\right)^3\right]$$

If the loaded flange is not restrained against rotation and $(d_c/t_w)/(l/b_f)$ is less than 1.7

(U.S. Customary Units)

$$R = \frac{6{,}800t_w^3}{h}\left[0.4\left(\frac{d_c/t_w}{l/b_f}\right)^3\right] \tag{50b}$$

(SI Units)

$$R = \frac{46\,882t_w^3}{h}\left[0.4\left(\frac{d_c/t_w}{l/b_f}\right)^3\right]$$

where

b_f = flange width, in. (mm)
d_c = web depth clear of fillets, in. (mm)
= $d - 2k$

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l = largest laterally unbraced length along either flange at the point of load, in. (mm)

Equations (50a) and (50b) need not be checked providing $(d_c/t_w)/(l/b_f)$ exceeds 2.3 or 1.7, respectively, or for webs subject to uniformly distributed load.

(b) Flanges

(1) The thickness of outstanding parts of flanges shall conform to the requirements of NF-3322.2(d)(1).

(2) Flanges of welded plate girders may be varied in thickness or width by splicing a series of plates or by the use of cover plates.

(3) The total cross-sectional area of cover plates of bolted girders shall not exceed 70% of the total flange area.

(c) Flange Development

(1) High-strength bolts or welds connecting flange to web or cover plate to flange shall be proportioned to resist the total horizontal shear resulting from the bending forces on the girder. The longitudinal distribution of these bolts or intermittent welds shall be in proportion to the intensity of the shear, but the longitudinal spacing shall not exceed the maximum permitted, respectively, for compression or tension members in NF-3322.4(a)(3) or NF-3322.5(a). Additionally, bolts or welds connecting flange to web shall be proportioned so as to transmit to the web any loads applied directly to the flange unless provision is made to transmit such loads by direct bearing.

(2) Partial length cover plates shall be extended beyond the theoretical cut-off point and the extended portion shall be attached to the beam or girder by high-strength bolts for friction-type joints or fillet welds adequate at the applicable stresses allowed in NF-3324.6(a), NF-3324.5(d), or NF-3332.4, to develop the cover plate portion of the flexural stresses in the beam or girder at the theoretical cut-off point. In addition, for welded cover plates, the welds connecting the cover plate termination to the beam or girder in the length a', defined in (-a) through (-c), shall be adequate at the allowed stresses to develop the cover plate portion of the flexural stresses in the beam or girder at the distance a' from the end of the cover plate. The length a' measured from the end of the cover plate, shall be

(-a) a distance equal to the width of the coverplate when there is a continuous weld equal to or larger than three-fourths of the plate thickness across the end of the plate and continuous welds along both edges of the cover plate in the length a'

(-b) a distance equal to $1\frac{1}{2}$ times the width of the cover plate when there is a continuous weld smaller than three-fourths of the plate thickness across the end of the plate and continuous welds along both edges of the cover plate in the length a'

(-c) a distance equal to two times the width of the cover plate when there is no weld across the end of the plate, but continuous welds along both edges of the cover plate in the length a'

(d) Reduction in Flange Stress. When the web depth–thickness ratio exceeds $760/\sqrt{F_b}$ (for SI units, use $2000/\sqrt{F_b}$), the maximum stress in the compression flange shall not exceed

(U.S. Customary Units)

$$F'_b \le F_b\left[1.0 - 0.0005\frac{A_w}{A_f}\left(\frac{h}{t} - \frac{760}{\sqrt{F_b}}\right)\right] \quad (51)$$

(SI Units)

$$F'_b \le F_b\left[1.0 - 0.0005\frac{A_w}{A_f}\left(\frac{h}{t} - \frac{2000}{\sqrt{F_b}}\right)\right]$$

where F_b is the applicable bending stress, ksi (MPa), given in NF-3322.1(d). The maximum stress in either flange of a hybrid girder shall not exceed the value given in eq. (51) or

$$F'_b \le F_b\left[\frac{12 + \left(A_w/A_f\right)\left(3\alpha - \alpha^3\right)}{12 + 2\left(A_w/A_f\right)}\right] \quad (52)$$

(e) Stiffeners

(1) Bearing. Bearing stiffeners shall be placed in pairs at unframed ends on the webs of plate girders and, where required by (a)(2), at points of concentrated loads. Such stiffeners, when the load normal to the flange is tensile, shall be welded to the loaded flange and when the load normal to the flange is compressive may be welded or bear on the loaded flange. They shall be designed as columns subject to the provisions of NF-3322.1, assuming the column section to comprise the pair of stiffeners and a centrally located strip of the web whose width is equal to not more than 25 times its thickness at interior stiffeners, or a width equal to not more than 12 times its thickness when the stiffeners are located at the end of the web. The effective length shall be taken as not less than three-fourths of the length of the stiffeners in computing the ratio l/r. Only that portion of the stiffener outside of the flange angle fillet or the flange to web welds shall be considered effective in bearing.

(2) Average Web Shear. Except as provided herein, the largest average web shear f_v, ksi (MPa), computed for any condition of complete or partial loading, shall not exceed the value given by eq. (53)

$$F_v = \left(S_y/2.89\right) C_v \le 0.4S_y \quad (53)$$

where, when C_v is less than 0.8,

(U.S. Customary Units)

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$$C_v = \frac{45{,}000k}{S_y\left(\frac{h}{t}\right)^2}$$

(SI Units)

$$C_v = \frac{310{,}000k}{S_y\left(\frac{h}{t}\right)^2}$$

when C_v is greater than 0.8,

(U.S. Customary Units)

$$C_v = \left(\frac{190}{\frac{h}{t}}\right)\sqrt{\frac{k}{S_y}}$$

(SI Units)

$$C_v = \left(\frac{500}{\frac{h}{t}}\right)\sqrt{\frac{k}{S_y}}$$

where

k = 4.00 + [5.34/$(a/h)^2$], when a/h is less than 1.0
= 5.34 + [4.00/$(a/h)^2$], when a/h is more than 1.0

Alternatively, for girders other than hybrid girders and tapered members, if intermediate stiffeners are provided and spaced to satisfy the provisions of (3) and if $C_v \le 1$, the allowable shear given by eq. (54) may be used in lieu of the value given in eq. (55).

$$F_v = \frac{S_y}{2.89}\left[C_v + \frac{1 - C_v}{1.15\sqrt{1 + (a/h)^2}}\right] \le 0.4S_y \qquad (54)$$

NOTE: Equation (54) recognizes the contribution of tension field action.

(3) Intermediate Stiffeners

(-a) Subject to the limitations of (a), intermediate stiffeners are not required when the ratio h/t is less than 260 and the maximum web shear stress f_v is less than that permitted for F_v by (2), eq. (53).

(-b) The spacing of intermediate stiffeners, when stiffeners are required, shall be such that the web shear stress will not exceed the value for F_v given by (2), eq. (53) or eq. (54), as applicable, and the ratio a/h shall not exceed [260/(h/t)]^2 or 3.

(-c) In girders designed on the basis of tension field action, the spacing between stiffeners at end panels, at panels containing large holes, and at panels adjacent to panels containing large holes shall be such that f_v does not exceed the value for F_v given by (2), eq. (53).

(4) Moment of Inertia and Gross Area

(-a) The moment of inertia, in.^{4} (mm^4), of a pair of intermediate stiffeners or a single intermediate stiffener, with reference to an axis in the plane of the web, shall not be less than $(h/50)^4$.

(-b) The gross area, in.^{2} (mm^2), of intermediate stiffeners spaced as required for (2), eq. (54) (total area, when stiffeners are furnished in pairs), shall be not less than that computed by eq. (55)

$$A_{st} = \frac{1 - C_v}{2}\left[\frac{a}{h} - \frac{(a/h)^2}{\sqrt{1 + (a/h)^2}}\right]YDht \qquad (55)$$

where

D = 1.0 for stiffeners furnished in pairs
= 1.8 for single angle stiffeners
= 2.4 for single plate stiffeners

(-c) When the greatest shear stress f_v in a panel is less than that permitted by (2), eq. (54), this gross area requirement may be reduced proportionately.

(-d) Intermediate stiffeners required by (2), eq. (54) shall be connected for a total shear transfer, kips/linear in. (N/linear mm) of single stiffener or pair of stiffeners, not less than that computed by eq. (56)

(U.S. Customary Units)

$$f_{vs} = h\left(\frac{S_y}{340}\right)^{3/2} \qquad (56)$$

(SI Units)

$$f_{vs} = h\left(\frac{S_y}{647}\right)^{3/2}$$

This shear transfer may be reduced in the same proportion that the largest computed shear stress f_v in the adjacent panels is less than that permitted by (2), eq. (54). However, bolts and welds in intermediate stiffeners which are required to transmit to the web an applied concentrated load or reaction shall be proportioned for not less than the applied load or reaction.

(-e) Intermediate stiffness may be stopped short of the tension flange, provided bracing is not needed to transmit a concentrated load or reaction; the weld by which intermediate stiffeners are attached to the web shall be terminated not closer than four times nor more than six times the web thickness from the near toe of the web to flange welds. When single stiffeners are used, they shall be attached to the compression flange, if it consists of a rectangular plate, to resist any uplift tendency due to torsion in the plate. When lateral bracing is attached to a stiffener or a pair of stiffeners, these, in turn, shall be connected to the compression flange to transmit 1% of the total flange stress, unless the flange is composed only of angles.

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(-f) Bolts connecting stiffeners to the girder web shall be spaced not more than 12 in. (300 mm) on center. If intermittent fillet welds are used, the clear distance between welds shall not be more than 16 times the web thickness, or more than 10 in. (250 mm).

(f) Splices. Groove welded splices in the plate girders and beams shall develop the full strength of the smaller spliced section; other types of splices in cross sections of plate girders and in beams shall develop the strength required by the stresses at the point of splice.

(g) Rotational Restraint at Points of Support. Beams, girders, and trusses shall be restrained against rotation about their longitudinal axis at points of support.

NF-3322.7 Simple and Continuous Spans, and Provision for Expansion.

(a) Design Requirements for Spans

(1) Simple Spans. Beams, girders, and trusses shall ordinarily be designed on the basis of simple spans whose effective length is equal to the distance between centers of gravity of the members to which they deliver their end reactions.

(2) Continuous Spans. When designed on the assumption of full or partial end restraint, due to continuous, semi-continuous, or cantilever action, the beams, girders, and trusses, as well as the sections of the members to which they connect, shall be designed to carry the shears and moments so introduced, as well as all other forces, without exceeding at any point the unit stresses prescribed in NF-3321.1, except that some nonelastic but self-limiting deformation of a part of the connection may be permitted when this is essential to the avoidance of overstressing of fasteners.

(3) Provision for Expansion. Adequate provision shall be made for expansion and contraction appropriate to the function of the support structure.

NF-3322.8 Gross and Net Areas.

(a) Determination of Gross and Net Areas. The gross area 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 area shall be determined by substituting the net width, computed in accordance with (c), for the gross width.

(b) Net Area and Effective Net Area. Unless otherwise specified, tension members shall be designed on the basis of net area. Compression members shall be designed on the basis of gross area. Beams and girders shall be designed in accordance with NF-3322.3(a). The effective net area of threaded members shall be the tensile stress area, with the exception that threaded hanger rods shall comply with NF-3412.3.

(c) Calculation of Net Area

(1) Parts With Holes

(-a) In the case of a chain of holes extending across a part in any diagonal or zigzag line, the net width of the part shall be obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding, for each gage space in the chain, the quantity $s^2/4g$.

(-b) The critical net area A_n of the part is obtained from that chain which gives the least net width.

(-c) In determining the net area across plug or slot welds, the weld metal shall not be considered as adding to the net area.

(-d) The effective net area A_e of axially loaded tension members, where the load is transmitted by bolts through some but not all of the cross-sectional elements of the member, shall be computed from the following equation:

$$A_e = C_t A_n$$

Unless a larger coefficient can be justified by tests or other recognized criteria, the following values of C_t shall be used in computations:

(-1) W, M, or S shapes with flange widths not less than two-thirds of the depth, and structural tees cut from these shapes, provided the connection is to the flanges and has no fewer than three fasteners per line in the direction of applied stress

$$C_t = 0.90$$

(-2) W, M, or S shapes not meeting the conditions of (-1), structural tees cut from these shapes, and all other shapes, including built-up cross sections, provided the connection has not less than three fasteners per line in the direction of applied stress

$$C_t = 0.85$$

(-3) all members whose connections have only two fasteners per line in the direction of applied stress

$$C_t = 0.75$$

When the load is transmitted by welds through some but not all of the cross-sectional elements of the member, the effective net area A_e shall be computed as

$$A_e = U A_g$$

where

A_g = gross area of member, in.^{2} (mm^2)

When load is transmitted by transverse welds to some but not all of the cross-sectional elements of W, M, or S shapes and structural tees cut from these shapes, A_e shall be taken as the area of the directly connected elements.

When the load is transmitted to a plate by longitudinal welds along both edges at the end of the plate, the length of the welds shall not be less than the width of the plate. The effective net area A_e shall be computed as above.

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Unless a larger coefficient can be justified by tests or other criteria, the following values of U shall be used: when $l > 2w$, $U = 1.0$; when $2w > l > 1.5w$, $U = 0.87$; when $1.5w > l > w$, $U = 0.75$

where

l = weld length, in. (mm)
w = plate width (distance between welds), in. (mm)

(-e) Bolted splice and gusset plates, and other connection fittings subject to tensile force shall be designed in accordance with the provisions of NF-3322.1(a) where the effective net area shall be taken as the actual net area, except that for the purpose of design calculations it shall not be taken as greater than 85% of the gross area.

(2) Size of Bolt Holes. In computing net area, the diameter of a bolt hole shall be taken as $^1/_{16}$ in. (1.5 mm) greater than the nominal dimension of the hole normal to the direction of applied stress.

(3) Angles. For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of angles less the thickness.

(4) Pin-Connected Members

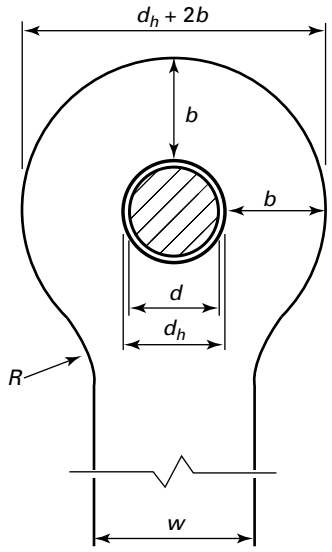
(-a) The available tensile strength of eyebars, as shown in Figure NF-3322.8-1, shall be determined in accordance with NF-3322.1(a), with the gross area taken as the cross-sectional area of the body. For calculation purposes, the width of the body of the eyebars shall not exceed 8 times its thickness. Eyebars shall be of uniform thickness, without reinforcement at the pin holes, and have circular heads with the periphery concentric with the pin hole. The radius of transition between the circular head and the eyebar body shall not be less than the head diameter. The pin diameter shall be not less than $^7/_8$ times the eyebar body width, and the pin hole diameter shall be not more than $^1/_{32}$ in. (0.8 mm) greater than the pin diameter. For steels having specified minimum yield stress greater than 70.0 ksi (485 MPa), the hole diameter shall not exceed 5 times the plate thickness, and the width of the eyebar body shall be reduced accordingly. A thickness of less than $^1/_2$ in. (13 mm) is permissible only if external nuts are provided to tighten pin plates and filler plates into snug contact. The width from the hole edge to the plate edge perpendicular to the direction of applied load shall be greater than two-thirds and, for the purpose of calculation, not more than $^3/_4$ times the eyebar body width.

NOTE: Members having a different thickness at the pinhole location are termed built-up.

(-b) In pin-connected plates other than eyebars, as shown in Figure NF-3322.8-2 , the tensile stress on the net effective area and on the gross section shall be determined in accordance with NF-3322.1(a). The shear stress on the minimum net area beyond the pinhole shall not exceed the stress allowed in NF-3322.1(b). The bearing stress on the projected area of the pin shall not exceed the stress allowed in NF-3322.1(f)(1).

(-c) The distance used in calculations, transverse to the axis of pin-connected plates other than eyebars or any individual element of a built-up member, from the edge of the pinhole to the edge of the member or element shall not exceed 2 times the thickness of the plate plus $^5/_8$ in. (16 mm), but not more than the actual distance from the edge of the pinhole to the edge of the part measured in the direction normal to the applied force. Members having a different thickness at the pinhole location are termed "built-up." The effective net area in tension is 2 times the thickness of the member times the calculated distance transverse to the axis of the member from the edge of the pinhole to the edge of the member. The effective net area in shear is 2 times the thickness of the member times the shortest distance from the center of the pin to the edge of the member measured parallel to the direction of the force.

Figure NF-3322.8-1
Dimensional Requirements for Eyebars



GENERAL NOTE: Dimensional requirements for eyebars are as follows:

$b \geq {}^2/_3 w$ but $\leq {}^3/_4 w$ (upper limit is for calculation purposes only)
$d \geq {}^7/_8 w$
$d_h \leq d + {}^1/_{32}$ in. (d + 0.8 mm), and if $S_y >$ 70.0 ksi (485 MPa), then $d_h \leq 5t$
$R \geq d_h + 2b$
$t \geq {}^1/_2$ in. (13 mm) [Exception is provided in NF-3322.8(c)(4)(-a).]
$w \leq 8t$ (for calculation purposes only)

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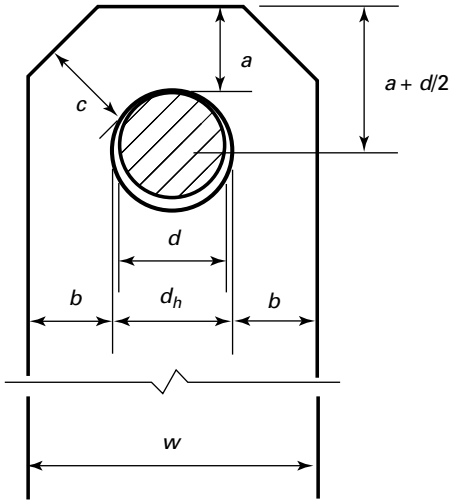
(23) **Figure NF-3322.8-2**
Dimensional Requirements for Pin-Connected Plates



GENERAL NOTE: Dimensional requirements for pin-connected plates are as follows:

$a \geq 1.33b_e$, where $b_e = 2t + \frac{5}{8}$ in. $(2t + 16$ mm$) \leq b$
$c \geq a$
$d_h \leq d + \frac{1}{32}$ in. $(d + 0.8$ mm$)$
$w \geq 2b_e + d$

(-d) In pin-connected plates other than eyebars, the pinhole shall be located midway between the edges of the member in the direction normal to the applied force. When the pin is expected to provide for relative movement between connected parts while under full load, the diameter of the pinhole shall be not more than $\frac{1}{32}$ in. (0.8 mm) greater than the diameter of the pin. The width of the plate at the pinhole, transverse to the axis of the member, and the minimum extension beyond the bearing end of the pinhole, parallel to the axis of the member, shall not be less than that defined in Figure NF-3322.8-2. The corners beyond the pinhole may be cut at 45 deg to the axis of the member, provided the net area beyond the pinhole, on a plane perpendicular to the cut, is not less than that required beyond the pinhole parallel to the axis of the member.

NF-3322.9 Rectangular Tubular Sections. For electric resistance welded rectangular tubular sections, the designer shall use a wall thickness of 0.93 times the nominal wall thickness for calculating section properties.

NF-3323 Design Requirements for Steel Castings and Forgings

NF-3323.1 Allowable Stresses. Allowable stresses for steel castings and forgings shall be the same as those provided in NF-3322 with the applicable values for yield strength of Section II, Part D, Subpart 1, Table Y-1.

NF-3324 Design Requirements for Connections and Joints

NF-3324.1 General Requirements.

(a) Types of Connections Permitted. Structural Connections of a welded, bolted, or welded and bolted type shall be used.

Types of bolted connections include

(1) Friction-type connections that are mechanically fastened structural connections that use high-strength bolts (such as SA-325 and SA-490) and are sufficiently tightened to reliably produce a high clamping force that prevents slip between faying surfaces. Load is transferred at the faying surfaces by friction [see Figure NF-3324.1(a)(1)].

(2) Bearing-type connections that are mechanically fastened structural connections that depend on direct shear of the fastener to transfer the load from one connected part to another.

(3) Other connections that are not covered by (1) and (2), such as clamps and U-bolts shown in Figure NF-1214-1, are not friction-type connections and shall meet the requirements of NF-3380, unless otherwise indicated in the design documents.

(b) Provision for Eccentric Connections. Axially stressed members meeting at a point shall have their gravity axes intersect at a point if practicable; if not, provision shall be made for bending stresses due to the eccentricity.

(c) Placement of Bolts and Welds. Except as otherwise provided, groups of bolts or welds at the ends of any member transmitting axial stress into that member shall have their centers of gravity on the gravity axis of the member, unless provision is made for the effect of the resulting eccentricity. Except in members subject to repeated variation in stress, as stipulated in NF-3330, disposition of fillet welds to balance the forces about the neutral axes for end connections of single angle, double angle, and similar type members is not required. Eccentricity between the gravity axes of such members and the gage lines for their bolted end connections may be neglected in statically loaded members, but should be considered in members subjected to fatigue loading.

NF-3324.2 Connection Design.

(a) Connections for Unrestrained Members

(1) Except as otherwise indicated by the design documents, connections of beams, girders, or trusses shall be designed as flexible and may ordinarily be proportioned for the reaction shears only.

(2) Flexible beam connections shall accommodate end rotations of unrestrained (simple) beams. To accomplish this, inelastic action in the connection is permitted.

(b) Connections for Restrained Members

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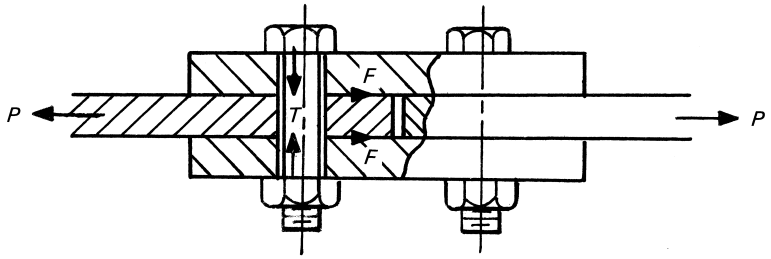
Figure NF-3324.1(a)(1)
Typical Friction-Type Connections Using High-Strength Bolts



Legend:
F = friction force
P = applied load
T = clamping force

(1) Fasteners or welds for end connections of beams, girders, and trusses shall be designed for the combined effect of forces resulting from moment and shear induced by the rigidity of the connections.

(2) When flanges or moment connection plates for end connections of beams and girders are welded to the flange of an I- or H-shaped column, a pair of column web stiffeners having a combined cross-sectional area A_{st} not less than that computed from eq. (57) shall be provided whenever the calculated value of A_{st} is positive

$$A_{st} = \frac{P_{bf} - F_{yc}t(t_b + 5k)}{F_{yst}} \quad (57)$$

(3) Notwithstanding the requirements of (2), a stiffener or a pair of stiffeners shall be provided opposite the compression flange when the column web depth clear of fillets d_c is greater than

(U.S. Customary Units)

$$\frac{4{,}100t^3 \times \sqrt{F_{yc}}}{P_{bf}}$$

(SI Units)

$$\frac{10\,765t^3 \times \sqrt{F_{yc}}}{P_{bf}}$$

and a pair of stiffeners shall be provided opposite the tension flange when the thickness of the column flange t_f is less than

$$0.4\sqrt{\left(P_{bf}/F_{yc}\right)}$$

(4) Stiffeners required by the provisions of (2) and (3) shall comply with the following criteria:

(-a) The width of each stiffener plus one-half the thickness of the column web shall not be less than one-third the width of the flange or moment connection plate delivering the concentrated force.

(-b) The thickness of stiffeners shall not be less than $t_b/2$.

(-c) When the concentrated force delivered occurs on only one column flange, the stiffener length need not exceed one-half the column depth.

(-d) The weld joining stiffeners to the column web shall be sized to carry the force in the stiffener caused by unbalanced moments on opposite sides of the column.

(5) The thickness of column webs within the boundaries of rigid connections of two or more members whose webs lie in a common plane shall not be less than

(U.S. Customary Units)

$$t_{\min} = \frac{32M}{d_b \cdot d_c \cdot S_y}$$

(SI Units)

$$t_{\min} = \frac{2\,666M}{d_b \cdot d_c \cdot S_y}$$

where

d_b = the beam depth, in. (mm)
d_c = the column depth, in. (mm)
M = the algebraic sum of clockwise and counterclockwise moments, kip-ft (N·mm), applied on opposite sides of the connection boundary
$t_{\min}$ = the web thickness, in. (mm)

When the web thickness is less than $t_{\min}$ doubler plates or longitudinal stiffeners may be provided to reinforce the column web.

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(c) Connections of Tension and Compression Members in Trusses. The connections at ends of the tension or compression member in trusses shall develop the force due to the Design Load but not less than 50% of the effective strength of the member, based upon the kind of stress that governs the selection of the member.

(d) Connections for Compression Members With Bearing Joints

(1) For members subjected to compression forces only, which bear on bearing plates, sufficient bolts or welds shall be provided to hold all parts securely in place.

(2) For members subjected to compression forces only, which are finished to bear at splices, the splice material and its bolting or welding shall be arranged to hold all parts in line and shall be proportioned for 50% of the computed stress.

(3) All of the foregoing joints shall be proportioned to resist any tension that would be developed by design moments acting in conjunction with 75% of the axial compression forces.

NF-3324.3 Design of Lap Joints and Fillers.

(a) Lap Joint Design. The minimum amount of lap on lap joints shall be five times the thickness of the thinner part joined but not less than 1 in. (25 mm). Lap joints subjected to axial stress shall be fillet welded along the end of both lapped parts, except where the deflection of the lapped parts is sufficiently restrained to prevent opening of the joint under maximum loading.

(b) Filler Design

(1) Bolted Construction. When bolts carrying computed stress pass through fillers thicker than $\frac{1}{4}$ in. (6 mm), except in friction-type connections assembled with high-strength bolts, the fillers shall be extended beyond the splice material and the filler extension shall be secured by enough bolts to distribute the total stress in the member uniformly over the combined section of the member and the filler or an equivalent number of fasteners shall be included in the connection. Fillers between $\frac{1}{4}$ in. (6 mm) and $\frac{3}{4}$ in. (19 mm) thick, inclusive, need not be extended and developed, provided the allowable shear stress in the bolts is reduced by the factor, 0.4 (t – 0.25) [for SI units, use 0.016 (t – 6)], where t is the total thickness of the fillers, up to $\frac{3}{4}$ in. (19 mm).

(2) Welded Construction. In welded construction, any filler $\frac{1}{4}$ in. (6 mm) or more in thickness shall extend beyond the edges of the splice plate and shall be welded to the part on which it is fitted with sufficient weld to transmit the splice plate stress, applied at the surface of the filler as an eccentric load. The welds joining the splice plate to the filler shall be sufficient to transmit the splice plate stress and shall be long enough to avoid overstressing the filler along the toe of the weld. Any filler less than $\frac{1}{4}$ in. (6 mm) thick shall have its edges made flush with the edges of the splice plate, and the weld size shall be the sum of the size necessary to carry the splice plate stress plus the thickness of the filler plate.

NF-3324.4 Joint Combinations.

(a) Combinations of Welds. If two or more of the general types of weld (groove, fillet, plug, or slot) are combined in a single joint, the effective capacity of each shall be separately computed with reference to the axis of the group, in order to determine the allowable capacity of the combination.

(b) Bolts in Combination With Welds. SA-307 bolts or high-strength bolts used in bearing-type connections shall not be considered as sharing the stress in combination with welds. Welds, if used, shall be provided to carry the entire stress in the connection. High-strength bolts installed as a friction-type connection prior to welding may be considered as sharing the stress with the welds.

NF-3324.5 Design of Welded Joints.

(a) Permissible Types of Welded Joints in Linear Supports. All welded joints in Linear Supports shall be as described in NF-3256.1 except that intermittent or lap joints using fillet welds may not be used for the support of Class 1 Components or Class 2 vessels designed to NCD-3200. The allowable stress limits shall be as defined in (b) and (c).

(b) Design Limits. The allowable stress limits that must be satisfied for welds for Design Loadings stated in the Design Specification shall be as follows:

(1) Full Penetration Groove Welds. The stress limits for full penetration groove welds shall not exceed the applicable stress value for the base metal being joined, as specified in NF-3321.1 and Table NF-3324.5(a)-1.

(2) Partial Penetration Groove Welds

(-a) Compression Normal to Effective Throat. The stress limits shall be the same as those for the base metal, as required by NF-3321.1.

(-b) Tension Normal to the Axis on the Effective Throat or Shear on the Effective Throat. The stress limits shall be as specified in Table NF-3324.5(a)-1.

(3) Fillet Welds. The allowable stress limits for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(c) Service Limits, Level A Through D, and Test. The rules and stress limits which must be satisfied for welds for any Level A through D Service and Test Loading stated in the Design Specification are those given in (b) multiplied by the appropriate base material stress limit factor given in Table NF-3312.1(b)-1.

(d) Fillet Welds

(1) Minimum Size of Fillet Welds and Partial Penetration Welds. Fillet and partial penetration welds shall not be specified less than $\frac{1}{8}$ in. (3 mm) (NF-4427). When fillet or partial penetration welds less than $\frac{1}{4}$ in. (6 mm) are used to join heavy section members, the designer shall consider specifying preheat and special requirements for fit-up of members to ensure adequate weld deposition.

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Table NF-3324.5(a)-1
Allowable Stress Limits for Class 1 Linear-Type Support Welds

Kind of Stress	Base Metal TS Range, ksi (MPa)	Weld Metal Min. TS, ksi (MPa) [Note (1)]	Stress Limits, ksi (MPa)
Tension and compression parallel to axis of any full penetration groove weld	...	...	Same as for base metal
Tension normal to effective throat of full penetration groove weld	...	...	Same as allowable tensile stress for base metal
Compression normal to effective throat of full penetration groove weld and partial penetration groove weld	...	...	Same as allowable compressive stress for base metal
Shear stress on effective throat of fillet weld, regardless of direction of application of load; tension normal to the axis on the effective throat of a partial penetration groove weld; shear on the partial or full penetration groove weld effective throat; and shear stress on effective area of a plug or slot weld. The given stresses shall also apply to such welds made with the specified electrode on steel having a yield stress greater than that of the matching base metal.	45–60 (310–410) 61–70 (411–480) 71–80 (481–550) 81–90 (551–620) 91–100 (621–690) 101–120 (691–830)	60 (410) 70 (480) 80 (550) 90 (620) 100 (690) 120 (830)	0.30 × minimum tensile strength of weld metal [ksi (MPa)], except shear stress on base metal shall not exceed 0.40 × yield stress of base metal

NOTE: (1) Weld metal one nominal strength level stronger than shown will be permitted (e.g., E70xx for E60xx applications).

(2) Maximum Effective Size of Fillet Welds. The maximum size of a fillet weld that may be assumed in the design of a connection shall be such that the stresses in the adjacent base material do not exceed the values allowed in Tables NF-3324.5(a)-1 and NF-3321.1. The maximum size that may be used along edges of connected parts shall be as stipulated in (-a) and (-b)

(-a) along edges of material less than $\frac{1}{4}$ in. (6 mm) thick, the maximum size may be equal to the thickness of the material

(-b) along edges of material $\frac{1}{4}$ in. (6 mm) or more in thickness, the maximum size shall be $\frac{1}{16}$ in. (1.5 mm) less than the thickness of the material, unless the weld is especially designated on the drawings to be built up to obtain full throat thickness

(3) Length of Fillet Welds

(-a) The effective length of a fillet weld shall be the overall length of a full-size fillet, including returns.

(-b) The minimum effective length of a strength fillet weld shall be not less than four times the nominal size, or else the size of the weld shall be considered not to exceed one-fourth of its effective length.

(-c) If longitudinal fillet welds are used alone in end connections of tension members, the length of each fillet weld shall be not less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 8 in. (200 mm), unless the design otherwise prevents excessive transverse bending in the connection.

(4) Effective Throat Thickness of Fillet Welds. The effective throat thickness of a fillet weld joining members at angles between 60 deg and 135 deg, inclusive (see Figure NF-4427-1), shall be the shortest distance from the root to the face of the diagrammatic weld, except that for fillet welds made by the submerged arc process the effective throat thickness shall be taken equal to the leg size for $\frac{3}{8}$ in. (10 mm) and smaller fillet welds, and equal to the theoretical throat plus 0.11 in. (2.8 mm) for fillet welds over $\frac{3}{8}$ in. (10 mm). For fillet welds joining members at angles less than 60 deg use the rules for partial penetration groove welds, (f)(3).

(5) Effective Area of Fillet Welds. The effective area of fillet welds shall be considered as the effective length of the weld times the effective throat thickness.

(6) Effective Area of Fillet Welds in Holes and Slots. The effective area of fillet welds in holes and slots shall be computed as specified in (5) for fillet welds using for effective length the length of centerline of the weld through the center of the plane through the throat. However, in the case of overlapping fillets the effective area shall not exceed the nominal cross-sectional area of the hole or slot in the plane of the faying surface.

(7) Intermittent Fillet Welds. Intermittent fillet welds may be used to transfer calculated stresses across a joint or faying surface, when the strength required is less than that developed by a continuous fillet weld of the smallest permitted size, and to join elements of built-up members. The effective length of any segment of intermittent fillet welding shall not be less than four times the weld size with a minimum of $1\frac{1}{2}$ in. (38 mm).

(8) End Returns to Fillet Welds. Side or end fillet welds terminating at ends or sides, respectively, of parts or members shall, when required by the designer,

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be returned continuously around the corners for a distance not less than twice the nominal size of the weld. This provision shall apply to side and top fillet welds connecting brackets, beam seats, and similar connections, on the plane about which bending moments are computed. For framing angles and simple end-plate connections which depend upon flexibility of the outstanding legs for connection flexibility, end returns shall not exceed four times the nominal size of the weld. Fillet welds which occur on opposite sides of a common plane shall be interrupted at the corner common to both welds. End returns, when required by the designer, shall be indicated on the drawings.

(9) Fillet Welds in Holes and Slots. Fillet welds in holes or slots may be used to transmit shear in lap joints or to prevent the buckling or separation of lapped parts and to join elements of built-up members. Such fillet welds may overlap, subject to the provisions of (6). Fillet welds in holes or slots are not to be considered plug or slot welds.

(e) Plug and Slot Welds

(1) Use of Plug and Slot Welds. Plug and slot welds may be used to transmit shear in a lap joint or to prevent buckling of lapped parts and to join component parts of built-up members.

(2) Diameter of Holes for Plug Welds. The diameter of the holes for a plug weld shall be not less than the thickness of the part containing it plus $^{5}/_{16}$ in. (8 mm), rounded to the next greater odd $^{1}/_{16}$ in. (1.5 mm), nor greater than the minimum diameter plus $^{1}/_{8}$ in. (3 mm) or $2^{1}/_{4}$ times the thickness of the weld metal.

(3) Spacing of Plug Welds. The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

(4) Length of Slot Welds. The length of slot for a slot weld shall not exceed 10 times the thickness of the weld. The width of the slot shall be not less than the thickness of the part containing it plus $^{5}/_{16}$ in. (8 mm), rounded to the next greater odd $^{1}/_{16}$ in. (1.5 mm), nor shall it be greater than $2^{1}/_{4}$ times the thickness of the weld. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except for those ends which extend to the edge of the part.

(5) Spacing of Slot Welds. The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center to center spacing in a longitudinal direction on any line shall be two times the length of the slot.

(6) Thickness of Plug and Slot Welds. The thickness of plug and slot welds in material $^{5}/_{8}$ in. (16 mm) or less in thickness shall be equal to the thickness of the material. In material over $^{5}/_{8}$ in. (16 mm) in thickness, it shall be at least one-half the thickness of the material but not less than $^{5}/_{8}$ in. (16 mm).

(7) Effective Shearing Area of Plug and Slot Welds. The effective shearing area of plug and slot welds shall be considered as the nominal cross-sectional area of the hole or slot in the plane of the faying surface.

(f) Full Penetration and Partial Penetration Joints. The effective area shall be the effective weld length multiplied by the effective throat thickness.

(1) The effective weld length for any groove weld, square or skewed, shall be the length of weld throughout which the correct proportioned cross section exists. In a curved weld it shall be its true length measured along its curvature.

(2) The effective throat thickness of a full penetration groove weld which shall conform to the requirements of Article NF-4000 shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

(3) The effective throat of partial penetration groove welds is dependent upon the type of groove.

(-a) For square, U, and J groove welds, the effective throat is equal to the depth of preparations.

(-b) For V and bevel groove welds with an included angle at the root equal to or greater than 60 deg, the effective throat shall be the minimum distance from the root to the face of the weld.

(-c) For V and bevel groove welds with an included angle at the root less than 60 deg but equal to or greater than 45 deg, the effective throat shall be the minimum distance from the root to the face of the weld less $^{1}/_{8}$ in. (3 mm).

(-d) For V and bevel groove welds, with an included angle at the root less than 45 deg but equal to or greater than 30 deg, the effective throat shall be the minimum distance from the root to the face of the weld less $^{1}/_{8}$ in. (3 mm) and multiplied by 0.75. The required effective throat must be specified on the drawing.

(-e) For V and bevel groove welds, angles less than 30 deg at the root are not allowed.

(-f) For flare bevel groove welds, when filled flush to the surface, the effective throat shall be 0.31 times the outside radius of the curved section forming the groove. For formed rectangular tubing, the outside radius may be considered as two times the wall thickness.

(-g) For flare V groove welds, when filled flush to the surface, the effective throat shall be 0.5 [except use 0.375 for GMAW when $R \geq {}^{1}/_{2}$ in. (13 mm)] times the outside radius.

(g) Consideration of Lamellar Tearing. Welded joint configurations causing significant through-thickness tensile stress [as defined in NF-1215(b)] during fabrication and/or service on rolled product forms should be avoided. However, if this type of construction is used, the designer should consider one or several of the following factors that may reduce the susceptibility of the joint to experience lamellar tearing and provide

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documentation, including fabrication requirements, in the Design Output Documents:

(1) Reduce volume of weld metal to the extent practical.

(2) Select materials that are resistant to lamellar tearing.

(3) Invoke any of the special fabrication requirements of NF-4441.

(23) **NF-3324.6 Design Requirements for Bolted Joints.** The rules and stress limits for bolting shall be as given in this paragraph. The stress limits which must be satisfied for any Design, Levels A through D, and Test Loadings, shall be those given in this paragraph, multiplied by the appropriate stress limit factors given in Table NF-3225.2-1 for the particular Loading specified in the Design Specification [NCA-3211.19(b)]. Table NF-3225.2-1 establishes additional stress limits based on the yield and tensile strength of the material at temperature.

(a) Allowable Stresses. Allowable tensile, shearing, and bearing stresses in bolts and threaded parts shall be as given in the paragraphs below. All allowables are expressed in ksi (MPa) acting on the actual bolt area available in the shear planes of the connected parts. All are expressed in terms of the ultimate tensile strength at temperature (Section II, Part D, Subpart 1, Table U). The shear capacity of bolts is directly proportional to the shear area available in the shear planes. Shear strength is unaffected by shear plane location.

(1) Tensile Stress Only. Bolts loaded in direct tension shall be so proportioned that their average tensile stress F_{tb}, computed on the basis of the actual tensile stress area available (independent of any initial tightening force), shall not exceed

For ferritic steels

$$F_{tb} = \frac{S_u}{2}$$

For austenitic or duplex stainless steels

$$F_{tb} = \frac{0.75S_u}{2}$$

For precipitation-hardened stainless steels

$$F_{tb} = \frac{0.75S_u}{2.25}$$

The applied load shall be the sum of the external load and any tension resulting from prying action produced by deformation of the connected parts.

(2) Shearing Stress Only

(-a) Bearing-Type Joints

(-1) Threads Excluded From Shear Planes. The allowable shear F_{vb} in bolts and threaded parts loaded in direct shear, expressed in ksi (MPa) of actual shear stress area available (applicable to the total nominal bolt area in the shear planes in this case), shall not exceed

For ferritic steels

$$F_{vb} = \frac{0.62S_u}{3}$$

For austenitic or duplex stainless steels

$$F_{vb} = \frac{0.55S_u}{2}$$

For precipitation-hardened stainless steels

$$F_{vb} = \frac{0.55S_u}{2.25}$$

(-2) Threads Not Excluded From Shear Planes. The allowable shear stress F_{vb} in bolts and threaded parts loaded in direct shear, expressed in ksi (MPa) of actual shear stress area available (applicable to the total bolt root area in the shear planes in this case), shall not exceed

For ferritic steels

$$F_{vb} = \frac{0.62S_u}{3}$$

For austenitic or duplex stainless steels

$$F_{vb} = \frac{0.45S_u}{2}$$

For precipitation-hardened stainless steels

$$F_{vb} = \frac{0.45S_u}{2.25}$$

(3) Combined Tensile and Shear Stresses

(-a) Bearing-Type Joints. Bolts subjected to combined shear and tension shall be so proportioned that either the shear or the tensile stress, ksi (MPa) of actual cross-sectional area, shall not exceed the value derived from the ellipse equation below when the corresponding computed tensile or shearing stress is substituted

$$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} = 1$$

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Table NF-3324.6(a)(4)-1
Effective Slip Coefficient Versus Surface Condition

Surface Condition	Slip Coefficient, k_s
Clean mill scale	0.25
Grit-blasted carbon and low alloy high-strength steel	0.41
Grit-blasted, heat-treated steel	0.25
Hot dip galvanized wire, brushed, scored, or blasted	0.31
Blast cleaned, zinc rich paint	0.31
Blast cleaned, zinc silicate paint	0.45

The allowable tensile and shear stress values shall be those derived from the equations given in (1) and (2).

(-b) Friction-Type Joints. A bolt in a connection designed as a friction-type joint is not subjected to shear (provided the joint does not slip into bearing); it experiences tension only. Friction-type joints shall be designed as given in (4).

(4) Slip Resistance — Friction-Type Joints. The maximum slip resistance to which a friction-type joint may be designed shall not exceed the value of P_s, calculated in the following equation [see Table NF-3324.6(a)(4)-1]:

$$P_s = mnT_i k_s$$

If the joint clamping force will be reduced by any direct tension load on the joint, the T_i value shall be reduced by an equivalent amount before substituting in the above equation. SA-307 and austenitic stainless steel bolting shall not be used for friction-type joints.

(5) Bearing Stress. Allowable bearing stress on the projected area of bolts in bearing-type connections shall be

$$F_p = \frac{LS_u}{2d} \leq 1.5S_u$$

For Level C and Level D Loadings, the allowable bearing stress on the projected area of bolts in bearing-type connections may be increased to

$$F_p = \frac{LS_u}{2d} \leq 2.1S_u$$

(b) Minimum Edge Distance

(1) Minimum Edge Distance in Line of Load. In both bearing- and friction-type joints the minimum distance from the center of the end bolt in a connection to that edge of the connected part toward which the load is directed shall be determined in accordance with either (-a) or (-b).

(-a) The edge distance shall satisfy all of the following:

(-1) $L/d \geq 0.5 + 1.43\ (f_p/S_u)$
(-2) $L/d \geq 1.2$
(-3) $f_p/S_u \leq 1.5$

where

$$f_p = P/dt$$

(-b) The edge distance shall be as shown in Table NF-3324.6(b)(1)-1.

(2) Minimum Edge Distance in Line of Load for Level C and Level D. For Level C and Level D Loadings, the edge distance shall satisfy all of the following:

(-a) $L/d \geq 0.5 + 1.2(f_p/S_u)$
(-b) $L/d \geq 1.2$
(-c) $f_p/S_u \leq 2.1$

(c) Maximum Edge Distance. The maximum distance from the center of any rivet or bolt to the nearest edge of parts in contact shall be 12 times the thickness of the connected part under consideration, but shall not exceed 6 in. (150 mm). Bolted joints in unpainted steel exposed to atmospheric corrosion require special limitations on pitch and edge distance.

For unpainted, built-up members made of weathering steel which will be exposed to atmospheric corrosion, the spacing of fasteners connecting a plate and a shape or two-plate components in contact shall not exceed 14 times the thickness of the thinnest part nor 7 in. (175 mm), and the maximum edge distance shall not exceed eight times the thickness of the thinnest part, or 5 in. (125 mm).

(d) Minimum Spacing. The distance between centers of standard, oversized, or slotted fastener holes shall be not less than three times the nominal diameter of the bolt. Along a line of transmitted force, the distance between centers of holes shall be not less than the following:

$$\text{Standard Holes: } 2P/S_u t + d/2$$

(e) Effective Bearing Area. The effective bearing area of bolts shall be the diameter multiplied by the length in bearing, except that for countersunk bolts one-half the depth of the countersink shall be deducted.

(f) Long Grips. SA-307 bolts, which carry calculated stress and the grip of which exceeds five diameters, shall have their number increased 1% for each additional $1/16$ in. (1.5 mm) in the grip.

(g) Anchor Bolts. Anchor bolts shall be designed to provide resistance to all conditions of tension and shear at the bases of columns, including the net tensile components of any bending moments which may result from fixation or partial fixation of columns.

NF-3324.7 Design Requirements for Column Bases. Proper provision shall be made to transfer the column loads and moments, if any, to the footings and foundations.

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Table NF-3324.6(b)(1)-1
Minimum Edge Distances From Center of Standard Hole

Bolt Diameter, in. (mm)	Minimum Edge Distance for Punched, Reamed, or Drilled Holes, in. (mm) [Notes (1), (2)]
1/2 (13)	3/4 (19)
5/8 (16)	7/8 (22)
3/4 (19)	1 (25)
7/8 (22)	1 1/8 (29)
1 (25)	1 1/4 (32)
1 1/8 (29)	1 1/2 (38)
1 1/4 (32)	1 5/8 (41)
>1 1/4 (32)	1 1/4 × diameter

NOTES:
(1) All edge distances in this column may be reduced 1/8 in. (3 mm) when the hole is at the point where stress does not exceed 25% of the maximum allowed stress in the element.
(2) For oversized bolt holes as defined in NF-4721(b)(1), minimum edge distance shall be increased by 1/16 in. (1.5 mm) for bolt diameters below 1 in. (25 mm), and 1/8 in. (3 mm) for bolt diameters 1 in. (25 mm) and greater.

NF-3330 HIGH CYCLE FATIGUE DESIGN FOR CLASS 1

NF-3331 Introduction

NF-3331.1 Scope. Members and their connections, subject to a number of cycles (>20,000) of fatigue loading resulting in damage as defined in NF-3331.2, shall be proportioned to satisfy the stress range limitations provided therein.

NF-3331.2 Definitions. High cycle fatigue, as used in this subsubarticle, is defined as the damage that may result in fracture after a sufficient number of fluctuations of stress. *Stress range* is defined as the numerical sum of maximum repeated tensile and compressive stresses or the sum of maximum shearing stresses of opposite direction at a given point, resulting from differing arrangements of live load.

NF-3332 Design Requirements

NF-3332.1 Design Considerations. In the design of members and connections subject to repeated variation of live load stress, consideration shall be given to the number of stress cycles, the expected range of stress, and the type and location of member or detail.

NF-3332.2 Classification of Loading Conditions. Loading conditions shall be classified as shown in Table NF-3332.2-1.

NF-3332.3 Stress Categories. Stress categories for use in establishing the maximum range of stress in relation to the type of member or part, material, and location shall be as stipulated in Table NF-3332.3-1. For illustrations of the members and parts, see Figure NF-3332.3-1.

NF-3332.4 Allowable Stresses. The maximum stress shall not exceed the basic allowable stress permitted by NF-3322 and the maximum range of stress shall not exceed that given in Table NF-3332.4-1.

NF-3332.5 Provisions for Mechanical Fasteners. Range in tensile stress in properly tightened ASTM A325 or ASTM A490 bolts need not be considered, but the maximum computed stress, including prying action, shall not exceed the values given in NF-3332.4 subject to the following stipulations:

(a) Connections subject to more than 20,000 cycles, but not more than 500,000 cycles of direct tension may be designed for the stress produced by the sum of applied and prying loads if the prying load does not exceed 10% of the externally applied load. If the prying force exceeds 10%, the allowable tensile stress given in NF-3324.6(a)(1) shall be reduced 40%, applicable to the external load alone.

(b) Connections subject to more than 500,000 cycles of direct tension may be designed for the stress produced by the sum of applied and prying loads if the prying load does not exceed 5% of the externally applied load. If the prying force exceeds 5%, the allowable tensile stress given in NF-3324.6(a)(1) shall be reduced 50%, applicable to the external load alone. The use of other bolts and threaded parts subject to tensile fatigue loading is not recommended. Bolts and threaded parts subjected to cyclic loading in shear may be designed for the bearing-type shear stresses given in NF-3324.6(a)(2) insofar as the fatigue strength of the fasteners is concerned.

NF-3340 LIMIT ANALYSIS DESIGN FOR CLASS 1

NF-3341 Introduction

NF-3341.1 Scope.

(a) Subject to the limitation of this subsubarticle, simple or continuous beams, rigid frames, and similar portions of structures rigidly constructed so as to be continuous over at least one interior support may be proportioned on the basis of plastic design, namely, on the basis of the lower bound collapse load. This strength, as determined by rational analysis, shall not be less than that required to support a factored load equal to 1.7 times those of the Level A and Level B Service Limits, 1.3 times that of the Level C Service Limits, or 1.1 times that of the Level D Service Limits. For Service Level D, the lower bound collapse load may be determined using a yield stress in the analysis that is the greater of $1.2S_y$ and $1.5S_m$, but not larger than $0.7S_u$.

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Table NF-3332.2-1
Classification of Loading Conditions

Loading Condition	Number of Loading Cycles	
	From	To
1	20,000 [Note (1)]	100,000 [Note (2)]
2	100,000	500,000 [Note (3)]
3	500,000	2,000,000 [Note (4)]
4	>2,000,000	

NOTES:
(1) Approximately equivalent to two applications every day for 25 yr.
(2) Approximately equivalent to ten applications every day for 25 yr.
(3) Approximately equivalent to 50 applications every day for 25 yr.
(4) Approximately equivalent to 200 applications every day for 25 yr.

NOTE: As used here, *interior support* may be taken to include a rigid frame knee formed by the junction of a column and a sloping or horizontal beam or girder.

(b) Connections joining a portion of a structure designed on the basis of plastic behavior with a portion not so designed need be no more rigid than ordinary seat and cap angle or ordinary web connections.

(c) When plastic design is used as the basis for proportioning continuous beams and structural frames, the provisions relating to allowable working stress contained in NF-3320 are waived. Except as modified by these rules, all other provisions of NF-3320 shall govern.

NF-3342 Design Requirements

NF-3342.1 General Design Requirements.

(a) Shear. Unless reinforced by diagonal stiffeners or a doubler plate, the webs of columns, beams, and girders, including areas within the boundaries of the connections, shall be so proportioned that

$$V_u \leq 0.555 S_y t d \quad (1)$$

where V_u is the shear, kips (N), that would be produced by the required factored loading.

(b) Combined Loads. When the interaction method of calculation (Section III Appendices, Nonmandatory Appendix A, Article A-9000) is used, members shall be so proportioned that the interaction of factored loads at a section shall satisfy the interaction equations of Section III Appendices, Nonmandatory Appendix A, Table A-9210(d)-1, except that columns subjected to combined bending and compression shall be governed by the requirements of NF-3342.2(b)(3).

(c) Depth–Thickness Ratio of Webs. The depth–thickness ratio of webs of members subjected to plastic bending shall not exceed the value given by eqs. (2) and (3), as applicable

(U.S. Customary Units)

$$\frac{d}{t} = \frac{412}{\sqrt{S_y}}\left[1 - \left(1.4\frac{P}{P_y}\right)\right] \quad (2)$$

when

$$\frac{P}{P_y} \leq 0.27$$

(SI Units)

$$\frac{d}{t} = \frac{1\,080}{\sqrt{S_y}}\left[1 - \left(1.4\frac{P}{P_y}\right)\right]$$

when

$$\frac{P}{P_y} \leq 0.27$$

(U.S. Customary Units)

$$\frac{d}{t} = \frac{257}{\sqrt{S_y}} \quad (3)$$

when

$$\frac{P}{P_y} > 0.27$$

(SI Units)

$$\frac{d}{t} = \frac{673}{\sqrt{S_y}}$$

when

$$\frac{P}{P_y} > 0.27$$

(d) Web Crippling. Web stiffeners are required on a member at a point of load application where a plastic hinge would form. At points on a member where the concentrated load delivered by the flanges of a member framing into it would produce web crippling opposite the compression flange or high tensile stress in the tension flange, web stiffeners are required in accordance with the provisions of NF-3324.2(b).

(e) Width–Thickness Ratios of Flanges

(1) The width–thickness ratio for flanges of rolled W shapes and similar built-up single web shapes that would be subjected to compression involving hinge rotation under ultimate loading shall not exceed the following values:

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(23)

Table NF-3332.3-1
Stress Categories

Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Figure NF-3332.3-1)
General Condition — Plain material			
Base metal with rolled or cleaned surfaces	T or Rev.	A	(1), (2)
General Condition — Built-up members			
Base metal and weld metal in members, without attachments, built up plates or shapes connected by continuous full or partial penetration groove welds, or continuous fillet welds parallel to the direction of applied stress	T or Rev.	B	(3) through (6)
Base metal in members without attachments, built-up plates or shapes connected by continuous full-penetration groove welds or by continuous fillet welds parallel to the direction of applied stress	T or Rev.	B′	(3) through (6)
Calculated flexural stress, f_b, in base metal at toe of welds on girder webs or flanges adjacent to welded transverse stiffeners	T or Rev.	C	(7)
Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends or wider than flange with welds across the ends			
Flange thickness ≤ 0.8 in. (20 mm)	T or Rev.	E	(5)
Flange thickness > 0.8 in. (20 mm)	T or Rev.	E′	(5)
Base metal at end of partial length welded cover plates wider than the flange without welds across the ends	T or Rev.	E′	(5)
General Condition — Mechanically fastened connections			
Base metal at gross section of high-strength bolted slip-critical connections, except axially loaded joints which induce out-of-plane bending in connected material	T or Rev.	B	(8)
Base metal at net section of other mechanically fastened joints [Note (3)]	T or Rev.	D	(8), (9)
Base metal at net section of fully tensioned high-strength, bolted-bearing connections	T or Rev.	B	(8), (9)
General Condition — Fillet welded connections			
Base metal at intermittent fillet welds	T or Rev.	E	...
Base metal at junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the member so as to balance weld stresses			
b ≤ 1 in. (25 mm)	T or Rev.	E	(17), (18)
b > 1 in. (25 mm)	T or Rev.	E′	(17), (18)
Base metal at members connected with transverse fillet welds			
b ≤ ½ in. (13 mm)	T or Rev.	C [Note (4)]	(20), (21)
b > ½ in. (13 mm)			(20), (21)
General Condition — Fillet welds			
Weld metal of continuous or intermittent longitudinal or transverse fillet welds	S	F [Note (4)]	(15), (17), (18), (20), (21)
General Condition — Groove welds			
Base metal and weld metal at full penetration groove welded splices of parts of similar cross section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of NF-5320 or NF-5330.	T or Rev.	B	(10)

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Table NF-3332.3-1
Stress Categories (Cont'd)

Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Figure NF-3332.3-1)
General Condition — Groove welds (Cont'd)			
Base metal and weld metal at full penetration groove welded splices at transitions in width or thickness, with welds ground to provide slopes no steeper than 1 to 2½, with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of NF-5320 or NF-5330	T or Rev.	B	(12), (13)
Base metal and weld metal at full penetration groove welded splices, with or without transitions having slopes no greater than 1 to 2½, when reinforcement is not removed and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of NF-5320 or NF-5330	T or Rev.	C	(10) through (13)
General Condition — Partial penetration groove welds			
Weld metal of partial penetration transverse groove welds, based on effective throat area of the weld or welds	T or Rev.	F [Note (4)]	(16)
General Condition — Plug or slot welds			
Base metal at plug or slot welds	T or Rev.	E	(27)
Shear on plug or slot welds	S	F	(27)
General Condition — Attachments			
Base metal at details attached by full-penetration groove welds subject to longitudinal and/or transverse loading when the detail embodies a transition radius R with the weld termination ground smooth and for transverse loading, the weld soundness established by radiographic or ultrasonic inspection in accordance with NF-5320 or NF-5330			
Longitudinal loading			
R > 24 in. (600 mm)	T or Rev.	B	(14)
24 in. (600 mm) > R > 6 in. (150 mm)	T or Rev.	C	(14)
6 in. (150 mm) > R > 2 in. (50 mm)	T or Rev.	D	(14)
2 in. (50 mm) > R	T or Rev.	E	(14)
Detail base metal for transverse loading: equal thickness and reinforcement removed			
R > 24 in. (600 mm)	T or Rev.	B	(14)
24 in. (600 mm) > R > 6 in. (150 mm)	T or Rev.	C	(14)
6 in. (150 mm) > R > 2 in. (50 mm)	T or Rev.	D	(14)
2 in. (50 mm) > R	T or Rev.	E	(14), (15)
Detail base metal for transverse loading: equal thickness and reinforcement not removed			
R > 24 in. (600 mm)	T or Rev.	C	(14)
24 in. (600 mm) > R > 6 in. (150 mm)	T or Rev.	C	(14)
6 in. (150 mm) > R > 2 in. (50 mm)	T or Rev.	D	(14)
2 in. (50 mm) > R	T or Rev.	E	(14), (15)
Detail base metal for transverse loading: unequal thickness and reinforcement removed			
R > 2 in. (50 mm)	T or Rev.	D	(14)
2 in. (50 mm) > R	T or Rev.	E	(14), (15)
Detail base metal for transverse loading: unequal thickness and reinforcement not removed			
all R	T or Rev.	E	(14), (15)
Detail base metal for transverse loading			
R > 6 in. (150 mm)	T or Rev.	C	(19)

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Table NF-3332.3-1
Stress Categories (Cont'd)

Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Figure NF-3332.3-1)
General Condition — Attachments (Cont'd)			
6 in. (150 mm) > R > 2 in. (50 mm)	T or Rev.	D	(19)
2 in. (50 mm) > R	T or Rev.	E	(19)
Base metal at detail attached by full-penetration groove welds subject to longitudinal loading			
2 < a < 12b or 4 in. (100 mm)	T or Rev.	D	(15)
a > 12b or 4 in. (100 mm) when b ≤ 1 in. (25 mm)	T or Rev.	E	(15)
a > 12b or 4 in. (100 mm) when b > 1 in. (25 mm)	T or Rev.	E′	(15)
Base metal at detail attached by fillet welds or partial-penetration groove welds subject to longitudinal loading			
a ≤ 2 in. (50 mm)	T or Rev.	C	(15), (23) through (26)
2 in. (50 mm) < a ≤ 12b or 4 in. (100 mm)	T or Rev.	D	(15), (23), (24), (26)
a > 12b or 4 in. (100 mm) when b ≤ 1 in. (25 mm)	T or Rev.	E	(15), (23), (24), (26)
a > 12b or 4 in. (100 mm) when b > 1 in. (25 mm)	T or Rev.	E′	(15), (23), (24), (26)
Base metal attached by fillet welds or partial-penetration groove welds subjected to longitudinal loading when the weld termination embodies a transition radius with the weld termination ground smooth:			
R > 2 in. (50 mm)	T or Rev.	D	(19)
R ≤ 2 in. (50 mm)	T or Rev.	E	(19)
Fillet-welded attachments where the weld termination embodies a transition radius, weld termination ground smooth, and main material subject to longitudinal loading:			
Detail base metal for transverse loading			
R > 2 in. (50 mm)	T or Rev.	D	(19)
R ≤ 2 in. (50 mm)	T or Rev.	E	(19)
Base metal at stud-type shear connector attached by fillet weld or automatic end weld	T or Rev.	C	(22)
Shear stress on nominal area of stud-type shear connectors	S	F	...

NOTES:
(1) T signifies range in tensile stress only; Rev. signifies a range involving reversal of tensile or compressive stress; S signifies range in shear, including shear stress reversal.
(2) These examples are provided as guidelines and are not intended to exclude other reasonably similar situations.
(3) When stress reversal is involved, use of SA-307 bolts is not recommended.
(4) Allowable fatigue stress range for transverse partial penetration and transverse fillet welds is a function of the effective throat, depth of penetration and plate thickness. See Frank and Fisher, "Fatigue Strength of Fillet Welded Cruciform Joints," Journal of the Structural Division, ASCE, Vol. 105, No. 519, 1979.

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Figure NF-3332.3-1
Illustrative Examples

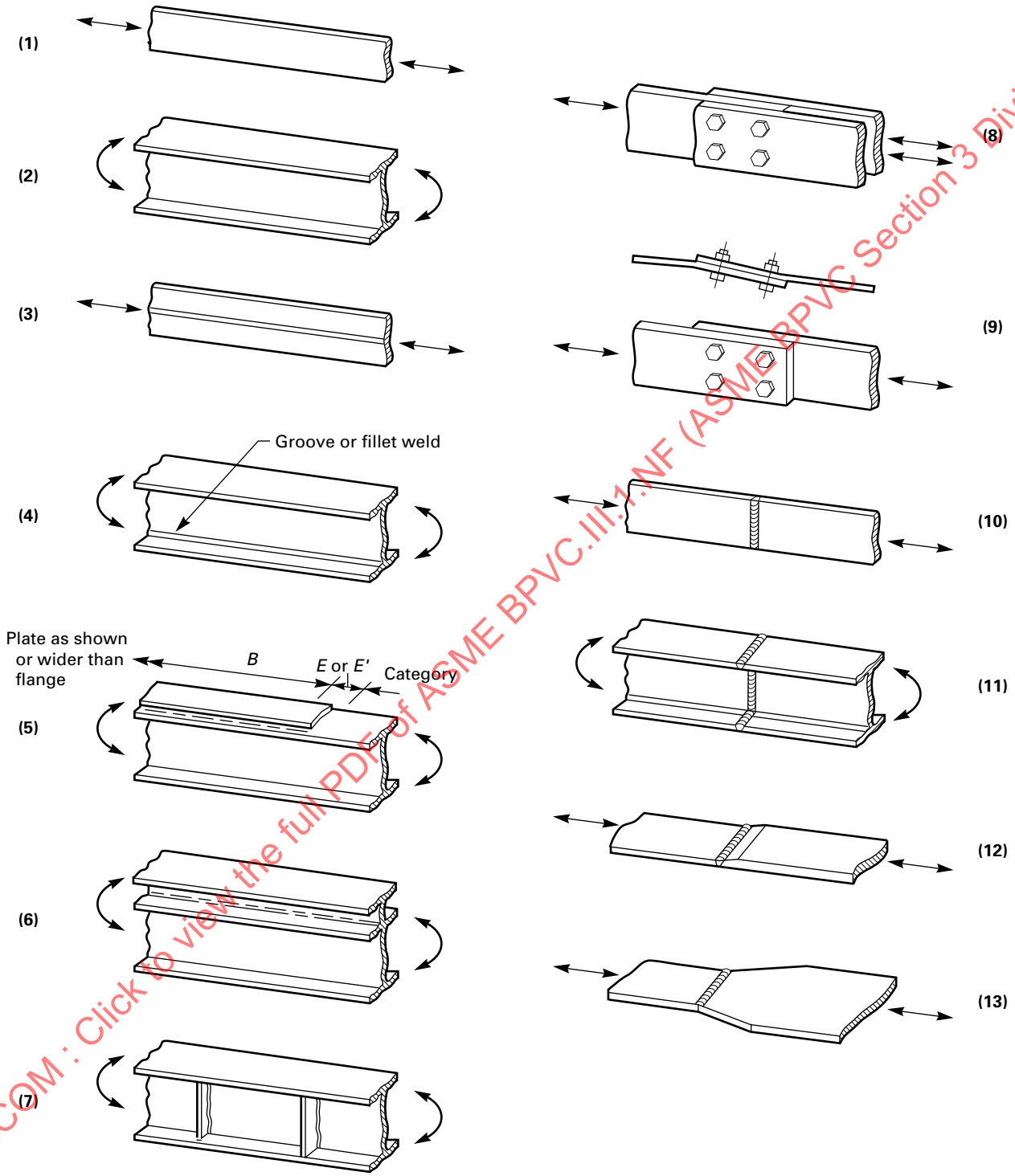

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Figure NF-3332.3-1
Illustrative Examples (Cont'd)

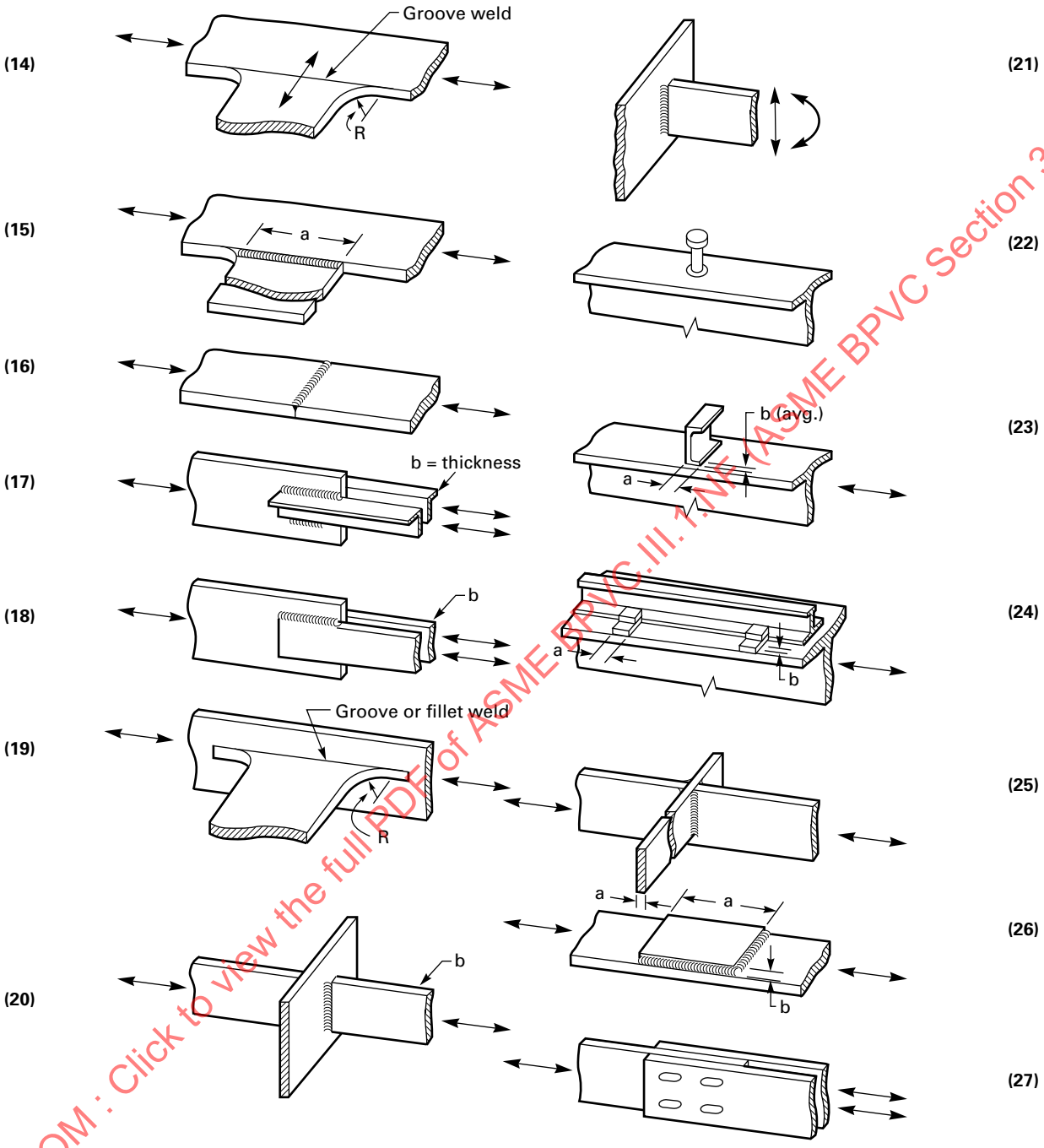

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Table NF-3332.4-1
Allowable Stress Ranges

Stress Category Used in Table NF-3332.3-1	Allowable Range of Stress, F_{sr}, ksi (MPa)			
	Loading Condition 1, F_{sr1}	Loading Condition 2, F_{sr2}	Loading Condition 3, F_{sr3}	Loading Condition 4, F_{sr4}
A	63 (430)	37 (255)	24 (165)	24 (165)
B	49 (340)	29 (200)	18 (125)	16 (110)
B′	39 (270)	23 (160)	15 (100)	12 (85)
C	35 (240)	21 (145)	13 (90)	10 (70) [Note 1]
D	28 (195)	16 (110)	10 (70)	7 (50)
E	22 (150)	13 (90)	8 (55)	5 (35)
E′	16 (110)	9 (60)	6 (40)	3 (20)
F	15 (100)	12 (85)	9 (60)	8 (55)

NOTE: (1) Flexural stress range of 12 ksi (83 MPa) permitted at toe of stiffener welds on webs or flanges.

S_y	$b_f/2t_f$
36 (248)	8.5
42 (290)	8.0
45 (310)	7.4
50 (345)	7.0
55 (380)	6.6
60 (413)	6.3
65 (448)	6.0

The thickness of sloping flanges may be taken as their average thickness.

(2) The width–thickness ratio of similarly compressed flange plates in box sections and cover plates shall not exceed $190/\sqrt{S_y}$ $\left(500/\sqrt{S_y}\right)$. For this purpose the width of a cover plate shall be taken as the distance between longitudinal lines of connecting high-strength bolts or welds.

(23) **NF-3342.2 Specific Design Requirements.**

(a) Beams. The maximum bending strength of a flexural member shall be

$$M_p = S_y Z_x \quad (4)$$

(b) Columns

(1) In the plane of bending of columns which would develop a plastic hinge at ultimate loading, the slenderness ratio l/r shall not exceed C_c defined in NF-3322.1(c).

(2) The maximum strength of an axially loaded compression member shall be taken as

$$P_{cr} = 1.7AF_a \quad (5)$$

where A is the gross area of the member, and F_a, as defined by NF-3322.1(c)(1)(-a), eq. (4), is based upon the applicable slenderness ratio.

(3) Members subject to combined axial load and bending moment, including moment resulting in secondary stress, shall be proportioned so as to satisfy the following interaction equations:

$$\frac{P}{P_{cr}} + \frac{C_m M}{[1 - (P/P_e)]M_m} \leq 1.0 \quad (6)$$

$$\frac{P}{P_y} + \frac{M}{1.18M_p} \leq 1.0;\ M \leq M_p \quad (7)$$

where

C_m = coefficient defined in NF-3322.1(e)
P_e = $1.92AF'_e$, where F'_e is defined in NF-3322.1(e)

The right-hand side of eq. (7) may be replaced by 1.5 when it can be shown that the bending moment results only in secondary stress.

(4) For columns braced in the weak direction

$$M_m = M_p$$

(5) For columns unbraced in the weak direction

(U.S. Customary Units)

$$M_m = M_p\left[1.07 - \frac{(l/r_y)\sqrt{S_y}}{3{,}160}\right] \leq M_p \quad (8)$$

(SI Units)

$$M_m = M_p\left[1.07 - \frac{(l/r_y)\sqrt{S_y}}{8\,280}\right] \leq M_p$$

(c) Basis for Maximum Strength Determination. For one or two story frames, the maximum strength may be determined by a routine plastic analysis procedure, and the

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frame instability effect $P\Delta$ may be ignored. For braced multistory frames, provisions should be made to include the frame instability effect in the design of the bracing system and frame members. For unbraced multistory frames, the frame instability effect should be included directly in the calculations for maximum strength. The vertical bracing system for a plastically designed braced multistory frame shall be shown to be adequate, as determined by a rational analysis, to prevent buckling of the structure under factored gravity load, and maintain the lateral stability of the structure, including consideration of the overturning effects of drift, under factored horizontal and gravity loads.

(1) Stability of Braced Frames. The vertical bracing system may be considered to function together with in-plane shear-resisting exterior and interior walls, floor slabs, and roof decks, if these walls, slabs, and decks are secured to the structural frames. The columns, girders, beams, and diagonal members, when used as the vertical bracing systems, may be considered to comprise a cantilever, simply connected truss in the analysis for frame buckling and lateral stability. Axial deformation of all members in the vertical bracing system shall be included in the lateral stability analysis. The axial force in these members, caused by factored horizontal and gravity loads, shall not exceed $0.85P_y$, where P_y is the product of yield stress times area of the member. Girders and beams included in the vertical bracing system of a braced multistory frame shall be proportioned for axial force and moment caused by the concurrent factored horizontal and gravity loads, in accordance with (b)(2), eq. (5) with P_{cr} taken as the maximum axial strength of the beam, based on the actual slenderness ratio between braced points in the plane of bending.

(2) Stability of Unbraced Frames. The strength of an unbraced multistory frame shall be determined by a rational analysis which includes the effects of frame instability and column axial deformation. Such a frame shall be designed to be stable under the following conditions:

(-a) factored gravity loads

(-b) factored gravity plus factored horizontal loads

The axial force in the column at factored load levels shall not exceed $0.75P_y$.

(d) Lateral Bracing

(1) Members shall be adequately braced to resist lateral and torsional displacements at the plastic hinge locations associated with the failure mechanism. The laterally unsupported distance l_{cr} from such braced hinge locations to similarly braced adjacent points on the member or frame shall not exceed the value determined from eq. (9) or eq. (10), as applicable

(U.S. Customary Units)

$$l_{cr}/r_y = 1{,}375/S_y + 25 \quad (9)$$

(SI Units)

$$l_{cr}/r_y = 9470/S_y + 25$$

when

$$+1.0 > M'/M_p > -0.5$$

or

(U.S. Customary Units)

$$l_{cr}/r_y = 1{,}375/S_y \quad (10)$$

(SI Units)

$$l_{cr}/r_y = 9470/S_y$$

when

$$-0.5 \geq M'/M_p > -1.0$$

where

M'/M_p = the end moment ratio, positive when the segment is bent in reverse curvature and negative when bent in single curvature

(2) The provisions of (1) need not apply in the region of the last hinge to form, in the failure mechanism assumed as the basis for proportioning a given member, nor in members oriented with their weak axis normal to the plane of bending. However, in the region of the last hinge to form and in regions not adjacent to a plastic hinge, the maximum distance between points of lateral support shall be such as to satisfy the requirements of NF-3322.1(d)(5)(-b), eq. (17); NF-3322.1(d)(5)(-b), eq. (18); NF-3322.1(d)(5)(-b), eq. (19); NF-3322.1(e)(1), eq. (20); or NF-3322.1(e)(1), eq. (21). For this case, the value of f_a and f_b shall be computed from the moment and axial force at factored loading, divided by the applicable load factor.

(3) Members built into a masonry wall and having their web perpendicular to this wall can be assumed to be laterally supported with respect to their weak axis of bending.

(e) Connections

(1) General Requirements. All connections, the rigidity of which is essential to the continuity assumed as the basis for the analysis, shall be capable of resisting the moments, shears, and axial loads to which they would be subjected by the full factored loading, or any probable partial distribution thereof.

(2) Corner Connections. Corner connections (haunches) that are tapered or curved for architectural reasons shall be so proportioned that the full plastic

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bending strength of the section adjacent to the connection can be developed, if required.

(3) Stiffeners. Stiffeners shall be used, as required, to preserve the flange continuity of interrupted members at their junction with other members in a continuous frame. Such stiffeners shall be placed in pairs on opposite sides of the web of the member which extends continuously through the joint.

(4) Stress in Bolts and Welds. High-strength bolts, SA-307 bolts, and welds shall be proportioned to resist the forces produced at factored load, using stresses equal to 1.7 times those given in NF-3324.6(a) for bolts and Table NF-3324.5(a)-1 for welds. In general, groove welds are preferable to fillet welds, but their use is not mandatory.

(5) Joints With Painted Contact Surfaces. High-strength bolts may be used in joints having painted contact surfaces when these joints are of such size that the slip required to produce bearing would not interfere with the formation, at factored loading, of the plastic hinges assumed in the design.

NF-3350 DESIGN BY ANALYSIS FOR CLASS 2 AND MC

The design by analysis of Class 2 and MC supports shall be in accordance with NF-3320 and NF-3340.

NF-3360 DESIGN BY ANALYSIS FOR CLASS 3

The design by analysis of Class 3 supports shall be in accordance with NF-3320 and NF-3340.

NF-3370 EXPERIMENTAL STRESS ANALYSIS

Supports of all types may be designed by experimental stress analysis in accordance with Section III Appendices, Mandatory Appendix II. When experimental stress analysis is used, the appropriate stress acceptance criteria and other limits of NF-3300 shall apply. For Level D Service Limits, the static or equivalent static loads shall not exceed 100% of the test collapse load.

NF-3380 DESIGN BY LOAD RATING

NF-3381 Procedure for Load Rating

The procedure for load rating shall consist of imposing a total load on one or more duplicate full-size samples for a support equal to or less than the load under which the support fails to perform its required function. Full-size samples composed of various parts may have each part or a number of parts load rated provided that all parts in the load path are either load rated or otherwise qualified per NF-3300 or by experimental stress analysis. When parts are connected by bolting or welding, the connection shall be either load rated or qualified per NF-3225 or NF-3226. Should more than one part be load rated in a single load test, then the load rating equations of NF-3380 shall be evaluated for each part using the part's $S_{y(act)}$ and $S_{u(act)}$ values. The part having the lowest load rating shall establish the load rating for the combination of parts. A single test sample is permitted, but in that case, the load ratings shall be decreased by 10%. Otherwise, tests shall be run on a statistically significant number of samples. The permissible types of welded joints shall be as permitted for the specific class of construction in NF-3226.1, NF-3256.1, NF-3266, and NF-3324. The requirements of NF-3324.5(b) for size of fillet and partial penetration welds do not apply, provided the full-size sample is fabricated for testing using the minimum weld stipulated in the Design Drawings. Bolted joints in the test sample shall be made up using the lowest strength bolt material and minimum edge distance allowed by the specification.

NF-3382 Load Ratings in Relation to Design Service and Test Loadings

The load rating for Design Loadings shall be determined in accordance with the requirements for Service Level A limits. The load ratings for Service Loadings for which Level A through D Limits have been designated shall be determined by means of the equations in the following subparagraphs. The load rating for Test Loadings shall be determined in accordance with the requirements for Service Level B limits.

NF-3382.1 Nomenclature. The symbols used in this paragraph are defined as follows:

F_{all} = allowable value for the type of stress in NF-3310, ksi (MPa)

Kl = load rating coefficient for supports in compression

S_T = specified minimum tensile strength of the material used in the support as given in the applicable tables of Section II, Part D, Subpart 1, ksi (MPa)

S_u = see NF-3313.1

$S_{u(act)}$ = actual tensile strength of the material used in the part or support which had reached ultimate capacity during the test, ksi (MPa)

S_Y = specified minimum yield strength of the material used in the support as given in the applicable tables of Section II, Part D, Subpart 1, ksi (MPa)

S_y = see NF-3313.1

$S_{y(act)}$ = actual yield strength of the material used in the part or support which yielded during the test, ksi (MPa)

TL_u = support test load at which a substantial increase in load displacement results in zero or negative increase in actual support load

TL_y = support test load at or below yield

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NF-3382.2 Linear-Type Supports. The load ratings for Linear-Type Supports for the Service Loadings shall be determined by the following equations:

Design and Level A Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.0\frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (1)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.0\frac{F_{\text{all}}}{S_{u(\text{act})}} \quad (2)$$

Test and Level B Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.33\frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (3)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.33\frac{F_{\text{all}}}{S_{u(\text{act})}} \quad (4)$$

Level C Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.5\frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (5)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.5\frac{F_{\text{all}}}{S_{u(\text{act})}} \quad (6)$$

Level D Limits (lowest of the three values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 2.0\frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (7)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 0.7\frac{S_u}{S_{u(\text{act})}} \quad (8)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 0.7 \quad (9)$$

NF-3382.3 Supports Loaded in Compression. The load rating for the supports loaded in compression shall be determined for Service Level A through D by the methods of NF-3382.2. In addition, for cases where buckling governs, TL_u shall be corrected for the ratio of Young's Modulus at the Design Temperature to Young's Modulus at the test temperature. The load rating shall be determined by the following equations:

Design and Level A Limits

$$\text{load rating} = 0.52Kl \times TL_u \quad (10)$$

Test and Level B Limits

$$\text{load rating} = 0.67Kl \times TL_u \quad (11)$$

Level C Limits

$$\text{load rating} = 0.67Kl \times TL_u \quad (12)$$

Kl = 1.0 for elastic buckling

$$Kl = \frac{S_y}{S_{y(\text{act})}} \text{ for inelastic buckling}$$

Level D Limits

$$\text{load rating} = 0.67Kl \times TL_u \quad (13)$$

NF-3382.4 Alternate Load Rating Method Using TL_y or TL_u Test Results Only. Either TL_y or TL_u test results may be used to establish a support load rating provided the load rating as determined by the method of NF-3382.2 or NF-3382.3 is modified as follows:

(a) For load rating based on TL_y test results only

(1) for supports constructed of materials having definitely determinable yield points and specified minimum S_Y/S_T ratios not greater than 0.625, the load rating shall be multiplied by 0.83. If $S_{y(\text{act})}$ of the material is not known, 0.67 shall be used in place of multiplier 0.83

(2) for supports constructed of carbon steel with specified minimum tensile strengths of not over 70,000 psi (480 MPa), $S_{y(\text{act})}$ shall be increased by 5,000 psi (34 MPa) prior to determining the load rating

(3) for all other materials the determined load rating shall be multiplied by 0.67

For supports loaded in compression, a TL_u test shall be performed with the compressive load rating determined in accordance with NF-3382.3.

(b) For load rating based on TL_u test results, the determined load rating shall be multiplied by 0.50.

NF-3400 DESIGN RULES FOR STANDARD SUPPORTS

NF-3410 GENERAL REQUIREMENTS

The following requirements apply in addition to the requirements of NF-3100, NF-3200, and NF-3300.

NF-3411 General Design Requirements

Standard Supports (see NF-1214) shall conform to the design considerations of NF-3120, the design rules of NF-3200 or NF-3300, and the following additional requirements.

NF-3411.1 Standard Supports Used as Component Supports. Standard Supports may be used as component supports, as defined in NF-3500.

NF-3411.2 Standard Supports Used as Piping Supports. Standard Supports may be used as piping supports, as defined in NF-3600.

NF-3411.3 Loads. (23)

(a) Standard Supports shall be capable of carrying all concurrently acting loads listed in NF-3111 and stipulated in the Design Specification. The supports shall be designed

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to provide the required supporting effort and to permit the designed piping or component movement.

(b) Spring supports shall be capable of exerting a supporting force equal to the load, as determined by weight–balance calculations, plus the weight of all hanger parts such as clamps and rods that will be supported by a spring at the point of attachment to a pressure-retaining component or to an integral attachment.

(1) The design shall be such as to prevent complete release of the piping or component load in the event of spring failure or misalignment.

(2) When springs are to be enclosed in spaces where high ambient temperatures occur, the spring material shall be such that the spring constants will not be significantly changed at the temperature to be experienced.

(c) Snubbers, dampers, and energy absorbers shall meet the requirements of (a), and (1) and (2) below.

(1) The following occasional loads shall be considered:

(-a) seismic inertial

(-b) seismic anchor displacement

(-c) hydraulic transient loads resulting from, but not limited to, water hammer, steam hammer, pump startup, pump shutdown, and safety and safety relief valve discharges, as specified in the Design Specification

(2) Thermal Expansion and Thermal Anchor Displacement. Snubbers, dampers, and energy absorbers shall not resist the effects of thermal growth of the component, the piping system, or the anchorage to the degree where it imposes a significant load or stress on the piping or component.

NF-3412 Standard Support Items

NF-3412.1 Constant Support Spring Hangers. Constant support spring hangers may be used to support piping or components at those locations requiring a substantially uniform supporting force throughout the travel range but which, while subject to thermal movement, cannot tolerate appreciable variability of the supporting force. They shall have a mean variability (deviation), including friction, of no more than 6% throughout the travel range. Deviation is the sum of kinematic friction and manufacturing tolerance factors. Determination of deviation is by load test machine and is calculated as follows:

$$\text{deviation} = (\text{maximum reading moving down} - \text{minimum reading moving up}) \div (\text{maximum reading moving down} + \text{minimum reading moving up})$$

NF-3412.2 Variable Support Spring Hangers. Variable support spring hangers may be used to support piping or components at those locations subject to vertical movement due to temperature differences. The variability factor of the supporting force is calculated by the following equation:

$$\text{variability factor} = (\text{travel} \times \text{spring rate}) / \text{load}$$

The recommended maximum variability factor is 0.25.

(a) The variability factor of the supporting force resulting from movement of the piping or component shall be considered in the loadings used in the stress analysis of the piping or component.

(b) Variable support spring hangers shall be provided with means to limit misalignment, buckling, and eccentric loading and to prevent overstressing of the spring.

(c) It is recommended that all hangers employing springs be provided with means to indicate at all times the compression of the spring with respect to the appropriate hot and cold positions of the piping or component.

NF-3412.3 Hanger Rods. Design loads for threaded hanger rods shall be based on the root area of the threads. In no case shall hanger rods less than $^{3}/_{8}$ in. (10 mm) diameter be used for supporting pipe NPS 2 (DN 50) and smaller, or less than $^{1}/_{2}$ in. (13 mm) diameter rod for supporting pipe NPS $2^{1}/_{2}$ (DN 65) and larger. Pipe, structural shapes, or bars may be used instead of hanger rods. Hanger rods, structural shapes, etc., shall be designed to permit the free movement of piping as indicated in the thermal stress analysis. The possibility of moment loading of hanger rods or shapes as a result of pipe motion shall be considered and avoided unless the support is specifically designed for such loading.

NF-3412.4 Snubbers.[6] (23)

(a) Snubbers may be incorporated in the system design to accommodate Design Mechanical Loads or conditions of a vibratory or dynamic nature. Snubbers may be attached to a piping or component to protect it against dynamic type loading. Snubbers shall allow essentially free movement of the piping or component to which they are attached during nondynamic application of load such as that imposed by expansion and contraction. Refer to Nonmandatory Appendix NF-E for function, applications, and modeling.

(b) Snubbers shall be carefully applied to ensure that they will perform their intended function without placing unacceptable loads on the piping system or other components.

(c) The Design Specification shall contain, as a minimum, the following:

(1) the Design Loadings for loading conditions and transients, and combinations of loadings for which the snubber is designed to accommodate

(2) required force, time, and displacement relationship

(3) the environmental conditions that the snubber will be exposed to, such as

(-a) temperature

(-b) irradiation

(-c) corrosive atmosphere

(-d) moisture

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(-e) airborne particles

(4) consideration of material characteristics, such as

(-a) compatibility

(-b) stability

(-c) fire resistance

(-d) wear

(-e) aging

(5) tests which are required prior to installation

(d) Design of functional members such as interconnections, tubing and fittings reservoirs, and flow distributors shall consider the effect of internal pressure, thermal expansion, and vibration loading.

(23) **NF-3412.5 Dampers.** Dampers provide similar system behavior as snubbers and can be used to mitigate dynamic events. Dampers shall meet the requirements of NF-3412.4. Refer to Nonmandatory Appendix NF-E for function, applications, and modeling.

(23) **NF-3412.6 Energy Absorbers.** Energy absorbers provide similar system behavior as snubbers and can be used to mitigate dynamic events. Energy absorbers shall meet the requirement of NF-3412.4. Energy absorbers shall be designed to meet the stress limits of Article NF-3000, except that the energy-absorbing material shall meet the requirements of Mandatory Appendix NF-III. Refer to Nonmandatory Appendix NF-E for function, applications, and modeling.

NF-3420 DESIGN BY ANALYSIS FOR CLASS 1

NF-3421 General Design Requirements

The design of Class 1 Standard Supports shall be in accordance with the requirements of NF-3420 using one of the design procedures indicated in Table NF-3131(a)-1 for Class 1 construction.

NF-3422 Design of Plate- and Shell-Type Standard Supports

The requirements of NF-3200 shall be met.

NF-3423 Design of Linear-Type Standard Supports

The requirements of NF-3300 shall be met.

NF-3425 Design of Bolting

The requirements of NF-3225 and NF-3324.6 shall be met.

NF-3426 Design of Welded Joints

NF-3426.1 Permissible Types. The permissible types of welded joints for Standard Supports are described in paragraphs NF-3226.1 and NF-3256.1. Additional types of joints are as follows. Typical examples of the types are shown in Figure NF-3426.1-1.

(a) Tee Joints. Tee joints shall be one of the following:

(1) fillet, double welded, sketch (a-1).

(2) fillet, single welded, when double members are used, sketch (a-2).

(3) fillet, single welded, between a flat surface and the end surface of a closed tubular section or a closed formed section, sketch (f). Partially closed tubular sections or partially closed formed sections and the total length of their respective welds shall encompass a minimum of 270 deg of the circumference and provide symmetrical loadings on closure plates.

(b) Corner Joints. Corner joints shall be one of the following:

(1) Partial penetration, without a fillet weld between the edge of a plate and the end surface of a closed tubular section or partially closed formed section, sketch (e). Partially closed tubular sections or partially closed formed sections as well as the total length of their respective welds shall encompass a minimum of 270 deg of the circumference and provide symmetrical loadings on closure plates.

(2) Fillet welds between the edge of a plate and the end surface of a closed tubular section or partially closed tubular section or partially closed formed section, sketches (b), (c), and (d). In addition, weld joints (b) and (d) may be used only if the lengths of the respective legs of the fillet weld are equal to the exposed thickness of the plate and shell elements. Partially closed tubular sections or partially closed formed sections as well as the total length of their respective welds shall encompass a minimum of 270 deg of the circumference and provide symmetrical loadings on closure plates.

(3) The use of welded joints permitted by (a)(3) and (b) is limited to housings for spring encapsulation of standard supports.

NF-3426.2 Design Stress Intensity and Allowable Stress Limits for Welded Joints. The limit of design stress intensity or of allowable stress for welded joints for Standard Supports shall not exceed the applicable design stress intensity value or allowable stress value for the base metal being joined.

NF-3450 DESIGN BY ANALYSIS FOR CLASS 2

NF-3451 General Design Requirements

The design of Class 2 Standard Supports shall be in accordance with the requirements of NF-3450 using one of the design procedures indicated in Table NF-3131(a)-1.

NF-3452 Design of Plate- and Shell-Type Standard Supports

The requirements of NF-3200 shall be met.

NF-3453 Design of Linear-Type Standard Supports

The requirements of NF-3300 shall be met.

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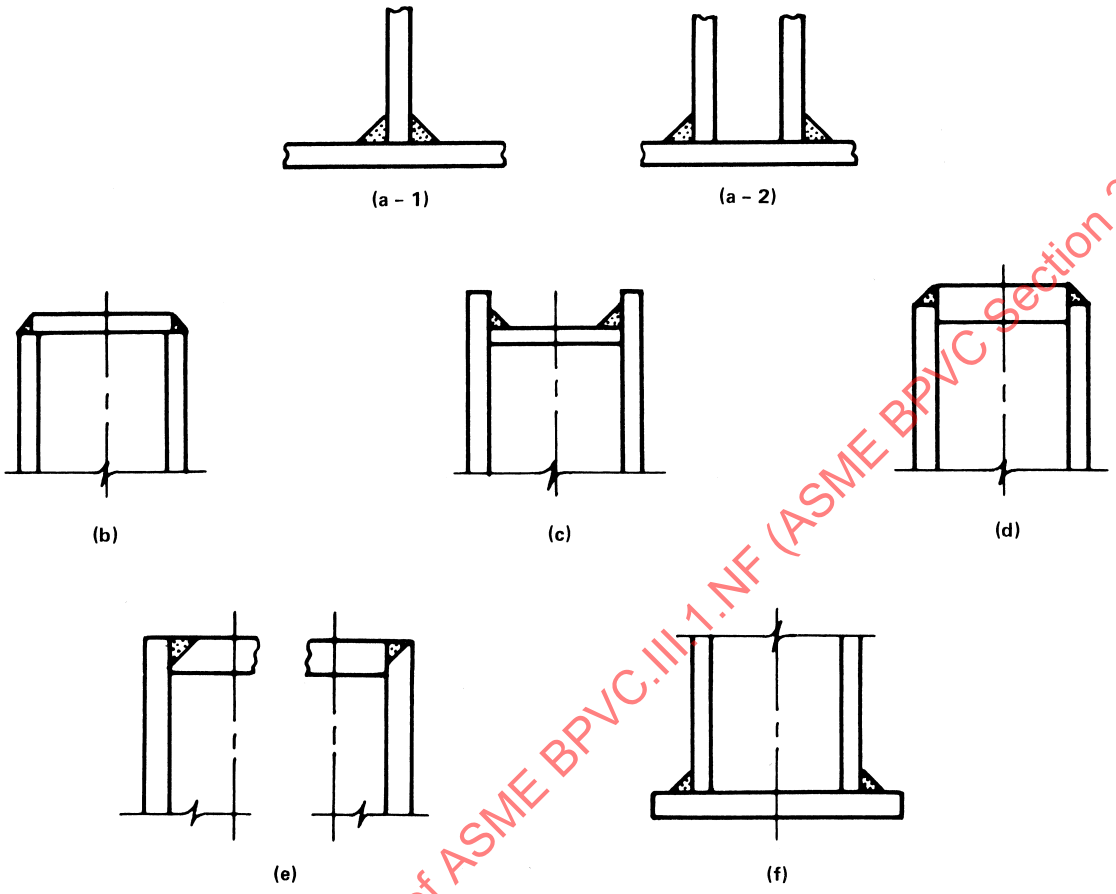
Figure NF-3426.1-1
Additional Permissible Welded Joints for Class 1 Standard Supports



NF-3455 Design of Bolting

The requirements of NF-3225 and NF-3324.6 shall be met.

NF-3456 Design of Welded Joints

The requirements of NF-3426 shall be met, except that for groove welded and fillet welded T-joints, the welds may be intermittent instead of continuous.

NF-3460 DESIGN BY ANALYSIS FOR CLASS 3

The design of Class 3 Standard Supports shall be in accordance with the requirements of NF-3450, using one of the design procedures indicated in Table NF-3131(a)-1.

NF-3470 DESIGN BY EXPERIMENTAL STRESS ANALYSIS

Standard Supports may be designed by experimental stress analysis in accordance with the requirements of NF-3270 for Plate- and Shell-Type Standard Supports and NF-3370 for Linear-Type Standard Supports.

NF-3480 PROCEDURE FOR LOAD RATING

Standard Supports may be designed by the procedure for load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type Standard Supports and NF-3380 for Linear-Type Standard Supports.

NF-3500 DESIGN RULES FOR COMPONENT SUPPORTS

NF-3510 GENERAL REQUIREMENTS

The design of component supports shall be in accordance with this subarticle and the applicable general requirements of NF-3110, NF-3210, NF-3310, and NF-3410.

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NF-3520 DESIGN BY ANALYSIS FOR CLASS 1

NF-3521 General Design Requirements

This subsubarticle provides stress limits for elements of Class 1 component supports. For general requirements as to stress determinations, definitions, derivations of stress intensities, and classification of stresses, refer to NF-3120.

NF-3522 Design of Plate- and Shell-Type Component Supports

(a) The design rules and stress intensity limits which must be satisfied for the Design and Service Loadings are given in NF-3220.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3221.2-1.

NF-3523 Design of Linear-Type Component Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3320.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3312.1(b)-1.

NF-3524 Design of Standard Component Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3420.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3221.2-1 or Table NF-3312.1(b)-1, as applicable.

NF-3525 Design of Bolting

The number and cross-sectional area of bolts required for the Design Loadings of NF-3112 shall be determined in accordance with the procedures of NF-3324.6.

NF-3526 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Component Supports shall be as stipulated in NF-3226.

(b) Welded joints used in Linear-Type Component Supports shall be as stipulated in NF-3324.5.

NF-3550 DESIGN BY ANALYSIS FOR CLASS 2, 3, AND MC

NF-3552 Design of Plate- and Shell-Type Component Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3250 and NF-3260.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3251.2-1.

NF-3553 Design of Linear-Type Component Supports

The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3523.

NF-3554 Design of Class 2 and 3 Standard Component Supports

The design of Standard Component Supports shall be in accordance with NF-3524.

NF-3555 Design of Bolting

The provision of NF-3525 shall be met.

NF-3556 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Component Supports shall be as stipulated in NF-3256 for Class 2 and MC and NF-3266 for Class 3.

(b) Welded joints in Linear-Type Component Supports shall be as stipulated in NF-3324.5.

NF-3570 EXPERIMENTAL STRESS ANALYSIS

Component supports of all types may be designed by experimental stress analysis in accordance with Section III Appendices, Mandatory Appendix II. The test collapse load may be determined by Section III Appendices, Mandatory Appendix II, II-1430. Supports designed by experimental stress analysis for Level A and Level B Service Conditions shall not exceed the test collapse load divided by 1.7. Supports designed by experimental stress analysis for Level C Service Condition shall not exceed the test collapse load divided by 1.3. Supports designed by experimental stress analysis for Level D Service Condition shall not exceed the test collapse load.

NF-3580 DESIGN BY LOAD RATING

Component supports of all types may be designed by load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type, NF-3380 for Linear-Type, and the applicable subsubarticle for Standard Component Supports.

NF-3600 DESIGN RULES FOR PIPING SUPPORTS

NF-3610 GENERAL REQUIREMENTS

The design of piping supports shall be in accordance with this subarticle and the applicable general requirements of NF-3110, NF-3210, NF-3310, and NF-3410.

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Table NF-3611-1
Suggested Piping Support Spacing

Nominal Pipe Size, in. (DN)	Suggested Maximum Span, ft (m)	
	Water Service	Steam, Gas, or Air Service
1 (25)	7 (2.1)	9 (2.7)
2 (50)	10 (3.0)	13 (3.9)
3 (80)	12 (3.6)	15 (4.5)
4 (100)	14 (4.2)	17 (5.1)
6 (150)	17 (5.1)	21 (6.4)
8 (200)	19 (5.7)	24 (7.3)
12 (300)	23 (7.0)	30 (9.1)
16 (400)	27 (8.2)	35 (10.6)
20 (500)	30 (9.1)	39 (11.8)
24 (600)	32 (9.7)	42 (12.8)

GENERAL NOTES:
(a) Suggested maximum spacing between piping supports for horizontal straight runs of standard and heavier piping with a maximum operating temperature of 750°F (400°C).
(b) Does not apply where span calculations are made or where there are concentrated loads between supports such as flanges, valves, specialties, etc.
(c) The spacing is based on a maximum combined bending and shear stress of 1.5 ksi (10 MPa) and insulated piping filled with water or the equivalent weight of steel pipe for steam, gas, or air service, and the pitch of the line is such that a sag of 0.1 in. (2.5 mm) between supports is permissible.

NF-3611 Spacing of Piping Supports

Supports for piping with a longitudinal axis in approximately a horizontal position shall be spaced to prevent excessive shear stresses resulting from sag and bending in the piping, with special consideration given when components such as pumps and valves impose concentrated loads. The suggested maximum spans for spacing of weight supports for standard weight and heavier piping are given in Table NF-3611-1.

NF-3612 Vibration

Piping shall be arranged and supported so that vibration will be minimized.

NF-3613 Anchors, Guides, Pivots, and Restraints

Anchors, guides, pivots, and restraints shall be designed to secure the desired points of piping in a relatively fixed position. They shall permit the piping to expand and contract freely as directed from the anchored or guided point and shall be structurally capable of withstanding the thrusts, moments, and other imposed loads.

NF-3614 Support Adjustments

(a) Screwed adjustments shall have threaded parts to conform to ASME B1.1 coarse threaded series, Class 2 fit. Alternatively, other thread forms, series, and fits may be used which permit adjustment after erection, and are designed to withstand the forces, moments, and other imposed loads acting on the support, considering the worst combination of thread tolerances.

(b) Turnbuckles and adjusting nuts shall have the full length of thread in engagement. Means shall be provided for determining that full thread length is engaged. All screw and equivalent adjustments shall be provided with suitable locking devices.

NF-3615 Piping Clamps

(a) When clamps are used to support vertical piping lines, it is recommended that shear lugs be welded to the piping to prevent slippage.

(b) In addition to the provision of (a), clamps to support vertical piping lines with rigid connections shall be designed to support the total load on either arm in the event the load shifts because of piping or hanger movement, or both.

NF-3616 Hanger Rods

The provisions for hanger rods of NF-3412.3 apply.

NF-3620 DESIGN BY ANALYSIS FOR CLASS 1

NF-3622 Design of Plate- and Shell-Type Piping Supports

(a) The design rules and stress intensity limits which must be satisfied for the Design and Service Loadings are given in NF-3220.

(b) When design by analysis is used, the stress intensity limit factors for each loading and stress category are specified in Table NF-3221.2-1.

NF-3623 Design of Linear-Type Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3320.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3312.1(b)-1.

NF-3624 Design of Standard Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3420.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3221.2-1 or Table NF-3312.1(b)-1, as applicable.

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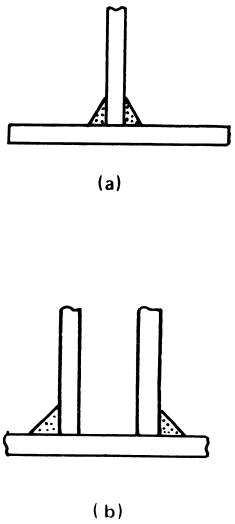
Figure NF-3626(a)-1
Additional Permissible Welded Joints for Class 1 Piping Supports



NF-3625 Design of Bolting

The number and cross-sectional area of bolts required for the Design Loadings of NF-3112 shall be determined in accordance with the procedures of NF-3324.6. The allowable bolt design stress value shall be determined in accordance with NF-3324.6.

NF-3626 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Piping Supports shall be as stipulated in NF-3226. In addition, tee joints, double fillet welded, sketch (a) [see Figure NF-3626(a)-1] and single welded, when double members, sketch (b), are permitted.

(b) Welded joints used in Linear-Type Piping Supports shall be as stipulated in NF-3324.5.

NF-3650 DESIGN BY ANALYSIS FOR CLASS 2 AND 3

NF-3652 Design of Plate- and Shell-Type Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3250 and NF-3260.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3251.2-1.

NF-3653 Design of Linear-Type Piping Supports

The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3623.

NF-3654 Design of Standard Piping Supports

The design of Standard Piping Supports shall be in accordance with NF-3624.

NF-3655 Design of Bolting

The provisions of NF-3625 shall be met.

NF-3656 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Piping Supports shall be as stipulated in NF-3256 for Class 2 and NF-3266 for Class 3.

(b) Welded joints used in Linear-Type Piping Supports shall be as stipulated in NF-3324.5.

NF-3670 EXPERIMENTAL STRESS ANALYSIS

Piping supports of all types may be designed by experimental stress analysis in accordance with Section III Appendices, Mandatory Appendix II. The test collapse load may be determined by Section III Appendices, Mandatory Appendix II, II-1430. Supports designed by experimental stress analysis for Level A and Level B Service Conditions shall not exceed the test collapse load divided by 1.7. Supports designed by experimental stress analysis for Level C Service Condition shall not exceed the test collapse load divided by 1.3. Supports designed by experimental stress analysis for Level D Service Condition shall not exceed the test collapse load.

NF-3680 DESIGN BY LOAD RATING

Piping supports of all types may be designed by load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type, NF-3380 for Linear-Type, and the applicable subsubarticle for Standard Piping Supports.

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ARTICLE NF-4000
FABRICATION AND INSTALLATION

NF-4100 GENERAL REQUIREMENTS

NF-4110 INTRODUCTION

NF-4111 Fabrication and Installation

Supports shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from material which meets the requirements of Article NF-2000.

NF-4112 Reassembly of Subsection NF Supports

The Certificate Holder may reassemble supports from completed supports that have not been in operating service or from parts and material of disassembled supports that have not been in operating service, provided all required documentation is available and the applicable Code requirements are met.

The program for maintaining identification of material and parts, including material documentation and certification documents (Certificate of Compliance and NS-1 Certificate of Conformance) shall be described in a written procedure.

NF-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY SUPPORT CERTIFICATE HOLDER

NF-4121 Means of Certification

The NS Certificate Holder for a support shall certify Code compliance by the furnishing of an NS-1 Certificate of Conformance [see NCA-3211.43(a)] for welded supports or a Certificate of Compliance [see NCA-3211.43(b)] for nonwelded supports.

(23) **NF-4121.1 Certification of Treatments, Tests, and Examinations.** If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles of this Section, it shall certify that it has fulfilled that requirement [see NCA-1224.1(c)]. Reports of all required treatments and the results of all required tests, repairs, and examinations performed by the NS Certificate Holder shall be maintained as quality assurance records in accordance with NCA-4134.17.

NF-4121.2 Repetition of Tensile or Impact Tests. If during the fabrication or installation of the support the material is subjected to heat treatment that has not been covered by treatment of the test coupons (see NF-2200) and that may reduce either the 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 NF-2000.

NF-4122 Material Identification

Material for supports shall carry identification markings which will remain distinguishable until the support is fabricated or installed. If the original identification markings are cut off or the material is divided, the marks shall be accurately transferred to the parts or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation, unless otherwise provided by NF-2150. Material supplied with a Certificate of Compliance and welding and brazing material shall be identified and controlled so that they can be traced to each support, or else a control procedure shall be employed which ensures that the specified material is used.

NF-4123 Visual 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 NF-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 NF-5500 and NF-5100, respectively, unless so specified.

NF-4125 Testing of Welding and Brazing Materials (23)

All welding material shall meet the requirements of NF-2400. All brazing material shall meet the requirements of NF-4512.

NF-4130 REPAIR OF MATERIAL

NF-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NF-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided

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the condition is corrected in accordance with the requirements of NF-2500 for the applicable product form, except

(a) weld repair is not required if the defect is removed by mechanical means and does not reduce the section below the minimum thickness required by Article NF-3000

(b) when weld repair is performed

(1) the weld repair restores the section to the minimum thickness required by Article NF-3000

(2) the limitation on the depth of weld repair does not apply

(3) the time of examination of weld repairs to weld edge preparations and to material shall be in accordance with NF-5120

(4) the provisions of NF-2610(e) for weld repair of structural material apply

NF-4200 FORMING, FITTING, AND ALIGNING

NF-4210 CUTTING, FORMING, AND BENDING

NF-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NF-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.

NF-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend materials, including weld metal, provided the required dimensions are attained (see NF-4214 and NF-4220), and provided the specified impact properties of the material, 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 NF-4213.

NF-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications, a procedure qualification test shall be conducted using specimens taken from material of the same material specification, grade or class, heat treatment, and with similar impact properties as required for the material in the support. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the support. Applicable tests shall be conducted to determine that the required impact properties of NF-2300 are met after straining.

NF-4213.1 Exemptions. Procedure qualification tests are not required for material listed in (a) through (f)

(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 material represented by test coupons which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts

(c) material which does not require impact tests in accordance with NF-2300

(d) material which has 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 NF-2300 is performed on each heat and lot, as applicable, after forming

NF-4213.2 Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f).

(a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of Article NF-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

For cylinders:

$$\%\ \text{strain} = \left(50t/R_f\right)\left[1 - \left(R_f/R_o\right)\right]$$

For spherical or dished surfaces

$$\%\ \text{strain} = \left(75t/R_f\right)\left[1 - \left(R_f/R_o\right)\right]$$

For pipe

$$\%\ \text{strain} = 100r/R$$

where

R = nominal bending radius to the centerline of the pipe, in. (mm)
r = nominal radius of the pipe, in. (mm)
R_f = final radius to centerline of shell, in. (mm)
R_o = original radius (equal to infinity for a flat part), in. (mm)
t = nominal thickness, in. (mm)

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(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 specimens shall be taken from each of three heats of material to establish a transition curve showing in both the upper and lower shelves. On each of these 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 each, depending on the product form.

(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 of the temperature under consideration or

(-b) the maximum change of temperature at the lateral expansion and energy levels under consideration or

(2) when lateral expansion is the acceptance criterion (see NF-2300), either the maximum change in temperature or the maximum change in lateral expansion

NF-4213.3 Acceptance Criteria for Formed Material. To be acceptable, the formed material used in the support shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NF-4213.4 Requalification. A new procedure qualification test is required when any of the following changes are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified considering NF-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

NF-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article NF-3000, the material may be repaired in accordance with NF-4130.

NF-4220 SUPPORT TOLERANCES

Tolerances not specified in this subsection shall be specified by the designer in accordance with NF-3134.

NF-4221 Tolerances for Plate- and Shell-Type Supports

(a) The outer surface of a plate- and shell-type support shall not deviate from the specified shape by more than 1¼% of the overall design dimension. Such deviations shall not include abrupt changes.

(b) For plate- and shell-type supports which are skirts, the difference between the maximum and minimum outside diameters shall not exceed 1% of the nominal outside diameter.

NF-4230 FITTING AND ALIGNING

NF-4231 Fitting and Aligning Methods

Parts that are to be joined may be fitted, aligned, and retained in position during the joining operation by the use of bars, jacks, clamps, drift pins, tack welds, or temporary attachments. Mechanical devices shall be carefully used to avoid damage to surfaces of the parts and to avoid enlargement of bolt holes.

NF-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.

NF-4231.2 Column Bases.

(a) Column bases shall be set level and to correct elevation with full bearing on the masonry.

(b) Column bases shall be finished in accordance with the requirements of (1) through (3).

(1) Rolled steel bearing plates 2 in. (50 mm) or less in thickness may be used without milling, provided a satisfactory contact bearing is obtained. Rolled steel bearing plates over 2 in. (50 mm) but not over 4 in. (100 mm) in thickness may be straightened by pressing or, if presses are not available, by milling for all bearing surfaces except those noted in (3) to obtain satisfactory contact bearing. Rolled steel bearing plates over 4 in. (100 mm) in thickness shall be milled for all bearing surfaces except as noted in (3).

(2) Column bases other than rolled steel bearing plates shall be planed for all bearing surfaces, except as noted in (3).

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Table NF-4232-1
Maximum Allowable Offset in Final Butt-Welded Joints

Section Thickness, in. (mm)	Maximum Allowable Offset
Up to $\frac{3}{4}$ (19), incl.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ to 6 (38 to 150), incl.	$\frac{1}{8}t$
Over 6 (150)	$\frac{3}{4}$ in. (19 mm)

(3) The bottom surfaces of bearing plates and column bases which are grouted to ensure full bearing contact on foundation need not be planed.

NF-4232 Maximum Offset of Aligned Sections

Alignment of butt joints shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NF-4232-1, where t is the nominal thickness of the thinner section of the joint.

NF-4232.1 Fairing of Offsets. Any offset within the allowable tolerance of Table NF-4232-1 shall be blended uniformly 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.

NF-4240 REQUIREMENTS FOR WELDED JOINTS

Butt welds may be made with or without backing or consumable insert rings. When the use of permanent backing rings is undesirable [see NF-3226.1(a) or NF-3256.1(a)]

(a) the backing ring shall be removed and the inside of the joint ground smooth

(b) the joint shall be welded without backing rings or

(c) consumable insert rings shall be used

NF-4245 Complete Joint Penetration Welds

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.

NF-4300 WELDING QUALIFICATIONS

NF-4310 GENERAL REQUIREMENTS

NF-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection shall be used for welding support material or attachments thereto. Any process used shall be such that the records required by NF-4320 can be prepared except that records for stud welds shall be traceable to the welders and welding operators, and not necessarily to each specific weld.

NF-4311.1 Stud Welding Restrictions. Stud welding is acceptable for insulation supports, nameplates, and locating lugs. Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs or an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. When studs are $\frac{1}{2}$ in. (13 mm) in diameter or less, postweld heat treatment, qualified welding procedures, and certified welding materials are not required.

NF-4311.2 Capacitor Discharge Welding. Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided

(a) temporary attachments are removed in accordance with the provisions of NF-4435(b)

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm)

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required

NF-4311.4 Inertia and Continuous Drive Friction Welding.

(a) Inertia and continuous drive friction welding shall not be used for fabrication of Class 1 Plate- and Shell-Type Component Supports.

(b) The weld between the two members shall be a full penetration weld.

NF-4320 WELDING QUALIFICATIONS AND RECORDS

NF-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by its organization and shall establish the procedure and conduct the tests required by this Article and Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to support elements and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies

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particularly to material and weld metal of 80 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Authorization.

NF-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of its qualified welding procedures and of the welders and welding operators qualified by it, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program.

NF-4322.1 Identification of Joints for Class 1 Component Supports.

(a) For Class 1 Plate- and Shell-Type, and Linear-Type Component Supports, the welder or welding operator shall apply the identification mark assigned to that person by the Certificate Holder on or adjacent to all permanent welds, including fillet welds, at 3 ft (1 m) intervals or less, except as noted in (b). The marking shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in a component support, and of the welders and welding operators used in making each of the joints.

(b) For partial penetration welds with a depth less than 1 in. (25 mm) and fillet welds with a throat dimension less than 1 in. (25 mm) in primary members, and for all welds in secondary members, the Certificate Holder need not identify the welder or welding operator who welded each joint provided

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification

NF-4322.2 Identification of Other Joints. For all types of Class 2, 3, and MC component supports and for all classes of piping supports and Standard Supports, the Certificate Holder shall certify that only welders and welding operators qualified in accordance with NF-4321 were used in making all welds.

NF-4322.3 Identification of Tack Welds. The identification of welder or welding operator is not required for tack welds.

NF-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NF-4320 and Section IX shall be used.

NF-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX.

NF-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NF-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

NF-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b).

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NF-4334.1 Coupons Representing the Weld Deposits. Impact test specimen and testing methods shall conform to NF-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$, and where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NF-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the

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weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld.

NF-4334.2 Coupons Representing the Heat-Affected Zone. Where impact tests of the heat-affected zone are required by NF-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c).

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to NF-2321. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat-affected zone values with base material values [see NF-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material.

(23) NF-4335 Impact Test Requirements

When materials are required to be impact tested per NF-2300, impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. Exemptions from impact testing under NF-2311(b)(9) and NF-2311(b)(10) do not apply to weld metal. Exemption from impact testing of the heat-affected zone of those base materials which are exempted by NF-2311(b)(9) and NF-2311(b)(10) is not permitted. The welding procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NF-2330 and NF-4334. Retests in accordance with the provisions of NF-2350 are permitted.

NF-4335.1 Impact Tests of Weld Metal. (23)

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $^{5}/_{8}$ in. (16 mm) in thickness when the weld is made on the surface or penetrates the base material that requires impact testing in accordance with NF-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NF-2310, regardless of the depth of the repair. Exemption from impact testing under NF-2311(b)(9) and NF-2311(b)(10) does not apply to weld metal of the welding procedure qualification test for either production weld joints or base material repairs.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NF-2330 for the base material to be welded or repaired. Where two materials which have different fracture toughness requirements are to be joined by welding, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification (WPS) qualified to the impact testing requirements of Subsection NB, NCD (Class 2 only), or NE may be accepted as an alternative to the WPS impact testing requirements of this Subsection.

NF-4335.2 Impact Tests of Heat-Affected Zone.

(a) Charpy V-notch tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $^{5}/_{8}$ in. (16 mm), and either of the base materials requires impact testing in accordance with the rules of NF-2310. Exemption of base materials by NF-2311(b)(9) or NF-2311(b)(10) does not apply to the welding procedure qualification of the heat-affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit

(2) the qualification for weld deposit cladding or hard-facing on any base material

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or $^{3}/_{16}$ in. (5 mm) thickness, whichever is less

(b) Charpy V-notch testing shall be performed as specified in (1) through (6).

(1) Charpy V-notch test specimens representing both the heat-affected zone and the unaffected base material shall be tested. The unaffected base material shall be tested at a temperature equal to or below that specified in NF-2311(c).

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(2) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of NF-2330 for the applicable Class and acceptance category. If the requirements are not met at the test temperature, additional testing shall be performed at higher temperatures until the above requirements are met.

(3) The heat-affected zone specimens shall be tested at the test temperature determined in (2). If the average applicable toughness value of the heat-affected zone specimens equals or exceeds the average applicable toughness value of the unaffected base material, the qualification test is acceptable for the essential and supplemental essential variables recorded on the Welding Procedure Qualification Record. If the heat-affected zone average applicable toughness value is less than the unaffected base material average applicable toughness value, the adjustment given in (4) through (6) shall be determined and applied as provided in (c). Alternatively, another test coupon may be welded and tested.

(4) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the applicable toughness values of all three specimens tested are not less than that specified in (2). The average applicable toughness value for each test meeting this requirement shall be plotted on a property-temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat-affected zone and the unaffected base material average applicable toughness values are the same and not less than that specified in (2) shall be used to determine the adjustment temperature T_{ADJ} where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \le 0$, then $T_{ADJ} = 0$.

(5) As an alternative to (4), if the applicable toughness values of the heat-affected zone are no less than those specified in NF-2330 for the applicable Class and acceptance category and the average applicable toughness value of the heat-affected zone specimens is not less than 7 ft-lb (10 J) or 5 mils (0.13 mm) below the average applicable toughness value of the unaffected base material, T_{ADJ} may be taken as 15°F (8°C).

(6) As a second alternative to (4), if the applicable toughness values of the heat-affected zone are no less than those specified in NF-2330 for the applicable Class and acceptance category, the difference between the average applicable toughness value of the heat-affected zone and the unaffected base material shall be calculated and used as described in (c)(3).

(c) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure.

(1) The lowest service temperature specified in the Design Specification for all of the material to be welded in production Welding Procedure Specifications supported by this Welding Procedure Qualification Record shall be increased by the adjustment temperature T_{ADJ}.

(2) The specified testing temperature for the production material may be reduced by T_{ADJ}.

(3) The materials to be welded may be welded using the Welding Procedure Specification, provided they exhibit toughness values that are no less than the minimum required toughness values specified in NF-2300 plus the difference in the average applicable toughness values established in (b)(6).

(d) The Charpy V-notch testing results shall be recorded on the Welding Procedure Qualification Record and any offsetting T_{ADJ} or increased toughness requirements shall be noted on the Welding Procedure Qualification Record and on the Welding Procedure Specification. More than one compensation method may be documented on the Welding Procedure Qualification Record.

(e) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NCD (Class 2 only), or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NF-4400 RULES GOVERNING MAKING AND REPAIRING WELDS

NF-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NF-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of supports (see NF-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NF-4412 Cleanliness and Protection of Weld Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NF-4420 RULES FOR MAKING WELDED JOINTS

NF-4421 Backing Strips

The materials for backing strips, when used, shall be compatible with the base metal.

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NF-4422 Peening

The weld metal may be peened when it is deemed necessary or helpful to control distortion.

NF-4423 Double-Welded Joints

Before applying weld metal on the second side to be welded, the root of full penetration double-welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

NF-4424 Surfaces of Welds

(a) The surface condition of the finished weld shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys for the proper interpretation of radiographic and other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of Article NF-3000.

(c) Fusion shall exist between adjacent layers of weld metal and between weld metal and base metal except as provided in NF-5360(c).

(d) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within ±10%. Flash shall be removed to sound metal.

NF-4427 Shape and Size of Welds

(a) Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Figure NF-4427-1. Convexity of fillet welds is not a criteria for acceptance and need not be measured.

(b) The faces of groove welds may be flat or convex. The thickness of groove welds shall be no less than $^{1}/_{32}$ in. (0.8 mm) less than the thickness of the thinner of the members joined.

(c) On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.

NF-4429 Plug Welds

When plug welds are used on supports, a fillet weld shall first be deposited around the circumference at the bottom of the hole.

NF-4430 WELDING OF ATTACHMENTS

NF-4435 Welding of Nonstructural and Temporary Attachments, and Their Removal

(a) Nonstructural attachments such as insulation supports, nameplates, locating lugs, and temporary attachments may be noncertified material and may be welded to the support or parts thereof with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (5) are met

(1) the welding procedure and the welders have been qualified in accordance with NF-4321

(2) the material is identified and is suitable for welding

(3) the material is compatible with the material to which it is attached

(4) the welding material is identified and compatible with the materials joined

(5) the welds are postweld heat treated when required by NF-4620

(b) Removal of nonstructural temporary attachments shall be accomplished as follows:

(1) the temporary attachment shall be completely removed in accordance with the procedures of NF-4211

(2) as an alternative to (a)(5), postweld heat treatment may be deferred until after removal of the attachment

(3) the surface of the support shall be visually examined after removal of the temporary attachment

NF-4440 SPECIAL REQUIREMENTS FOR WELDING

NF-4441 Through-Thickness Loading

Welded joint configurations causing significant through-thickness tensile stress [as defined in NF-1215(b)] during fabrication or service on rolled product forms should be avoided. When this type of construction is used, weld volume and welding heat input on the rolled surfaces should be limited to the extent practical. When identified by the Design Output Documents [see NF-3226.3, NF-3256.4, and NF-3324.5(g)], weld joints in primary members 1 in. (25 mm) or greater in thickness in component supports subjected to significant through-thickness tensile loads and any other weld joints identified in the Design Output Documents shall meet one of the following requirements:

(a) After completion of welding, the base material directly underneath the attachment shall be ultrasonically examined in accordance with the requirements of NF-5214, NF-5224, or NF-5234, as appropriate to the component support class.

(b) A weld metal inlay or overlay shall be made in accordance with Figure NF-4441-1 and ultrasonically examined in accordance with NF-5214, NF-5224, or NF-5234, prior

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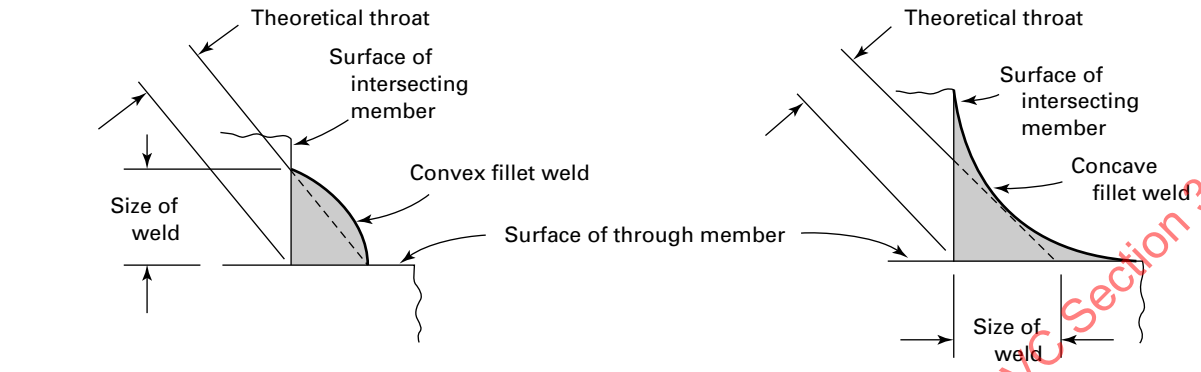
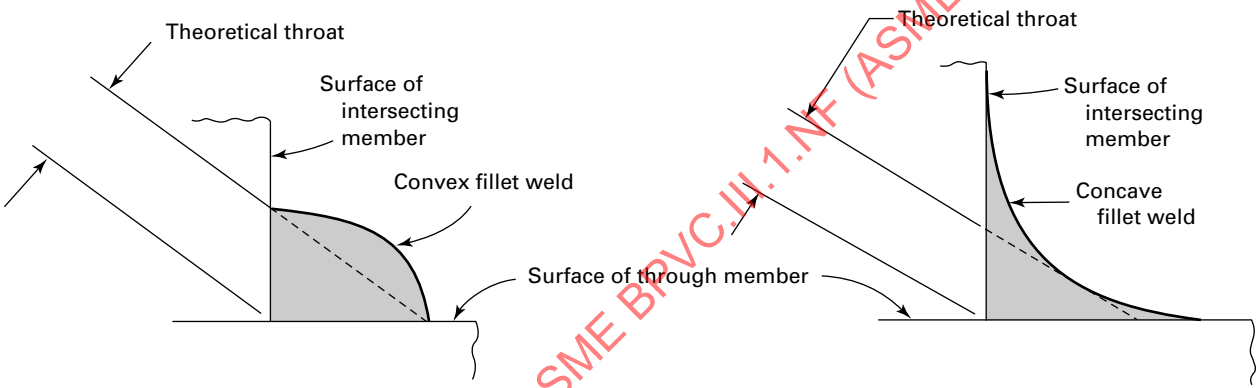
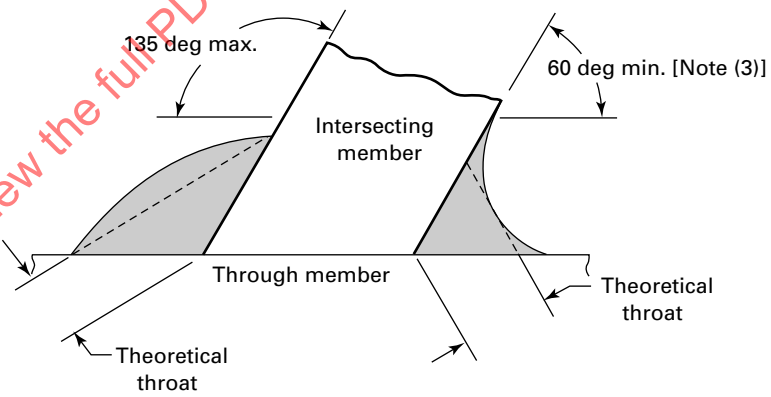
Figure NF-4427-1
Fillet Weld Dimensions



(a) Equal Leg Fillet Weld [Note (1)]



(b) Unequal Leg Fillet Weld [Note (2)]



(c) Skewed T-Joints [Note (3)]

NOTES:
(1) The "size" of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat = 0.7 × size of weld.
(2) The "size" of an unequal leg fillet weld is the shorter leg length of the largest right triangle, which can be inscribed within the fillet weld cross section.
(3) When the intersecting member is less than 60 deg, the weld shall be considered a partial penetration groove weld [NF-3324.5(d)(4)].

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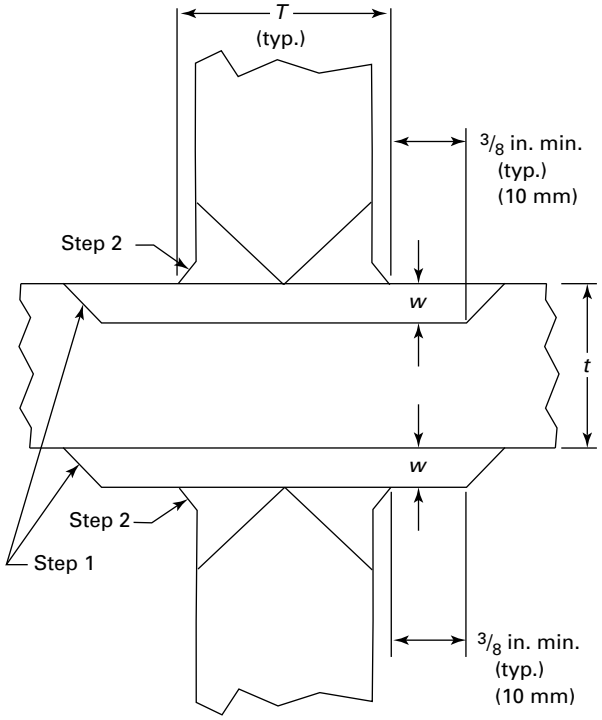
Figure NF-4441-1
Weld Joint Producing Through-Thickness Loading



Step 1: Inlay or overlay weldment

Step 2: Completion of weldment

GENERAL NOTES:
(a) T is the width of the welded zone measured on the primary member surface.
(b) Members may be welded on one side only or from both sides.
(c) Inlay or overlay thickness shall be $\frac{1}{4}$ in. (6 mm) min. for t = 1 in. (25 mm) and shall be increased $\frac{1}{16}$ in. (1.5 mm) for each additional $\frac{3}{8}$ in. (10 mm) of t but not exceed $\frac{1}{2}$ in. (13 mm).
(d) When T exceeds t, w shall be increased by an additional $\frac{1}{16}$ in. (1.5 mm) for each $\frac{3}{8}$ in. (10 mm) of T over t, to a maximum of $\frac{1}{2}$ in. (13 mm).
(e) The minimum specified tensile strength of the electrodes used for inlay or overlay shall not exceed the minimum specified tensile strength of the base metal by more than 12 ksi (83 MPa).

to making the weld joining the attachment member to the inlay or overlay.

(c) The material shall meet the acceptance standards of SA-770, Through-Thickness Tension Testing of Steel Plates for Special Applications.

NF-4450 REPAIR OF WELD METAL DEFECTS

NF-4451 General Requirements (23)

Discontinuities detected in weld metal by examination (see Article NF-5000) and classified as defects shall be reduced to imperfections of acceptable size and, if necessary, repaired by welding.

NF-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided that the requirements of (a) through (c) are met.

(a) The remaining thickness of the section is not reduced below that required by Article NF-3000.

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

(c) The area is examined after blending by a magnetic particle or liquid penetrant method in accordance with NF-5110 and meets the acceptance standards of NF-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by the visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NF-4453 Requirements for Making Repairs to Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NF-4453.1 Defect Removal. Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NF-5110 and shall meet the acceptance standards of NF-5340 or NF-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NF-4453.2 Requirements for Welding Materials, Procedures, and Welders. The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NF-4125 and NF-4300.

NF-4453.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NF-4453.4 Examination of Repair Welds. The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the

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liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(a) $\frac{1}{3}t_w$ for $t_w \le \frac{3}{4}$ in. (19 mm)

(b) $\frac{1}{4}$ in. (6 mm) for $\frac{3}{4}$ in. (19 mm) $< t_w \le 2\frac{1}{2}$ in. (64 mm)

(c) the lesser of $\frac{3}{8}$ in. (10 mm) or 10% t_w for $t_w > 2\frac{1}{2}$ in. (64 mm)

where t_w equals the nominal thickness of the original weld.

NF-4453.5 Heat Treatment of Repaired Areas. The repaired area shall be heat treated when required by NF-4620.

NF-4500 BRAZING

NF-4510 RULES FOR BRAZING

NF-4511 Where Brazing May Be Used

Furnace brazing is permitted for the construction of supports in accordance with the rules of this Subsection provided the following additional requirements are met:

(a) Brazing procedures and brazing operators shall be qualified in accordance with Section IX.

(b) Clearance or interference between mating parts shall be in accordance with the Brazing Procedure Specification.

(c) Base material shall be limited to material permitted by NF-2120 and Section IX, P-Nos. 101 and 102 ferritic material.

(d) Brazing alloys shall be limited to Section IX, F-No. 105.

(e) The allowable shear stress shall be 15 ksi (105 MPa) or 0.4 times the yield strength of the base material [see NF-3322.1(b)], whichever is less, and the joint shall be loaded principally in shear only.

(f) Postbrazing heat treatment to develop or restore base material mechanical properties shall be qualified by test specimens which meet the thickness requirements of Section IX, QB-451. The base material test specimens shall be exposed to the same thermal treatment as a brazed part but need not contain a brazed joint. Postbrazing heat treatment of actual parts or test specimens may be performed in the same heat cycle as the brazing operation or in a separate heat cycle. Postbrazing heat treatment shall not exceed 1,850°F (1 010°C).

(g) Brazing alloy shall be preplaced on one side of the joint only. Each production joint shall be visually examined after brazing. Brazing metal must be continuous on the preplaced brazing metal side and 85% continuous on the other side.

NF-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in NF-2150 and to the following requirements:

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (425°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined and to promote free flowing of the filler material.

NF-4600 HEAT TREATMENT

NF-4610 WELDING PREHEAT AND INTERPASS REQUIREMENTS

NF-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheat requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NF-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NF-4613 Interpass Temperatures

Consideration should be given to limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

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NF-4620 POSTWELD HEAT TREATMENT

NF-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NF-4622 PWHT Time and Temperature Requirements

NF-4622.1 General Requirements.[1] Except as otherwise permitted in NF-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges and for the minimum holding times specified in Table NF-4622.1-1, except as otherwise permitted in NF-4622.4(c). P-Number groups in Table NF-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NF-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NF-4622.2 Time–Temperature Recordings. Time–temperature recordings of all postweld heat treatments shall be maintained as quality assurance records in accordance with NCA-4134.17. Identification on the time–temperature recording shall be to the weld, part, or support. A summary of the time–temperature recording may be provided for permanent records in accordance with NCA-4134.17.

(23) **NF-4622.3 Definition of Nominal Thickness Governing PWHT.** Nominal thickness in Table NF-4622.7(b)-1 is the thickness of the weld, the base material, or the thinner of the base materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3 mm). For fillet welds, the nominal thickness is the throat thickness, and for partial penetration and repair welds, the nominal thickness is the depth of the weld groove or preparation.

NF-4622.4 Holding Times at Temperature.

(a) The holding time at temperature as specified in Table NF-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treatment cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NF-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NF-2200, NF-2400, and NF-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NF-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NF-4622.4(c)-1 and (1) through (3).

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NF-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the impact test specimens for the welding procedure qualification required by NF-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NF-4622.1-1 and at the lower minimum temperature and increased minimum holding time permitted by Table NF-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table NF-4622.1-1 and the alternative requirements of Table NF-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NF-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NF-2400 shall be made using the same minimum temperatures and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NF-4622.1-1, and at the lower minimum temperatures and increased minimum holding time permitted by Table NF-4622.4(c)-1 is also certified for any temperature in between.

(3) Base material certified in accordance with NF-2210 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

NF-4622.5 PWHT Requirements When Different P-Number Materials Are Joined. When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NF-4622.1-1 for the material requiring the higher PWHT temperature range.

NF-4622.6 PWHT Requirements for Non-Pressure-Retaining Parts. When non-pressure-retaining material is welded to pressure-retaining material, the postweld

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Table NF-4622.1-1
Mandatory Requirements for Postweld Heat Treatment (PWHT) of Welds

(23)

P-No. (Section IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Nominal Thickness of the Weld			
		½ in. (13 mm) or less	Over ½ in. to 2 in. (13 mm to 50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
1, 3	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
4	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1,250–1,400 (675–760)	30 min.	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
6 Gr. 4	1,050–1,150 (565–620)				
7	1,300–1,400 (705–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9A Gr.1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9B Gr. 1	1,100–1,175 (595–635)				
10A Gr. 1, 10C Gr. 1, 10F Gr. 1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
10I Gr. 1	1,300–1,400 (705–760)				
11A Gr. 1	1,025–1,085 (550–585)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)
11A Gr. 4	1,000–1,050 (540–565)				
11A Gr. 5	1,100–1,150 (595–620)				
11B Gr. 1 through 10	1,000–1,100 (540–595)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)
15E Gr. 1	1,350–1,425 (730–775)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45 and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in NF-4622.7.

NOTE: (1) All temperatures are metal temperatures.

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Table NF-4622.4(c)-1
Alternative Holding Temperatures and Times

Material P-Numbers	Alternative Minimum Holding Temperatures, °F (°C)	Alternative Minimum Holding Times
1, 3, 9A Gr. 1, 9B Gr. 1	1,050 (565)	2 hr/in. (4 min/mm) thick
1, 3, 9A Gr. 1, 10A Gr. 1, 9B Gr. 1	1,000 (540)	4 hr/in. (8 min/mm) thick

GENERAL NOTES: All other requirements of NF-4622 shall apply.

heat treatment temperature range of the pressure-retaining material shall control.

(23) **NF-4622.7 Exemptions to Mandatory Requirements.** Postweld heat treatment in accordance with this subarticle is not required for

(a) nonferrous materials

(b) welds exempted in Table NF-4622.7(b)-1

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NF-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material has been heat treated at the higher temperature

(d) postweld heat treatment is not required for supports constructed of Type 405 material or of Type 410 material with carbon content not to exceed 0.08%, welded with electrodes that produce an austenitic chromium–nickel weld deposit or a non-air-hardening nickel–chromium–iron weld deposit, provided the plate nominal thickness at the welded joint does not exceed $^{3}/_{8}$ in. (10 mm), and for thicknesses over $^{3}/_{8}$ in. to $1^{1}/_{2}$ in. (10 mm to 38 mm), provided a preheat of 450°F (230°C) is maintained during welding and the joints are completely radiographed

NF-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (425°C), the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.5 m) interval of weld length. The exceptions of (a) and (b) are permitted.

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table NF-4622.1-1.

(b) For P-No. 7 materials, the cooling rate at temperatures above 1,200°F (650°C) shall not exceed 100°F/hr (56°C/h) after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NF-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NF-4624.1 Furnace Heating — One Heat. Heating the support or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the support or item is prohibited.

NF-4624.2 Furnace Heating — More Than One Heat. The support or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NF-4624.1 apply and overlap of the heated sections of the support or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the support or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the support or item projects from the furnace shall not intersect a structural discontinuity.

NF-4624.3 Local Heating. Welds may be locally postweld heat treated when it is not practical to heat treat the entire support or item. Local postweld heat treatment shall consist of heating a circumferential band around the support or item at temperatures within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the support or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NF-4624.4 Internal Heating. The support or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the support or item. Previous to this operation, the support or item should be fully enclosed with insulating material.

NF-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1^{1}/_{2}$ in. (38 mm) in nominal thickness at the joints shall be given a grain refining heat treatment.

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Table NF-4622.7(b)-1
Exemptions to Mandatory PWHT

(23)

P-Number (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (NF-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)	Minimum Lateral Expansion mils (mm) [Note (3)]
1	All welds where the materials being joined are 1½ in. (38 mm) and less	1¼ in. (32 mm) and less	0.30 or less	...	NR
	All welds where the materials being joined are 1½ in. (38 mm) and less	Over 1¼ in. (32 mm) to 1½ in. (38 mm)	0.30 or less	200 (95)	NR
	All welds where the materials being joined are 1½ in. (38 mm) and less	¾ in. (19 mm) or less	Over 0.30	...	NR
	All welds where the materials being joined are 1½ in. (38 mm) and less	Over ¾ in. (19 mm) to 1½ in. (38 mm)	Over 0.30	200 (95)	NR
	All welds in material over 1½ in. (38 mm)	¾ in. (19 mm) or less	...	200 (95)	NR
1 Gr. 1 [Notes (4), (5)]	All Welds	1½ in. (38 mm) or less	...	50 (10)	NR
	All Welds	over 1½ in. (38 mm) to 4 in. (100 mm)	...	200 (95)	25 (0.64)
1 Gr. 2 and 3 [Notes (4), (5)]	All Welds	1 in. (25 mm) or less	0.30 or less	50 (10)	NR
	All Welds	over 1 in. (25 mm) to 4 in. (100)	0.30 or less	200 (95)	25 (0.64)
3 Gr. 1 [Notes (4), (5)]	All Welds	⅝ in. (16 mm) or less	0.25 or less	150 (65)	NR
	All Welds	Over ⅝ in. (16 mm) to 1 in. (25 mm)	0.25 or less	150 (65)	15 (0.38)
	All Welds	Over 1 in. (25 mm) to 1½ in. (38 mm)	0.25 or less	150 (65)	25 (0.64)
	All Welds	Over 1½ in. (38 mm) to 4 in. (100 mm)	0.25 or less	250 (120)	25 (0.64)
3 Gr. 3	All Welds	½in. (13 mm) or less	0.25 or less	200 (95)	NR
3 Gr. 3 [Notes (4), (5)]	All Welds	⅝ in. (16 mm) or less	0.25 or less	200 (95)	NR
	All Welds	Over ⅝ in. (16 mm) to 1 in. (25 mm)	0.25 or less	200 (95)	15 (0.38)
	All Welds	Over 1 in. (25 mm) to 1½ in. (38 mm)	0.25 or less	200 (95)	25 (0.64)
	All Welds	Over 1½ in. (38 mm) to 4 in. (100 mm)	0.25 or less	300(150)	25 (0.64)
4	All welds in pipes NPS 4 (DN 100) or less or tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	½ in. (13 mm) or less	0.15 or less	250 (120)	NR
5A, 5B, 5C	All welds in pipes or tubes with maximum specified chromium 3.00% or less, NPS 4 (DN 100) or less pipe, and nominal O.D. 4.5 in. (114 mm) or less tubes	½ in. (13 mm) or less	0.15 or less	300 (150)	NR
6 (for Type 410S) or 7 Gr. 1 (for Type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	⅜ in. (10 mm) or less	0.08 or less	...	NR

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Table NF-4622.7(b)-1
Exemptions to Mandatory PWHT (Cont'd)

P-Number (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (NF-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)	Minimum Lateral Expansion mils (mm) [Note (3)]
9A Gr. 1	All welds, except those listed below, provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	5/8 in. (16 mm) or less	...	200 (95)	NR
	Attachment welds joining non-pressure-retaining material to pressure-retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	...	200 (95)	NR
	All welds in pipes NPS 4 (DN 100) or less or tubes with nominal O.D. 4.5 in. (114 mm) and less	1/2 in. (13 mm) or less	0.15 or less	250 (120)	NR
9B Gr. 1	All welds, except those listed below, provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	5/8 in. (16 mm) or less	...	200 (95)	NR
	Attachment welds joining non-pressure-retaining material to pressure-retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	...	200 (95)	NR
10A Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	5/8 in. (16 mm) or less	...	200 (95)	NR
	Attachment welds joining non-pressure-retaining material to pressure-retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	0.25 or less	200 (95)	NR
	All welds in pipes or tubes to pressure-retaining material over 5/8 in. (16 mm)	1/2 in. (13 mm) or less	0.25 or less	200 (95)	NR
10C Gr. 1	All welds in materials 1 1/2 in. (38 mm) and less	1 1/4 in. (32 mm) or less	0.30 or less	...	NR
	Attachment welds joining non-pressure-retaining material to pressure-retaining material over 1 1/4 in. (32 mm)	Over 1 1/4 in. (32 mm) to 1 1/2 in. (38 mm)	...	200 (95)	NR
		1/2 in. (13 mm) or less	...	200 (95)	NR
	Groove or fillet welds attaching nozzle connections not over 2 in. (50 mm) finished I.D. in material over 1 1/4 in. (32 mm), provided ligaments do not require an increased shell or head thickness	1/2 in. (13 mm) or less	...	200 (95)	NR
10I Gr. 1	All welds in material 1/2 in. (13 mm) and less	1/2 in. (13 mm) or less	...	...	NR
11A Gr. 1	All welds in material 1/2 in. (13 mm) and less	1/2 in. (13 mm) or less	...	...	NR
11A Gr. 4	All welds in material 1/2 in. (13 mm) and less	1/2 in. (13 mm) or less	...	250 (120)	NR

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Table NF-4622.7(b)-1
Exemptions to Mandatory PWHT (Cont'd)

P-Number (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (NF-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)	Minimum Lateral Expansion mils (mm) [Note (3)]
11B Gr. 1 through Gr. 10	All welds in materials ½ in. (13 mm) and less	½ in. (13 mm) or less	...	...	NR

GENERAL NOTE: The exemptions noted in this table do not apply to the following:
(a) electron beam welds in ferritic materials over ⅛ in. (3 mm) in thickness
(b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410S), P-No. 10, and P-No. 11 materials

NOTES:
(1) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the thicker of the base materials at the welded joint.
(2) Carbon level of the materials being joined.
(3) Impact testing is required where lateral expansion values are listed, and shall be performed in accordance with the requirements of NF-2300, NF-2400, and NF-4335. When impact testing is required, the base material, heat affected zone, and weld shall be tested. "NR" indicates impact testing is not required.
(4) In addition to the requirements of NF-5120, magnetic particle or liquid penetrant examination shall be performed at ambient temperature after sufficient time (no sooner than 48 hr after reaching ambient temperature).
(5) Carbon and low alloy steel electrodes shall be supplied with a diffusible hydrogen limit of H4 for SMAW electrodes and H8 for flux cored electrodes.
(6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

(23) **Table NF-4622.7(b)-2**
Additional Exemptions to Mandatory PWHT

DELETED

NF-4700 REQUIREMENTS FOR BOLTED CONSTRUCTION

NF-4710 BOLTING AND THREADING

NF-4711 Thread Engagement

The threads of all bolts or studs shall be engaged for the full length of thread in the load carrying nut unless otherwise specified in the Design Documents.

NF-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with any support element material. Contact surfaces within friction-type joints shall be free of lubricants.

NF-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be welded.

NF-4720 BOLTING

NF-4721 Bolt Holes (23)

For the purpose of this Article, high-strength bolts shall be considered those with specified minimum yield strength greater than 80 ksi (550 MPa). Bolt holes shall meet the requirements of (a) through (e).

(a) Holes for nonfitted bolts shall meet the requirements of Table NF-4721(a)-1. For anchor bolts set in concrete or concrete expansion anchor, the hole sizes indicated in this Subsection may be increased by 1/16 in. (1.5 mm). When the bolt hole size is ⅛ in. (3 mm) larger than the bolt, and the bolt is ½ in. (13 mm) or smaller, standard washers shall be used.

(b) Oversized or slotted bolt holes may be used with high-strength bolts ½ in. (13 mm) in diameter and larger, except as restricted in (1), (2), and (3).

(1) Oversized holes shall not exceed the requirements of Table NF-4721(b)-1. They may be used in any or all plies of friction-type connections. Hardened washers shall be installed over exposed oversized holes.

Table NF-4721(a)-1
Bolt Hole Sizes

Bolt Size	Hole Size
≤1 in. (25 mm)	Bolt diameter plus 1/16 in. (1.5 mm)
1⅛ in. to 2 in. (28 mm to 50 mm)	Bolt diameter plus ⅛ in. (3 mm)
>2 in. (50 mm)	Bolt diameter plus 3/16 in. (5 mm)

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Table NF-4721(b)-1
Tolerances on Oversized Holes

Bolt Size	Hole Size
≤½ in. (13 mm)	Bolt diameter plus ⅛ in. (3 mm)
>½ in. (13 mm) and <1 in. (25 mm)	Bolt diameter plus 3⁄16 in. (5 mm)
1 in. (25 mm)	Bolt diameter plus ¼ in. (6 mm)
>1 in. (25 mm)	Bolt diameter plus 5⁄16 in. (8 mm)

(2) Short-slotted holes shall not be wider than permitted by (a) and shall not have a length exceeding the oversize diameter allowed in (1) by more than 1⁄16 in. (1.5 mm). They may be used in any or all plies of friction-type or bearing-type connections. The slots may be used without regard to direction of loading in friction-type connections, but shall be normal to the direction of the load in bearing-type connections. Hardened washers shall be installed over exposed short-slotted holes.

(3) Long-slotted holes shall not be wider than permitted by (a) and shall not have a length which exceeds 2½ times the bolt diameter. In friction-type connections, the long-slotted holes may be used without regard to direction of loading, provided the stress on the bolts does not exceed 75% of the allowable working stress given in Article NF-3000. In bearing-type connections, the long diameter of the slot shall be normal to the direction of loading. Long-slotted holes may be used in only one of the connected parts of either a friction-type or bearing-type connection at an individual faying surface. Structural plate washers or a continuous bar not less than 5⁄16 in. (8 mm) in thickness shall be used to cover long slots that are in the outer plies of joints. These washers or bars shall have a size sufficient to cover the slot completely after installation and shall meet the requirements of Article NF-3000.

(c) Except as specified in (d), holes may be punched, provided the thickness of the material is not greater than the nominal diameter of the bolt plus ⅛ in. (3 mm). When the thickness of the material is greater than the nominal diameter of the bolt plus ⅛ in. (3 mm), holes shall be drilled, subpunched, and reamed, or thermally cut. Thermal cutting shall not be used unless the load-bearing surfaces are machined or ground smooth. For subpunched holes, the die shall be at least 1⁄16 in. (1.5 mm) smaller than the nominal diameter of the bolt.

(d) Bolt holes in material over ½ in. (13 mm) thick having a specified minimum yield strength greater than 80 ksi (550 MPa) shall be drilled.

(e) For bolts not subjected to shear, the limits for oversized and slotted holes in (b) may be increased if structural plate washers or continuous bars which meet the requirements of Article NF-3000 are provided.

NF-4722 Bolted Connections

(a) Surfaces of bolted parts in contact with the bolt head and nut shall not have a slope of more than 1:20 with respect to a plane normal to the bolt axis. Where the surface of high-strength bolted part has a slope of more than 1:20, a beveled washer shall be used to compensate for the lack of parallelism.

(b) Bolts loaded in pure shear shall not have threads located in the load-bearing part of the shank unless permitted by the Design Specifications.

NF-4723 Precautions Before Bolting

All parts assembled for bolting shall have contact surfaces free from scale, chips, or other deleterious material. Surfaces and edges to be joined shall be smooth, uniform, and free from fins, tears, cracks, and other defects which would degrade the strength of the joint.

NF-4724 Bolt Tension

All high-strength structural bolts shall be preloaded to a value not less than that given in the Design Specifications. Preloading shall be monitored by the turn of nut method, by properly calibrated wrenches, by load indicating washers, or by direct extension indicators. Bolts preloaded by means of a calibrated wrench shall be installed with a hardened washer under the nut or bolt head, whichever is the element turned in preloading. Hardened washers are required under the bolt head and the nut when the direct extension or load indicating washer method is used. Hardened washers are not required when bolts are preloaded by the turn of nut method, except that hardened washers are required under the nut and bolt head when the bolts are used to connect material having a specified yield strength less than 40 ksi (270 MPa).

NF-4725 Locking Devices

NF-4725.1 Types of Locking Devices. Threaded fasteners shall be provided with locking devices to prevent loosening during service. Elastic stop nuts and thread locking compounds (when compatible with service conditions), lock nuts, including full or jam, slotted, drilled and wired, free spinning and prevailing torque are all acceptable locking devices. Upset threads by cold working or tack welding may serve as locking devices. Welders making such welds shall be qualified for the process to be used, and a WPS shall be followed, but it is not necessary to qualify the WPS. The welds shall be visually examined and be free of cracks. (23)

Internally and externally toothed washers, and disk and helical spring lock washers shall not be used as locking devices.

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NF-4725.2 Preloading of High-Strength Fasteners. Preloading threaded fasteners made of material with a yield strength of 80 ksi (550 MPa) or greater, loaded in tension, to a value at least 20% above the maximum load on the fastener for the specified loading conditions, limited to 70% of the specified minimum tensile strength of the fastener material satisfies the requirement for locking.

NF-4725.3 Preloading of Non-High-Strength Fasteners. When locking devices cannot be installed because of assembly geometry, preloading of the threaded fasteners in an assembly with fastener material of a yield strength below 80 ksi (550 MPa) is an acceptable method for locking provided the resulting preload is at least 20% above the maximum load on the fastener for the specified loading conditions, but is limited to 70% of the specified minimum tensile strength of the fastener. The threaded assembly shall be tested for the dynamic loading conditions specified in the Design Specification, and the established preload shall be verified on the assembly by properly calibrated wrenches, direct extension indicators, or the turn of the nut method. The results of the test, required preload, and specified thread lubrication shall be provided in the Design Report.

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ARTICLE NF-5000
EXAMINATION

NF-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NF-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATIONS

NF-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and visual examination shall be in accordance with Section V, Article 9. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NF-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of a Level III Examiner. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be maintained on file as detailed in the Certificate Holder's Quality Program. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NF-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination material is applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NF-5114 Rounding-Off of Weld Measurements

In order to properly evaluate specified dimensional sizes, measurements shall be rounded off to the nearest $^{1}/_{32}$ in. (0.8 mm) for undercut and $^{1}/_{16}$ in. (1.5 mm) for weld size. Other dimensions of welds shall be rounded off to the nearest $^{1}/_{8}$ in. (3 mm) or as otherwise specified in the design documents.

NF-5120 TIME OF EXAMINATION OF WELDS

Examinations of welds required by NF-5200 shall be performed at the times stipulated in (a) and (b) during fabrication and installation.

(a) Radiography of welds may be performed prior to any postweld heat treatment.

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

NF-5200 REQUIRED EXAMINATION OF WELDS

NF-5210 EXAMINATION OF CLASS 1 SUPPORT WELDS

NF-5211 Scope

The requirements of this subsubarticle shall apply to all Class 1 supports except that supports for Class 1 piping, NPS 2 (DN 50) and less, may be examined by the rules of NF-5220.

NF-5212 Primary Member Welded Joints

(a) All full penetration butt-welded joints in primary members shall be examined by the radiographic method.

(b) All other welded joints in primary members shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.

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NF-5213 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5214 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld shall be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have ¼ in. (6 mm) diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

NF-5215 Special Exceptions

When the joint detail does not permit radiographic examination to be performed in accordance with this Article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure that has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The procedure shall comply with the appropriate Article of Section V for the particular examination method. The nondestructive examinations shall be in accordance with NF-5110 and meet the acceptance standards of NF-5300.

NF-5220 EXAMINATION OF CLASS 2 AND MC SUPPORT WELDS

NF-5221 Primary Member Welded Joints

(a) All butt-welded joints in primary members shall be examined by the liquid penetrant or magnetic particle method.

(b) All partial penetration or fillet welds in primary members that have a groove depth or throat dimensions greater than 1 in. (25 mm) and T-welded joints welded with throat dimensions of ½ in. (13 mm) or greater shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.

(c) All primary welds exclusive of those described in (a) and (b) shall be examined by the visual method.

NF-5222 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5224 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. (25 mm) and greater in thickness, the base material beneath the weld shall be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have ¼ in. (6 mm) diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

NF-5230 EXAMINATION OF CLASS 3 SUPPORT WELDS

NF-5231 Primary Member Welded Joints

(a) Primary member welded joints that have a groove depth or throat dimension greater than 1 in. (25 mm) shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.

(b) Primary welded joints exclusive of those described in (a) shall be examined by the visual method.

NF-5232 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5234 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. (25 mm) and greater in thickness, the base material beneath the weld shall be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have ¼ in. (6 mm) diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

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NF-5240 INERTIA AND CONTINUOUS DRIVE FRICTION WELDS

(a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

(b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.

(c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.

(d) The weld between the two members shall be a full penetration weld.

NF-5300 ACCEPTANCE STANDARDS

NF-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

(23) **NF-5321 Evaluation of Indications**

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration

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

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

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (56 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (56 mm)

where t is the thickness of the thinner portion of the weld

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (b)

(d) any group of aligned indications (excluding nonrelevant indications) having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication

(e) rounded indications are not a factor in the acceptability of welds that are radiographed

NF-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards as given in (a) and (b).

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding

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

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (56 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (56 mm) where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NF-5332 Acceptance Standards for Laminar Indications

Any indication detected in the base material beneath the weld which is of a laminar type is unacceptable if the indication cannot be contained within a circle having a diameter equal to one-half of the thickness of the thinner of the members joined.

NF-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NF-5341 Evaluation of Indications

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

(b) Any indication 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. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are 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.

NF-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.5 mm) are required to be evaluated for acceptance.

(b) Imperfections producing the following indications are unacceptable:

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(1) linear indications with dimensions greater than $^{1}/_{16}$ in. (1.5 mm)

(2) rounded indications with dimensions greater than $^{3}/_{16}$ in. (5 mm)

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

(4) ten or more rounded 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), with the area taken in the most unfavorable location relative to the indications being evaluated

NF-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NF-5351 Evaluation of Indications

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

(b) Any indication 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 indications which result from imperfections. Linear indications are 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.

NF-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $^{1}/_{16}$ in. (1.5 mm) are required to be evaluated for acceptance.

(b) Imperfections producing the following indications are unacceptable:

(1) linear indications with dimensions greater than $^{1}/_{16}$ in. (1.5 mm)

(2) rounded indications with dimensions greater than $^{3}/_{16}$ in. (5 mm)

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

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

NF-5360 VISUAL ACCEPTANCE STANDARDS

When visual examination is performed in accordance with NF-5200, the acceptance standards shall be in accordance with the following:

(a) Cracks are unacceptable.

(b) A fillet weld is permitted to be less than the size specified by $^{1}/_{16}$ in. (1.5 mm) for one-fourth the length of the weld. Oversized fillet welds are acceptable if the oversized weld does not interfere with mating parts.

(c) In fillet welds, incomplete fusion of $^{3}/_{8}$ in. (10 mm) in any 4 in. (100 mm) segment, and $^{1}/_{4}$ in. (6 mm) in welds less than 4 in. (100 mm) long, is acceptable. For groove welds, incomplete fusion is not acceptable. For fillet and groove welds, rounded end conditions that occur in welding (starts and stops) shall not be considered indications of incomplete fusion and are irrelevant.

(d) Overlap is acceptable provided the criteria for weld size and fusion can be satisfied. When fusion in the overlap length cannot be verified, an overlap length of $^{3}/_{8}$ in. (10 mm) in any 4 in. (100 mm) segment, and $^{1}/_{4}$ in. (6 mm) in welds less than 4 in. (100 mm) long, is acceptable.

(e) Craters are acceptable when the criteria for weld size are met. Craters that occur outside the specified weld length are irrelevant provided there are no cracks.

(f) Requirements for acceptability of undercuts are as follows:

(1) For material $^{3}/_{8}$ in. (10 mm) and less nominal thickness, undercut depth of $^{1}/_{32}$ in. (0.8 mm) on one side of the member for the full length of the weld, or $^{1}/_{32}$ in. (0.8 mm) on one side for one-half the length of the weld, and $^{1}/_{16}$ in. (1.5 mm) for one-fourth the length of the weld on the same side of the member is acceptable. For members welded on both sides where undercut exists in the same plane of a member, the cumulative lengths of undercut are limited to the lengths of undercut allowed on one side. Melt-through that results in a hole in the base metal is unacceptable.

(2) For material greater than $^{3}/_{8}$ in. (10 mm) nominal thickness, undercut depth of $^{1}/_{32}$ in. (0.8 mm) for the full length of the weld and $^{1}/_{16}$ in. (1.5 mm) for one-fourth the length of the weld on both sides of the member is acceptable. When either welds or undercut exist only on one side of the member or are not in the same plane, the allowable undercut depth of $^{1}/_{32}$ in. (0.8 mm) may be increased to $^{1}/_{16}$ in.(1.5 mm) for the full length of the weld.

(g) Only surface porosity whose major surface dimension exceeds $^{1}/_{16}$ in. (1.5 mm) shall be considered relevant. Fillet and groove welds that contain surface porosity are unacceptable if

(1) the sum of diameters of random porosity exceeds $^{3}/_{8}$ in. (10 mm) in any linear inch of weld or $^{3}/_{4}$ in. (19 mm) in any 12 in. (300 mm) of weld or

(2) four or more pores are aligned and the pores are separated by $^{1}/_{16}$ in. (1.5 mm) or less, edge to edge

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(h) The length and location of welds shall be as specified on the detail drawing, except that weld lengths may be longer than specified. For weld lengths less than 3 in. (75 mm), the permissible underlength is $\frac{1}{8}$ in. (3 mm), and for welds 3 in. (75 mm) and longer, the permissible underlength is $\frac{1}{4}$ in. (6 mm). Intermittent welds shall be spaced within 1 in. (25 mm) of the specified location.

(i) Arc strikes and associated blemishes on the weld or in the base material are acceptable provided no cracking is visually detected.

(j) Slag whose major surface dimension is $\frac{1}{8}$ in. (3 mm) or less is irrelevant. Isolated surface slag that remains after weld cleaning and does not exceed $\frac{1}{4}$ in. (6 mm) in its major surface dimension is acceptable. [Slag is considered to be isolated when it does not occur more frequently than once per weld or more than once in a 3 in. (75 mm) weld segment.] Spatter remaining after the cleaning operation is acceptable.

NF-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

(23) NF-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NF-5520 or NF-5540. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, it shall verify the qualification of personnel to the requirements of NF-5520 or NF-5540. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

NF-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

(23) NF-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.[7, 8] The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE personnel shall not be used for Section III. The Employer's[9] written practice required by paragraph 5 of SNT-TC-1A shall identify Employer requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements except as modified in (1) through (5).

(1) Qualification of level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paras. 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examinations, para. 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside Agency. The employer or outside agency administering the specific examination shall identify the minimum grade requirement in a written program when the basic and method examinations have been administered by ASNT which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform a nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The training and experience times shall be described in the written practice and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(-a) The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

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(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NF-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Level I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [see NF-5521(a)(1)(-a)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

(23) NF-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3315, and subcontractors who provide nondestructive examination services to them.

NF-5530 RECORDS

Personnel qualification records identified in para. 9.4 of SNT-TC-1A shall be retained by the Employer.

NF-5540 ALTERNATIVE RULES (23)

As an alternative to the requirements of NF-5520 and NF-5530, the use of ANSI/ASNT CP-189 is permitted. When this alternative is used, the following requirements apply:

(a) The ACCP Level III provisions for qualification and certification of NDE personnel shall not be used for Section III.

(b) The Employer's procedures for control and administration of personnel training, examination, and certification shall be referenced in the Employer's Quality Program.

(c) NF-5523 remains applicable.

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ARTICLE NF-8000
CERTIFICATES OF AUTHORIZATION AND CERTIFICATION DOCUMENTS

NF-8100 GENERAL REQUIREMENTS

The requirements for Certificates of Authorization and certification documents (Certificate of Compliance and NS-1 Certificate of Conformance) shall be as specified in Article NCA-8000 and shall apply only to those items fabricated under an NCA-4100 Quality Assurance Program. Inspection by an ANI and Certification Mark are not required for supports.

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MANDATORY APPENDIX NF-I ADDITIONAL MATERIAL FOR SUPPORTS

ARTICLE NF-I-1000 INTRODUCTION

NF-I-1100 SCOPE

This Mandatory Appendix provides additional materials that may be used in Section III, Division 1 Class 1, 2, 3, and MC support construction.

NF-I-1200 GENERAL REQUIREMENTS

The requirements of Subsection NF shall be met except as modified by this Appendix.

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ARTICLE NF-I-2000
MATERIALS

NF-I-2100 GENERAL

The additional materials, design stress intensity and allowable stress values, yield strength, and tensile strength values, listed in Table NF-I-2100-1 (U.S. Customary Units) and Table NF-I-2100-1M (SI Units) of this Appendix may be used in the construction of Class 1, 2, 3, and MC supports for Section III, Division 1, in addition to those listed in Section II, Part D. Other than the units used, Tables NF-I-2100-1 and NF-I-2100-1M are the same. The tabulated values of tensile strength and yield strength are those suitable for use in design calculations required by Section III, Division 1. At temperatures above room temperature, the values of tensile strength trend toward an average or expected value that may be as much as 10% above the tensile strength trend curves adjusted to the minimum specified room temperature tensile strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum" as these terms are applied to a statistical treatment of a homogenous set of data.

Neither the ASME or ASTM material specifications nor the rules of Section III, Division 1 require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material, suggesting the possibility of some error), further investigation by retest or other means should be considered.

The applicable revisions of the ASTM specifications in Tables NF-I-2100-1 and NF-I-2100-1M are listed in Table NF-I-2100-2.

NF-I-2200 REQUIREMENTS

NF-I-2210

When the Material Grade column in Tables NF-I-2100-1 and NF-I-2100-1M references AISI grades, only materials meeting the chemical composition requirements of the specific AISI grades listed shall be used, with the exception that 0.60% maximum silicon is permitted for castings. Free machining modifications of the specific AISI grades listed may be used at the same design stress intensities, allowable stresses, and yield strengths of the reference grades but their use is limited to 400°F (205°C) maximum temperature.

NF-I-2220

Unless specifically exempted by Tables NF-I-2100-1 and NF-I-2100-1M, the maximum measured tensile strength of the support material should not exceed 170 ksi (1 172 MPa), in view of the susceptibility of high-strength materials to brittleness and stress corrosion cracking. Certain applications may exist where a tensile strength value of up to 190 ksi (1 310 MPa) could be considered acceptable for a material. Under this condition, the Design Specification shall specify impact testing per NF-2300 for the material, and shall include requirements for the consideration of the effects of sustained loads, environment, and heat treatment on the susceptibility to stress corrosion cracking of these high-strength materials.

NF-I-2230

When the ASTM specification referenced in Tables NF-I-2100-1 and NF-I-2100-1M does not specify minimum tensile and yield strengths, the material shall meet the values listed under the appropriate columns.

NF-I-2240

Materials in Tables NF-I-2100-1 and NF-I-2100-1M that are listed as an AISI composition may be accepted as satisfying the requirements of the ASTM specification provided the chemical requirements of the AISI specification are within the specified range of the designated ASTM specification.

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels																				
A108	1015, 1018, 1020	CW	...	P-No. 1	1	Bar	(4), (29), (31)	40	60	S_m	16.7	16.7	16.7	16.7	...	...	...	...	...	...
										S	14.3	14.3	14.3	14.3	...	...	...	...	...	...
										S_y	32.0	29.2	28.3	27.4	...	...	...	...	...	...
										S_u	50.0	50.0	50.0	50.0	...	...	...	...	...	...
A108	1015, 1018, 1020	CW	...	...	...	Bar	(2), (4), (31)	40	60	S_m	20.0	20.0	20.0	20.0	...	...	...	...	...	...
										S	17.1	17.1	17.1	17.1	...	...	...	...	...	...
										S_y	40.0	36.5	35.4	34.2	...	...	...	...	...	...
										S_u	60.0	60.0	60.0	60.0	...	...	...	...	...	...
A108	1045	CW	...	...	...	Bar and bolt	(1), (31)	100	120	S_m	40.0	40.0	40.0	40.0	...	...	...	...	...	...
										S	34.3	34.3	34.3	34.3	...	...	...	...	...	...
										S_y	100.0	91.2	88.4	85.6	...	...	...	...	...	...
										S_u	120.0	120.0	120.0	120.0	...	...	...	...	...	...
A108	1050	CW	...	...	...	Bar and bolt	(1), (31)	125	140	S_m	46.7	46.7	46.7	46.7	...	...	...	...	...	...
										S	40.0	40.0	40.0	40.0	...	...	...	...	...	...
										S_y	125.0	114.0	110.5	107.0	...	...	...	...	...	...
										S_u	140.0	140.0	140.0	140.0	...	...	...	...	...	...
A108	1117	...	...	...	...	Bar	(1), (31)	60	70	S_m	23.3	23.3	23.3	23.3	...	...	...	...	...	...
										S	20.0	20.0	20.0	20.0	...	...	...	...	...	...
										S_y	60.0	54.7	53.0	51.4	...	...	...	...	...	...
										S_u	70.0	70.0	70.0	70.0	...	...	...	...	...	...
A108	1141, 12L14	Cold drawn and tempered	...	...	...	Bolt 3 in. max.	(1), (31)	81	105	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	81.0	73.9	71.6	69.3	...	...	...	...	...	...
										S_u	105.0	105.0	105.0	105.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A108	1144	...	...	...	...	Bar	(1), (31)	100	115	S_m	38.3	38.3	38.3	38.3	...	...	...	...	...	...
										S	32.9	32.9	32.9	32.9	...	...	...	...	...	...
										S_y	100.0	91.2	88.4	85.6	...	...	...	...	...	...
										S_u	115.0	115.0	115.0	115.0	...	...	...	...	...	...
A108	1144	Cold drawn and tempered	...	...	...	Bolt 3 in. max.	(1), (31)	105	125	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	105.0	95.8	92.8	89.8	...	...	...	...	...	...
										S_u	125.0	125.0	125.0	125.0	...	...	...	...	...	...
A108	1144	...	...	...	...	Bolt over 3 in. to 10 in. max.	(1), (31)	81	105	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	81.0	73.9	71.6	69.3	...	...	...	...	...	...
										S_u	105.0	105.0	105.0	105.0	...	...	...	...	...	...
A108	12L14	...	...	...	...	Bar	(1)	55	65	S_m	21.7	21.7	21.7	21.7	...	...	...	...	...	...
										S	18.6	18.6	18.6	18.6	...	...	...	...	...	...
										S_y	55.0	50.2	48.6	47.1	...	...	...	...	...	...
										S_u	65.0	65.0	65.0	65.0	...	...	...	...	...	...
A228	...	...	...	...	...	Wire	(1), (6), (30)	250	270	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	250.0	220.5	202.5	187.5	...	...	...	...	...	...
										S_u	270.0	270.0	270.0	270.0	...	...	...	...	...	...
A381	...	...	Y35	P-No. 1	1	Pipe	...	35	60	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	35.0	31.9	31.0	30.0	28.3	25.9	25.6	25.2	...	...
										S_u	60.0	60.0	60.0	60.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A500	B	...	...	P-No. 1	1	Tube (shaped)	...	46	58	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	46.0	41.9	40.8	39.4	37.2	34.0	33.3	33.1	...	...
										S_u	58.0	58.0	58.0	58.0	...	...	...	...	...	...
A500	B	...	...	P-No. 1	1	Tube (round)	...	42	58	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	42.0	38.3	37.2	35.9	33.9	31.0	30.4	30.2	...	...
										S_u	58.0	58.0	58.0	58.0	...	...	...	...	...	...
A500	C	...	...	P-No. 1	1	Tube (shaped)	...	50	62	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	50.0	45.6	44.3	42.9	40.4	37.0	36.3	36.0	...	...
										S_u	62.0	62.0	62.0	62.0	...	...	...	...	...	...
A500	C			P-No. 1	1	Tube (round)		46	62	S_m										
										S	...	...	...	...	...	...	...	...	...	...
										S_y	46.0	41.9	40.8	39.4	37.2	34.0	33.3	33.1	...	...
										S_u	62.0	62.0	62.0	62.0	...	...	...	...	...	...
A501	...	...	...	P-No. 1	1	Tube	...	36	58	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	36.0	32.8	31.9	30.8	29.1	26.6	26.1	25.9	...	...
										S_u	58.0	58.0	58.0	58.0	...	...	...	...	...	...
A513	1015	CW	...	P-No. 1	1	Tube	(4), (29)	55	65	S_m	16.7	16.7	16.7	16.7	...	...	...	...	...	...
										S	14.3	14.3	14.3	14.3	...	...	...	...	...	...
										S_y	32.0	29.2	28.3	27.4	...	...	...	...	...	...
										S_u	50.0	50.0	50.0	50.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A513	1020	CW	...	P-No. 1	2	Tube	(4), (29)	60	70	S_m	16.7	16.7	16.7	16.7	...	...	...	...	...	...
										S	14.3	14.3	14.3	14.3	...	...	...	...	...	...
										S_y	32.0	29.2	28.3	27.4	...	...	...	...	...	...
										S_u	50.0	50.0	50.0	50.0	...	...	...	...	...	...
A513	1015	CW	...	...	...	Tube	(2), (4)	55	65	S_m	21.7	21.7	21.7	21.7	...	...	...	...	...	...
										S	18.6	18.6	18.6	18.6	...	...	...	...	...	...
										S_y	55.0	50.2	48.6	47.1	...	...	...	...	...	...
										S_u	65.0	65.0	65.0	65.0	...	...	...	...	...	...
A513	1020	CW	...	...	...	Tube	(2), (4)	60	70	S_m	23.3	23.3	23.3	23.3	...	...	...	...	...	...
										S	20.0	20.0	20.0	20.0	...	...	...	...	...	...
										S_y	60.0	54.7	53.0	51.4	...	...	...	...	...	...
										S_u	70.0	70.0	70.0	70.0	...	...	...	...	...	...
A513	1025	CW	...	P-No. 1	2	Tube	(5), (29)	65	75	S_m	18.3	18.3	18.3	18.3	...	...	...	...	...	...
										S	15.7	15.7	15.7	15.7	...	...	...	...	...	...
										S_y	35.0	31.9	31.0	30.0	...	...	...	...	...	...
										S_u	55.0	55.0	55.0	55.0	...	...	...	...	...	...
A513	1026	CW	...	P-No. 1	3	Tube	(5), (29)	70	80	S_m	18.3	18.3	18.3	18.3	...	...	...	...	...	...
										S	15.7	15.7	15.7	15.7	...	...	...	...	...	...
										S_y	35.0	31.9	31.0	30.0	...	...	...	...	...	...
										S_u	55.0	55.0	55.0	55.0	...	...	...	...	...	...
A513	1025	CW	...	...	...	Tube	(2), (5)	65	75	S_m	25.0	25.0	25.0	25.0	...	...	...	...	...	...
										S	21.4	21.4	21.4	21.4	...	...	...	...	...	...
										S_y	65.0	59.3	58.5	55.6	...	...	...	...	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A513	1026	CW	...	...	...	Tube	(2), (5)	70	80	S_m	26.7	26.7	26.7	26.7	...	...	...	...	...	...
										S	22.9	22.9	22.9	22.9	...	...	...	...	...	...
										S_y	70.0	63.8	61.9	59.8	...	...	...	...	...	...
										S_u	80.0	80.0	80.0	80.0	...	...	...	...	...	...
A519	1018, 1020, 1022	HR	...	P-No. 1	1	Tube	...	32	50	S_m	16.7	16.7	16.7	16.7	...	...	...	...	...	...
										S	14.3	14.3	14.3	14.3	...	...	...	...	...	...
										S_y	32.0	29.2	28.3	27.4	...	...	...	...	...	...
										S_u	50.0	50.0	50.0	50.0	...	...	...	...	...	...
A519	1018, 1020, 1022	CW	...	P-No. 1	2	Tube	(4), (29)	60	70	S_m	16.7	16.7	16.7	16.7	...	...	...	...	...	...
										S	14.3	14.3	14.3	14.3	...	...	...	...	...	...
										S_y	32.0	29.2	28.3	27.4	...	...	...	...	...	...
										S_u	50.0	50.0	50.0	50.0	...	...	...	...	...	...
A519	1018, 1020, 1022	CW	...	...	...	Tube	(2), (4)	60	70	S_m	23.3	23.3	23.3	23.3	...	...	...	...	...	...
										S	20.0	20.0	20.0	20.0	...	...	...	...	...	...
										S_y	60.0	54.7	53.0	51.4	...	...	...	...	...	...
										S_u	70.0	70.0	70.0	70.0	...	...	...	...	...	...
A519	1025, 1026	HR	...	P-No. 1	1	Tube	...	35	55	S_m	18.3	18.3	18.3	18.3	...	...	...	...	...	...
										S	15.7	15.7	15.7	15.7	...	...	...	...	...	...
										S_y	35.0	31.9	31.0	30.0	...	...	...	...	...	...
										S_u	55.0	55.0	55.0	55.0	...	...	...	...	...	...
A519	1025, 1026	CW	...	P-No. 1	2	Tube	(3), (5), (29)	65	75	S_m	18.3	18.3	18.3	18.3	...	...	...	...	...	...
										S	15.7	15.7	15.7	15.7	...	...	...	...	...	...
										S_y	35.0	31.9	31.0	30.0	...	...	...	...	...	...
										S_u	55.0	55.0	55.0	55.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A519	1025, 1026	CW	...	...	...	Tube	(2), (3), (5)	65	75	S_m	25.0	25.0	25.0	25.0	...	...	...	...	...	...
										S	21.4	21.4	21.4	21.4	...	...	...	...	...	...
										S_y	65.0	59.3	58.5	55.6	...	...	...	...	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...
A521	1020, 1025, 1030	...	CC	S-No. 1	1	Forging	(31)	30	60	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	30.0	27.3	26.6	25.7	24.3	22.2	21.8	21.6	...	...
										S_u	60.0	60.0	60.0	60.0	...	...	...	...	...	...
A521	1020, 1025, 1030	...	CE	S-No. 1	2	Forging	(31)	37	75	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	37.0	33.7	32.8	31.7	29.9	27.4	26.9	26.6	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...
A521	1035, 1040	...	CG	...	...	Forging 4 in. and under	(1), (31)	55	90	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	55.0	50.2	48.6	47.1	44.5	40.7	39.9	39.6	...	...
										S_u	90.0	90.0	90.0	90.0	...	...	...	...	...	...
A521	1035, 1040	...	CG	...	...	Forging over 4 in. to 10 in. incl.	(1), (31)	50	85	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	50.0	45.6	44.3	42.9	40.4	37.0	36.3	36.0	...	...
										S_u	85.0	85.0	85.0	85.0	...	...	...	...	...	...
A653	33	A	...	S-No. 1	1	Sheet	(13)	33	45	S_m	15.0	15.0	15.0	15.0	...	...	...	...	...	...
										S	12.9	12.9	12.9	12.9	...	...	...	...	...	...
										S_y	33.0	30.1	29.2	28.3	26.5	...	...	...	...	...
										S_u	45.0	45.0	45.0	45.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A668	1020, 1022, 1025, 1026, 1030	...	B	S-No. 1	1	Forging	(8), (31)	30	60	S_m	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...
										S	17.1	17.1	17.1	17.1	...	...	...	...	...	...
										S_y	30.0	27.3	26.6	25.7	24.3	22.2	21.8	21.6	...	...
										S_u	60.0	60.0	60.0	60.0	...	...	...	...	...	...
A668	1035	...	B	...	...	Forging	(1), (8), (9), (31)	30	60	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	30.0	27.3	26.6	25.7	24.5	22.2	21.8	21.6	...	...
										S_u	60.0	60.0	60.0	60.0	...	...	...	...	...	...
A668	1020, 1022, 1025, 1026, 1030	...	C	S-No. 1	1	Forging	(8), (31)	33	66	S_m	22.0	22.0	22.0	22.0	22.0	22.0	22.0	...	...	...
										S	18.9	18.9	18.9	18.9	...	...	...	...	...	...
										S_y	33.0	30.1	29.2	28.3	26.5	24.4	24.1	23.8	...	...
										S_u	66.0	66.0	66.0	66.0	...	...	...	...	...	...
A668	1035	...	C	...	...	Forging	(1), (8), (9), (31)	33	66	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	33.0	30.1	29.2	28.3	26.5	24.4	24.1	23.8	...	...
										S_u	66.0	66.0	66.0	66.0	...	...	...	...	...	...
A668	1020, 1022, 1025, 1026, 1030	...	D	S-No. 1	2	Forging	(8), (31)	37.5	75	S_m	25.0	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...
										S	21.4	21.4	21.4	21.4	...	...	...	...	...	...
										S_y	37.5	34.2	33.2	32.1	30.3	27.7	27.2	27.0	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...
A668	1035	...	D	...	...	Forging	(1), (8), (9), (31)	37.5	75	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	37.5	34.2	33.2	32.1	30.3	27.7	27.2	27.0	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...

Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Carbon Steels (Cont'd)																				
A668	1030, 1330	...	F	S-No. 1	3	Forging 4 in. and under	(7), (8), (31)	55	90	S_m	30.0	30.0	30.0	30.0	...	...	...	...	...	...
										S	25.7	25.7	25.7	25.7	...	...	...	...	...	...
										S_y	55.0	50.2	48.6	47.1	44.5	40.7	39.9	39.6	...	...
										S_u	90.0	90.0	90.0	90.0	...	...	...	...	...	...
A668	1030, 1330	...	F	S-No. 1	3	Forging over 4 in. to 10 in. incl.	(8), (31)	50	85	S_m	28.3	28.3	28.3	28.3	...	...	...	...	...	...
										S	24.3	24.3	24.3	24.3	...	...	...	...	...	...
										S_y	50.0	45.6	44.3	42.9	40.4	37.0	36.3	36.0	...	...
										S_u	85.0	85.0	85.0	85.0	...	...	...	...	...	...
A668	1035, 1040 1045	...	F	...	...	Forging 4 in. and under	(1), (7), (8), (9), (31)	55	90	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	55.0	50.2	48.6	47.1	44.5	40.7	39.9	39.6	...	...
										S_u	90.0	90.0	90.0	90.0	...	...	...	...	...	...
A668	1035, 1040, 1045	...	F	...	...	Forging over 4 in. to 10 in. incl.	(1), (8), (9), (31)	50	85	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	50.0	45.6	44.3	42.9	40.4	37.0	36.3	36.0	...	...
										S_u	85.0	85.0	85.0	85.0	...	...	...	...	...	...
A675	75	...	...	S-No. 1	2	Bar	(28)	37.5	75	S_m	25.0	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...
										S	21.4	21.4	21.4	21.4	...	...	...	...	...	...
										S_y	37.5	34.2	33.2	32.1	30.3	27.7	27.4	27.0	...	...
										S_u	75.0	75.0	75.0	75.0	...	...	...	...	...	...
Low Alloy Steels																				
A148	Grade 90-60: 4130, 4320, 4330	...	...	S-No. 4	3	Casting	(11), (19), (31)	60	90	S_m	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	...	...
										S	25.7	25.7	25.7	25.7	25.7	25.7	...	...	...	...
										S_y	60.0	58.2	55.9	52.8	50.1	49.8	...	...	...	...
										S_u	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A148	Grade 105-85: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (17), (31)	85	105	S_m	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	...	...
										S	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	...	...
										S_y	85.0	82.5	79.2	74.8	71.0	70.5	70.5	70.5	...	...
										S_u	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	...	...
A148	Grade 115-95: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (18), (31)	95	115	S_m	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	...	...
										S	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	...	...
										S_y	95.0	92.1	88.5	83.5	79.3	78.9	78.9	78.9	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A148	Grade 135-125: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (31)	125	135	S_m	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	...	...
										S	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	...	...
										S_y	125.0	121.1	116.5	110.0	104.3	103.9	103.9	103.9	...	...
										S_u	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	...	...
A322	4150	...	...	...	...	Bar	(1), (31)	100	115	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	100.0	93.5	90.2	87.8	85.1	81.4	78.9	76.0	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar $1\frac{1}{2}$ in. and under	(1), (31)	90	110	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	90.0	84.1	81.3	79.0	76.6	73.3	71.0	68.4	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 1½ in. to 2½ in. incl.	(1), (31)	80	105	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	80.0	74.8	72.3	70.3	68.1	65.1	63.1	60.0	...	...
										S_u	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 2½ in. to 4 in. incl.	(1), (31)	75	100	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	75.0	70.1	67.7	65.8	63.8	61.0	59.1	57.0	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 4 in. to 7 in. incl.	(1), (31)	75	95	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	75.0	70.1	67.7	65.8	63.8	61.0	59.1	57.0	...	...
										S_u	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 7 in. to 9½ in. incl.	(1), (31)	65	90	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	65.0	60.7	58.6	57.1	55.3	52.9	51.2	49.4	...	...
										S_u	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar 1½ in. and under	(1), (31)	110	130	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	110.0	102.9	99.4	96.6	93.6	89.5	86.8	83.6	...	...
										S_u	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 1½ in. to 2½ in. incl.	(1), (31)	105	125	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	105.0	98.1	94.8	92.2	89.4	85.5	82.9	79.8	...	...
										S_u	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 2½ in. to 4 in. incl.	(1), (31)	95	115	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	95.0	88.5	85.4	83.0	80.6	77.0	74.6	72.0	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 4 in. to 7 in. incl.	(1), (31)	85	110	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	85.0	79.5	76.8	74.6	72.4	69.1	67.0	64.6	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 7 in. to 9½ in. incl.	(1), (31)	80	105	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	80.0	74.8	72.3	70.3	68.1	65.1	63.1	60.9	...	...
										S_u	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar 1½ in. and under	(1), (31)	130	155	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	130.0	121.5	117.2	114.1	110.7	105.7	102.5	98.8	...	...
										S_u	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 1½ in. to 2½ in. incl.	(1), (31)	120	150	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	120.0	112.1	108.4	105.2	102.1	97.6	94.6	91.1	...	...
										S_u	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 2½ in. to 4 in. incl.	(1), (31)	110	140	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	110.0	102.9	99.4	96.6	93.6	89.5	86.8	83.6	...	...
										S_u	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 4 in. to 7 in. incl.	(1), (31)	105	135	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	105.0	98.1	94.8	92.2	89.4	85.5	82.9	79.8	...	...
										S_u	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 7 in. to 9½ in. incl.	(1), (31)	100	130	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	100.0	93.5	90.2	87.8	85.1	81.4	78.9	76.0	...	...
										S_u	130.0	130.0	130.0	130.0	130.0	130.0	130.0	130.0	...	...
A471	3Ni–Cr–Mo–V	...	2	...	...	Forging	(1), (10)	90	105	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	90.0	84.8	82.1	80.3	79.0	77.6	76.4	75.4	...	...
										S_u	105.0	105.0	105.0	104.0	103.3	101.9	100.4	98.8	...	...
A471	3Ni–Cr–Mo–V	...	3	...	...	Forging	(1), (10)	100	110	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	100.0	94.2	91.2	89.2	87.8	86.2	85.0	83.8	...	...
										S_u	110.0	110.0	110.0	108.9	108.1	106.7	105.1	103.5	...	...
A471	3Ni–Cr–Mo–V	...	4	...	...	Forging	(1), (10)	110	120	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	110.0	103.7	100.4	98.2	96.5	94.9	93.5	92.2	...	...
										S_u	120.0	120.0	120.0	118.8	118.0	116.4	114.7	112.9	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A471	3Ni–Cr–Mo–V	...	5	...	...	Forging	(1), (10)	120	130	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	120.0	113.1	109.5	107.1	105.3	103.5	102.0	100.6	...	...
										S_u	130.0	130.0	130.0	128.7	127.8	126.1	124.3	122.3	...	...
A471	3Ni–Cr–Mo–V	...	6	...	...	Forging	(1), (10)	130	140	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	130.0	122.5	118.6	116.0	114.1	112.1	110.5	109.0	...	...
										S_u	140.0	140.0	140.0	138.5	137.7	135.8	133.8	131.7	...	...
A471	3Ni–Cr–Mo–V	...	7	...	...	Forging	(1), (10)	135	150	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	135.0	127.1	123.0	120.3	118.3	116.2	114.8	113.1	...	...
										S_u	150.0	150.0	150.0	148.5	147.5	145.5	143.4	141.1	...	...
A471	3Ni–Cr–Mo–V	...	8	...	...	Forging	(1), (10)	145	160	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	145.0	136.6	132.2	129.3	127.1	124.9	123.2	121.8	...	...
										S_u	160.0	160.0	160.0	158.4	157.3	155.2	152.9	150.5	...	...
A471	3Ni–Cr–Mo–V	...	9	...	...	Forging	(1), (10)	155	170	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	155.0	146.0	141.2	138.1	136.0	133.5	131.8	130.0	...	...
										S_u	170.0	170.0	170.0	168.3	167.2	164.9	162.5	159.9	...	...
A490	4137, 4140, 4142, 4145, 4340	1	...	...	...	Bolt	(1)	130	150	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	130.0	121.5	117.2	114.1	110.7	105.7	102.5	98.8	...	...
										S_u	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A514	A	...	...	P-No. 11B	1	Plate $1\frac{1}{4}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...
A514	B	...	...	P-No. 11B	4	Plate $1\frac{1}{4}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...
A514	E	...	...	P-No. 11B	2	Plate $2\frac{1}{2}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...
A514	F	...	...	P-No. 11B	3	Plate $2\frac{1}{2}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...
A514	P	...	...	P-No. 11B	8	Plate $2\frac{1}{2}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...
A514	Q	...	...	P-No. 11B	9	Plate $2\frac{1}{2}$ in. and less	...	100	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.5	35.9	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	30.8	...	...
										S_y	100.0	95.5	92.5	89.8	87.6	85.5	84.3	83.0	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	107.7	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A514	E	...	...	P-No. 11B	2	Plate over 2½ in. to 6 in. incl.	...	90	100	S_m	33.3	33.3	33.3	33.3	33.3	33.3	33.2	32.6	...	...
										S	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.0	...	...
										S_y	90.0	86.0	83.3	80.8	78.8	77.0	75.9	74.7	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.9	...	...
A514	P	...	...	P-No. 11B	8	Plate over 2½ in. to 6 in. incl.	...	90	100	S_m	33.3	33.3	33.3	33.3	33.3	33.3	33.2	32.6	...	...
										S	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.0	...	...
										S_y	90.0	86.0	83.3	80.8	78.8	77.0	75.9	74.7	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.9	...	...
A514	Q	...	...	P-No. 11B	9	Plate over 2½ in. to 6 in. incl.	...	90	100	S_m	33.3	33.3	33.3	33.3	33.3	33.3	33.2	32.6	...	...
										S	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.0	...	...
										S_y	90.0	86.0	83.3	80.8	78.8	77.0	75.9	74.7	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.9	...	...
A519	4140	4140SR	...	...	...	Tube	(1)	100	120	S_m	40.0	40.0	40.0	40.0	...	...	...	...	...	...
										S	34.3	34.3	34.3	34.3	...	...	...	...	...	...
										S_y	100.0	93.5	90.2	87.8	...	...	...	...	...	...
										S_u	120.0	120.0	120.0	120.0	...	...	...	...	...	...
A519	4142	4142SR	...	...	...	Tube	(1)	100	120	S_m	40.0	40.0	40.0	40.0	...	...	...	...	...	...
										S	34.3	34.3	34.3	34.3	...	...	...	...	...	...
										S_y	100.0	93.5	90.2	87.8	...	...	...	...	...	...
										S_u	120.0	120.0	120.0	120.0	...	...	...	...	...	...
A572	42	...	...	P-No. 1	1	Plate and shapes	(14)	42	60	S_m	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...
										S	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	...	...
										S_y	42.0	40.0	38.3	36.8	35.2	33.5	32.7	31.8	...	...
										S_u	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A572	50	...	...	P-No. 1	1	Plate and shapes	(14)	50	65	S_m	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	...	...
										S	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	...	...
										S_y	50.0	47.5	45.6	43.8	41.8	39.9	38.9	37.9	...	...
										S_u	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	...	...
A572	55	...	...	P-No. 1	2	Plate and shapes	...	55	70	S_m	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	...	...
										S	20.0	20.0	20.0	20.0	...	...	...	...	...	...
										S_y	55.0	52.3	50.2	48.2	46.0	43.9	42.8	41.7	...	...
										S_u	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	...	...
A579	5Ni–Cr–Mo–V	12a	...	...	...	Forging	(1)	140	150	S_m	50.0	49.5	48.0	47.0	47.0	47.0	46.0	44.0	...	...
										S	42.9	42.4	41.1	40.3	40.3	40.3	39.4	37.7	...	...
										S_y	140.0	138.6	134.0	129.5	127.7	126.3	123.5	117.6	...	...
										S_u	150.0	148.5	144.0	141.0	141.0	141.0	138.0	132.0	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar 4 in. and less, all shapes	(7), (15)	50	70	S_m	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	...	...
										S	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...
										S_y	50.0	47.5	45.6	43.0	41.8	39.9	38.9	37.9	...	...
										S_u	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar over 4 in. to 5 in. incl.	(7), (14)	46	67	S_m	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	...	...
										S	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	...	...
										S_y	46.0	43.8	41.9	40.3	38.6	36.7	35.8	34.8	...	...
										S_u	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar over 5 in. to 8 in. incl.	(14)	42	63	S_m	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	...	...
										S	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	...	...
										S_y	42.0	40.0	38.3	36.8	35.2	33.5	32.7	31.8	...	...
										S_u	63.0	63.0	63.0	63.0	63.0	63.0	63.0	63.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A618	Mn–Cu–V	...	II	P-No. 1	2	Tube ¾ in. and less	...	50	70	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	50.0	45.4	41.7	38.0	34.6	33.9	33.6	33.1	...	...
										S_u	70.0	70.0	70.0	70.0	70.0	70.0	70.0	69.3	...	...
A618	Mn–Cu–V	...	II	P-No. 1	2	Tube over ¾ in. to 1½ in. incl.	...	46	67	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	46.0	41.7	38.4	35.0	31.8	31.2	30.9	30.5	...	...
										S_u	67.0	67.0	67.0	67.0	67.0	67.0	67.0	66.3	...	...
A618	Mn–V	...	III	P-No. 1	1	Tube	...	50	65	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	50.0	45.4	41.7	38.0	34.6	33.9	33.6	33.1	...	...
										S_u	65.0	65.0	65.0	65.0	65.0	65.0	65.0	64.4	...	...
A633	A	...	...	P-No. 1	1	Plate and shapes 4 in. and less	...	42	63	S_m	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.8	...	...
										S	18.0	18.0	18.0	18.0	18.0	18.0	18.0	17.8	...	...
										S_y	42.0	38.2	35.1	31.9	29.1	28.5	28.2	27.8	...	...
										S_u	63.0	63.0	63.0	63.0	63.0	63.0	63.0	62.4	...	...
A633	C, D	...	...	P-No. 1	2	Plate and shapes 2½ in. and less	...	50	70	S_m	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.1	...	...
										S	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.8	...	...
										S_y	50.0	45.4	41.7	38.0	34.6	33.9	33.6	33.1	...	...
										S_u	70.0	70.0	70.0	70.0	70.0	70.0	70.0	69.3	...	...
A633	C, D	...	...	P-No. 1	1	Plate, bar, and shapes over 2½ in. to 4 in. incl.	...	46	65	S_m	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.5	...	...
										S	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.4	...	...
										S_y	46.0	41.8	38.4	35.0	31.8	31.2	30.9	30.4	...	...
										S_u	65.0	65.0	65.0	65.0	65.0	65.0	65.0	64.4	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A633	E	...	...	P-No. 1	3	Plate 4 in. and less, all shapes	(3)	60	80	S_m	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.4	...	...
										S	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.3	...	...
										S_y	60.0	54.5	50.1	45.6	41.4	40.7	40.3	39.7	...	...
										S_u	80.0	80.0	80.0	80.0	80.0	80.0	80.0	78.2	...	...
A668	4130, 4320, 4330, 8620, 8630	...	K	S-No. 4	3	Forging 7 in. and less	(7), (8), (31)	80	105	S_m	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	...	...
										S	30.0	30.0	30.0	30.0	30.0	30.0	30.0	...	...	...
										S_y	80.0	74.8	72.3	70.3	68.1	65.4	63.1	60.9	...	...
										S_u	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	...	...
A668	4130, 4320, 4330, 8620, 8630	...	K	S-No. 4	3	Forging over 7 in. to 10 in. incl.	(8), (31)	75	100	S_m	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	...	...
										S	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	...	...
										S_y	75.0	70.1	67.7	65.8	63.8	61.0	59.0	57.0	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	...	...
A668	4140, 4340	...	K	...	...	Forging 7 in. and less	(1), (7), (8), (9), (16), (31)	80	105	S_m	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	...	...
										S	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	...	...
										S_y	80.0	74.8	72.3	70.3	68.1	65.1	63.1	60.9	...	...
										S_u	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	...	...
A668	4140, 4340	...	K	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (16), (31)	75	100	S_m	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	...	...
										S	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	...	...
										S_y	75.0	70.1	67.7	65.8	63.8	61.0	59.0	57.0	...	...
										S_u	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	...	...
A668	4130, 4320, 4330, 8620, 8630	...	L	S-No. 4	3	Forging 4 in. and less	(7), (8), (11), (31)	105	125	S_m	41.7	41.7	41.7	41.7	41.7	41.7	...	...	...	...
										S	35.7	35.7	35.7	35.7	35.7	35.7	...	...	...	...
										S_y	105.0	98.1	94.8	92.2	89.4	85.5	82.9	79.8	...	...
										S_u	125.0	125.0	125.0	125.0	125.0	125.0	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A668	4130, 4320, 4330, 8620, 8630	...	L	S-No. 4	3	Forging over 4 in. to 7 in. incl.	(7), (8), (11), (31)	95	115	S_m	38.3	38.3	38.3	38.3	38.3	38.3	...	...	...	...
										S	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	...	...
										S_y	95.0	88.5	85.4	83.0	80.0	77.0	74.6	72.0	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A668	4130, 4320, 4330, 8620, 8630	...	L	S-No. 4	3	Forging over 7 in. to 10 in. incl.	(8), (11), (31)	85	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	...	...
										S_y	85.0	79.5	76.8	74.6	72.4	69.1	67.0	64.6	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	...	...
A668	4135	...	L	...	...	Forging 4 in. and less	(1), (7), (8), (9), (31)	105	125	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	105.0	98.1	94.8	92.2	89.4	85.5	82.9	79.8	...	...
										S_u	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	...	...
A668	4135	...	L	...	...	Forging over 4 in. to 7 in. incl.	(1), (7), (8), (9), (31)	95	115	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	95.0	88.5	85.4	83.0	80.6	77.0	74.6	72.0	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A668	4135	...	L	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (31)	85	110	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	85.0	79.5	76.8	74.6	72.4	69.1	67.0	64.6	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	...	...
A668	4140, 4340	...	L	...	...	Forging 4 in. and less	(1), (7), (8), (9), (16), (31)	105	125	S_m	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	...	...
										S	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	...	...
										S_y	105.0	98.1	94.8	92.2	89.4	85.5	82.9	79.8	...	...
										S_u	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A668	4140, 4340	...	L	...	...	Forging over 4 in. to 7 in. incl.	(1), (7), (8), (9), (16), (31)	95	115	S_m	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	...	...
										S	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	...	...
										S_y	95.0	88.5	85.4	83.0	80.6	77.0	74.6	72.0	...	...
										S_u	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	...	...
A668	4140, 4340	...	L	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (16), (31)	85	110	S_m	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	...	...
										S	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	...	...
										S_y	85.0	79.5	76.8	74.6	72.4	69.1	67.0	64.6	...	...
										S_u	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	...	...
A668	4135, 4330	...	M	...	...	Forging 4 in. and less	(1), (7), (8), (9), (12), (31)	120	145	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	120.0	112.1	108.4	105.2	102.1	97.6	91.6	91.1	...	...
										S_u	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	...	...
A668	4135, 4330	...	M	...	...	Forging over 4 in. to 7 in. incl.	(1), (7), (8), (9), (12), (31)	115	140	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	115.0	107.5	103.8	101.0	98.0	93.6	90.7	87.5	...	...
										S_u	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	...	...
A668	4135, 4330	...	M	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (12), (31)	110	135	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	110.0	102.9	99.4	96.6	93.6	89.5	86.8	83.6	...	...
										S_u	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	...	...
A668	4140, 4340	...	M	...	...	Forging 4 in. and less	(1), (7), (8), (9), (16), (31)	120	145	S_m	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3	...	...
										S	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	...	...
										S_y	120.0	112.1	108.4	105.2	102.1	97.6	91.6	91.1	...	...
										S_u	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Low Alloy Steels (Cont'd)																				
A668	4140, 4340	...	M	...	...	Forging over 4 in. to 7 in. incl.	(1), (7), (8), (9), (16), (31)	115	140	S_m	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	...	...
										S	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	...	...
										S_y	115.0	107.5	103.8	101.0	98.0	93.6	90.7	87.5	...	...
										S_u	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	...	...
A668	4140, 4340	...	M	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (16), (31)	110	135	S_m	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	...	...
										S	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	...	...
										S_y	110.0	102.9	99.4	96.6	93.6	89.5	86.8	83.6	...	...
										S_u	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	...	...
A668	4340	...	N	...	...	Forging 4 in. and less	(1), (7), (8), (9), (16), (31)	140	170	S_m	56.7	56.7	56.7	56.7	56.7	56.7	56.7	56.7	...	...
										S	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	...	...
										S_y	140.0	131.0	126.3	123.0	119.1	114.0	110.4	106.3	...	...
										S_u	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	...	...
A668	4340	...	N	...	...	Forging over 4 in. to 7 in. incl.	(1), (7), (8), (9), (16), (31)	135	165	S_m	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	...	...
										S	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	...	...
										S_y	135.0	126.1	121.9	118.5	115.0	109.9	106.5	102.7	...	...
										S_u	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	...	...
A668	4340	...	N	...	...	Forging over 7 in. to 10 in. incl.	(1), (8), (9), (16), (31)	130	160	S_m	53.3	53.3	53.3	53.3	53.3	53.3	53.3	53.3	...	...
										S	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	...	...
										S_y	130.0	121.5	117.2	114.1	110.7	105.7	102.5	98.8	...	...
										S_u	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	...	...
A992	...	...	...	P-No. 1	1	Shapes	(14)	50	65	S_m	21.7	21.7	21.7	21.7	21.7	21.7	21.7	...	...	...
										S	18.6	18.6	18.6	18.6	18.6	18.6	18.6	...	...	...
										S_y	50.0	45.8	44.2	42.7	40.7	38.3	37.1	...	...	...
										S_u	65.0	65.0	65.0	65.0	65.0	65.0	65.0	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Age-Hardening Steels																				
A710	A	...	1	S-No. 12	1	Plate, bar, and shapes $^5/_{16}$ in. and less	...	85	90	S_m	30.0	30.0	30.0	30.0	30.0	30.0	...	...	...	...
										S	25.7	25.7	25.7	25.7	25.7	25.7	...	...	...	...
										S_y	85.0	80.0	77.1	74.1	71.5	69.6	...	...	...	...
										S_u	90.0	90.0	90.0	90.0	90.0	90.0	...	...	...	...
A710	A	...	1	S-No. 12	1	Plate, bar, and shapes over $^5/_{16}$ in. to $^3/_4$ in.	...	80	90	S_m	30.0	30.0	30.0	30.0	30.0	30.0	...	...	...	...
										S	25.7	25.7	25.7	25.7	25.7	25.7	...	...	...	...
										S_y	80.0	75.3	72.6	69.4	67.6	65.5	...	...	...	...
										S_u	90.0	90.0	90.0	90.0	90.0	90.0	...	...	...	...
A710	A	...	2	S-No. 12	1	Plate, bar, and shapes 1 in. and less	...	65	72	S_m	24.0	24.0	24.0	24.0	24.0	24.0	...	...	...	...
										S	20.6	20.6	20.6	20.6	20.6	20.6	...	...	...	...
										S_y	65.0	61.1	56.5	56.8	54.9	53.2	...	...	...	...
										S_u	72.0	72.0	72.0	72.0	72.0	72.0	...	...	...	...
A710	A	...	2	S-No. 12	1	Plate, bar, and shapes over 1 in. to 2 in.	...	60	72	S_m	24.0	24.0	24.0	24.0	24.0	24.0	...	...	...	...
										S	20.6	20.6	20.6	20.6	20.6	20.6	...	...	...	...
										S_y	60.0	56.5	54.1	52.4	50.7	49.1	...	...	...	...
										S_u	72.0	72.0	72.0	72.0	72.0	72.0	...	...	...	...
A710	A	...	2	S-No. 12	1	Plate, bar, and shapes over 2 in. to 4 in.	...	55	65	S_m	21.7	21.7	21.7	21.7	21.7	21.7	...	...	...	...
										S	18.6	18.6	18.6	18.6	18.6	18.6	...	...	...	...
										S_y	55.0	51.8	47.6	48.1	46.5	45.0	...	...	...	...
										S_u	65.0	65.0	65.0	65.0	65.0	65.0	...	...	...	...
A710	A	...	3	S-No. 12	1	Plate, bar, and shapes 2 in. and less	...	75	85	S_m	28.3	28.3	28.3	28.3	28.3	28.3	...	...	...	...
										S	24.3	24.3	24.3	24.3	24.3	24.3	...	...	...	...
										S_y	75.0	70.6	68.0	66.0	65.4	61.4	...	...	...	...
										S_u	85.0	85.0	85.0	85.0	85.0	85.0	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Age-Hardening Steels (Cont'd)																				
A710	A	...	3	S-No. 12	1	Plate, bar, and shapes over 2 in. to 4 in.	...	65	75	S_m	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...	...
										S	21.4	21.4	21.4	21.4	21.4	21.4	...	...	...	...
										S_y	65.0	61.2	57.0	56.6	54.7	53.2	...	...	...	...
										S_u	75.0	75.0	75.0	75.0	75.0	75.0	...	...	...	...
Martensitic Stainless Steels																				
A276	...	440C	...	...	...	Bar	(1), (20), (21), (24), (30)	210	275	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	210.0	205.9	205.2	205.2	204.4	200.0	195.8	...	...	...
										S_u	275.0	275.0	275.0	274.2	269.2	261.2	255.9	...	...	...
A276	...	440C	...	...	...	Bar	(1), (20), (22), (24), (25), (30)	275	285	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	275.0	...	...	...	...	...	...	...	...	...
										S_u	285.0	...	...	...	...	...	...	...	...	...
A276	...	420	...	...	...	Bar	(1), (23)	65	95	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	65.0	60.0	57.5	56.1	55.3	54.5	53.8	...	...	...
										S_u	95.0	95.0	95.0	94.7	...	...	...	...	...	...
A582	...	416, 416Se	...	...	...	Bar	(1), (26)	40	70	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	40.0	38.1	36.9	35.7	...	...	...	...	...	...
										S_u	70.0	...	...	...	...	...	...	...	...	...
Austenitic Stainless Steels																				
A580	302, 304, 316, 317	...	B	...	...	Wire	(1), (6)	100	125	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	100.0	83.3	75.0	69.0	...	...	...	...	...	...
										S_u	125.0	118.3	110.0	103.7	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Austenitic Stainless Steels (Cont'd)																				
A582	303	HR	...	...	...	Bar	(1), (26)	30	75	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	30.0	25.0	22.5	20.7	19.4	18.2	17.9	17.7	17.3	16.0
										S_u	75.0	71.0	66.0	64.4	63.5	63.5	63.5	63.5	63.1	62.7
A582	303Se	...	...	...	...	Bar	(1), (26)	30	75	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	30.0	25.0	22.5	20.7	19.4	18.2	17.9	17.7	17.3	16.0
										S_u	75.0	71.0	66.0	64.4	63.5	63.5	63.5	63.5	63.1	62.7
Copper and Copper Alloys																				
B16	C36000	...	H02	...	...	Bar ½ in. and less	(1)	25	57	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	25.0	...	...	...	...	...	...	...	...	...
										S_u	57.0	...	...	...	...	...	...	...	...	...
B16	C36000	...	H02	...	...	Bar over ½ in. to 1 in. incl.	(1)	25	55	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	25.0	...	...	...	...	...	...	...	...	...
										S_u	55.0	...	...	...	...	...	...	...	...	...
B16	C36000	...	H02	...	...	Bar	(1)	20	50	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	20.0	...	...	...	...	...	...	...	...	...
										S_u	50.0	...	...	...	...	...	...	...	...	...
B124	C37700	...	M30	...	...	Forging	(1)	18	50	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	18.0	16.3	14.9	14.2	...	...	...	...	...	...
										S_u	50.0	45.5	40.0	34.0	...	...	...	...	...	...

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, ksi	Min. Tensile Strength, ksi		Stress and Strength, ksi, (Multiply by 1,000 to Obtain psi) for Metal Temperatures, °F, Not to Exceed									
											100	200	300	400	500	600	650	700	750	800
Nickel Alloys																				
B670	50Ni–17Cr–Mo–Cb	...	...	...	...	Plate and sheet	(1), (27), (30)	150	180	S_m	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...
										S_y	150.0	...	...	...	...	...	...	...	...	...
										S_u	...	...	...	...	...	...	...	...	...	...

GENERAL NOTE: (a) The allowable stress values (S) are based on the revised criterion of tensile strength divided by 3.5, where applicable.

NOTES:
(1) Welding is not permitted on these materials.
(2) These values are for material that is not welded.
(3) These materials are limited for use only for standard supports.
(4) Max. BHN 215.
(5) Max. BHN 225.
(6) This material may be used only in fully constrained applications, such as thread inserts, so that failure of the wire would not affect the function of the support. This material is exempt from the requirements of NF-I-2220.
(7) By agreement between Purchaser and Material Manufacturer, these materials may be procured to the lower specified minimum tensile strength and minimum yield strength values given in this table.
(8) For each forging 250 lb and less, the marking requirements of A668 shall be met by a suitable code or symbol identified by the manufacturer in its Certificate of Compliance or Certified Material Test Report.
(9) The hardness test requirement may be performed only on the tensile specimen.
(10) The minimum specified yield strength shall be taken at 0.2% offset.
(11) There is no standard AISI composition 4330. By agreement with the material manufacturer, the carbon content of AISI 4320 can be ordered as 0.27% to 0.33%.
(12) There is no standard AISI composition 4330. By agreement with the material manufacturer, the carbon content of AISI 4340 can be ordered as 0.27% to 0.33%, the molybdenum as 0.40% to 0.60%, the vanadium as 0.04% to 0.10%, and the silicon to 0.35% max.
(13) Proper ventilation for the welder is required when welding on galvanized steel (Ref. ANSI Z49.1).
(14) Maximum tensile strength shall not exceed specified minimum tensile strength by more than 30 ksi, per SA-6, para. S18.
(15) Maximum tensile strength shall not exceed specified minimum tensile strength by more than 25 ksi, per SA-6, para. S18.
(16) E4340H may be used with the molybdenum range increased by agreement to 0.40% max. E4340H may be used for linear design only.
(17) The elongation and reduction of area requirements for Grade 105-85 may be specified as 14% and 30%, respectively.
(18) The elongation and reduction of area requirements for Grade 115-95 may be specified as 11% and 25%, respectively.
(19) The elongation and reduction of area requirements for this material may be specified as 17% and 35% minimum, respectively.
(20) This material may be used only in fully constrained applications, such as valve disk or flow restrictor balls or mechanical snubber parts such as gears, so that failure of these parts does not significantly affect the function of the item. Design stresses are limited to $0.4S_y$.
(21) Austenitize 1,850°F to 1,950°F, oil quench, temper at 700°F min.
(22) Austenitize 1,850°F to 1,950°F, oil quench, temper at 600°F min.
(23) Austenitize at 1,800°F minimum, rapid cool by forced air or oil, temper at 1,300°F minimum.
(24) For compressive applications, tensile testing is not required and each size and lot shall be accepted on the basis of hardness testing of three pieces. Each test specimen shall meet RC53 min. in the final heat-treated condition.
(25) Hot finished, heat treated.

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Table NF-I-2100-1
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

NOTES: (Cont'd)
(26) For bar sizes under ½ in. nominal size, this material may be ordered to A581-95b.
(27) Solution heat treated and hardened (1,325°F for 8 hr, furnace cooled to 1,150°F, held to a total of 18 hr, air cooled).
(28) Max. carbon 0.35% for welded connections.
(29) These values are for material that is welded. The Max. BNH must be met prior to welding. The stress and strength values at temperature are based on the equivalent hot rolled material.
(30) These materials are exempt from the requirements of NF-I-2220.
(31) These materials grades are AISI grades. See NF-I-2210.

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels																												
A108	1015, 1018, 1020	CW	...	P-No. 1	1	Bar	(4), (29), (31)	276	414	S_m	115	115	115	115	115	115	115	115	...	...	...	...	...	...	...	...	...
										S	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	...	...	...	...	...	...	...	...	...
										S_y	221	217	208	201	198	195	192	189	...	...	...	...	...	...	...	...	...
										S_u	345	345	345	345	345	345	345	345	...	...	...	...	...	...	...	...	...
A108	1015, 1018, 1020	CW	...	...	...	Bar	(2), (4), (31)	276	414	S_m	138	138	138	138	138	138	138	138	...	...	...	...	...	...	...	...	...
										S	118	118	118	118	118	118	118	118	...	...	...	...	...	...	...	...	...
										S_y	276	271	260	251	248	244	240	237	...	...	...	...	...	...	...	...	...
										S_u	414	414	414	414	414	414	414	414	...	...	...	...	...	...	...	...	...
A108	1045	CW	...	...	...	Bar and bolt	(1), (31)	689	827	S_m	276	276	276	276	276	276	276	276	...	...	...	...	...	...	...	...	...
										S	236	236	236	236	236	236	236	236	...	...	...	...	...	...	...	...	...
										S_y	689	677	650	627	618	610	601	592	...	...	...	...	...	...	...	...	...
										S_u	827	827	827	827	827	827	827	827	...	...	...	...	...	...	...	...	...
A108	1050	CW	...	...	...	Bar and bolt	(1), (31)	862	965	S_m	322	322	322	322	322	322	322	322	...	...	...	...	...	...	...	...	...
										S	276	276	276	276	276	276	276	276	...	...	...	...	...	...	...	...	...
										S_y	862	846	813	784	773	762	751	740	...	...	...	...	...	...	...	...	...
										S_u	965	965	965	965	965	965	965	965	...	...	...	...	...	...	...	...	...
A108	1117	...	...	...	...	Bar	(1), (31)	414	483	S_m	161	161	161	161	161	161	161	161	...	...	...	...	...	...	...	...	...
										S	138	138	138	138	138	138	138	138	...	...	...	...	...	...	...	...	...
										S_y	414	406	390	381	381	381	380	380	...	...	...	...	...	...	...	...	...
										S_u	483	483	483	483	483	483	483	483	...	...	...	...	...	...	...	...	...
A108	1141, 12L14	Cold drawn and tempered	...	...	...	Bolt 75 mm max.	(1), (31)	558	724	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	558	548	527	508	501	494	486	479	...	...	...	...	...	...	...	...	...
										S_u	724	724	724	724	724	724	724	724	...	...	...	...	...	...	...	...	...
A108	1144	...	...	...	...	Bar	(1), (31)	689	793	S_m	264	264	264	264	264	264	264	264	...	...	...	...	...	...	...	...	...
										S	227	227	227	227	227	227	227	227	...	...	...	...	...	...	...	...	...
										S_y	689	677	650	627	618	610	601	592	...	...	...	...	...	...	...	...	...
										S_u	793	793	793	793	793	793	793	793	...	...	...	...	...	...	...	...	...
A108	1144	Cold drawn and tempered	...	...	...	Bolt 75 mm max.	(1), (31)	724	862	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	724	711	683	659	649	640	630	621	...	...	...	...	...	...	...	...	...
										S_u	862	862	862	862	862	862	862	862	...	...	...	...	...	...	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels (Cont'd)																													
A108	1144	...	...	...	...	Bolt over 75 mm to 250 mm max.	(1), (31)	558	724	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	558	548	527	508	501	494	486	479	...	...	...	...	...	...	...	...	...
										S_u	724	724	724	724	724	724	724	724	...	...	...	...	...	...	...	...	...
A108	12L14	...	...	...	...	Bar	(1)	379	448	S_m	150	150	150	150	150	150	150	150	...	...	...	...	...	...	...	...	...
										S	128	128	128	128	128	128	128	128	...	...	...	...	...	...	...	...	...
										S_y	379	372	358	345	340	335	330	326	...	...	...	...	...	...	...	...	...
										S_u	448	448	448	448	448	448	448	448	...	...	...	...	...	...	...	...	...
A228	...	...	...	...	...	Wire	(1), (6), (30)	1 724	1 862	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	1 724	1 681	1 592	1 509	1 453	1 396	1 349	1 302	...	...	...	...	...	...	...	...	...
										S_u	1 862	1 862	1 862	1 862	1 862	1 862	1 862	1 862	...	...	...	...	...	...	...	...	...
A381	...	...	Y35	P-No. 1	1	Pipe	...	240	415	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	240	236	227	219	217	214	211	207	200	198	191	183	178	176	...	...	...
										S_u	415	415	415	415	415	415	415	415	...	...	...	...	...	...	...	...	...
A500	B	...	...	P-No. 1	1	Tube (shaped)	...	317	400	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	317	311	299	288	285	281	277	273	263	261	250	240	233	229	...	...	...
										S_u	400	400	400	400	400	400	400	400	...	...	...	...	...	...	...	...	...
A500	B	...	...	P-No. 1	1	Tube (round)	...	290	400	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	290	284	273	263	260	256	252	248	240	238	228	219	212	209	...	...	...
										S_u	400	400	400	400	400	400	400	400	...	...	...	...	...	...	...	...	...
A500	C	...	...	P-No. 1	1	Tube (shaped)	...	345	427	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	345	338	325	314	310	305	301	297	286	283	272	262	253	250	...	...	...
										S_u	427	427	427	427	427	427	427	427	...	...	...	...	...	...	...	...	...
A500	C	...	...	P-No. 1	1	Tube (round)	...	317	427	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	317	311	299	288	285	281	277	273	263	261	250	240	233	229	...	...	...
										S_u	427	427	427	427	427	427	427	427	...	...	...	...	...	...	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels (Cont'd)																													
A501	...	...	...	P-No. 1	1	Tube	...	250	400	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	250	245	235	226	223	220	216	213	206	204	196	188	182	180	...	...	...	...	...
										S_u	400	400	400	400	400	400	400	400	...	...	...	...	...	...	...	...	...	...	...
A513	1015	CW	...	P-No. 1	1	Tube	(4), (29)	379	448	S_m	115	115	115	115	115	115	115	115	...	...	...	...	...	...	...	...	...	...	...
										S	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	...	...	...	...	...	...	...	...	...	...	...
										S_y	221	217	208	201	198	195	192	189	...	...	...	...	...	...	...	...	...	...	...
										S_u	345	345	345	345	345	345	345	345	...	...	...	...	...	...	...	...	...	...	...
A513	1020	CW	...	P-No. 1	2	Tube	(4), (29)	414	483	S_m	115	115	115	115	115	115	115	115	...	...	...	...	...	...	...	...	...	...	...
										S	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	...	...	...	...	...	...	...	...	...	...	...
										S_y	221	217	208	201	198	195	192	189	...	...	...	...	...	...	...	...	...	...	...
										S_u	345	345	345	345	345	345	345	345	...	...	...	...	...	...	...	...	...	...	...
A513	1015	CW	...	...	...	Tube	(2), (4)	379	448	S_m	150	150	150	150	150	150	150	150	...	...	...	...	...	...	...	...	...	...	...
										S	128	128	128	128	128	128	128	128	...	...	...	...	...	...	...	...	...	...	...
										S_y	379	372	358	345	340	335	330	326	...	...	...	...	...	...	...	...	...	...	...
										S_u	448	448	448	448	448	448	448	448	...	...	...	...	...	...	...	...	...	...	...
A513	1020	CW	...	...	...	Tube	(2), (4)	414	483	S_m	161	161	161	161	161	161	161	161	...	...	...	...	...	...	...	...	...	...	...
										S	138	138	138	138	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...
										S_y	414	406	390	376	371	365	360	355	...	...	...	...	...	...	...	...	...	...	...
										S_u	483	483	483	483	483	483	483	483	...	...	...	...	...	...	...	...	...	...	...
A513	1025	CW	...	P-No. 1	2	Tube	(5), (29)	448	517	S_m	126	126	126	126	126	126	126	126	...	...	...	...	...	...	...	...	...	...	...
										S	108	108	108	108	108	108	108	108	...	...	...	...	...	...	...	...	...	...	...
										S_y	241	237	227	219	217	214	211	207	...	...	...	...	...	...	...	...	...	...	...
										S_u	379	379	379	379	379	379	379	379	...	...	...	...	...	...	...	...	...	...	...
A513	1026	CW	...	P-No. 1	3	Tube	(5), (29)	483	552	S_m	126	126	126	126	126	126	126	126	...	...	...	...	...	...	...	...	...	...	...
										S	108	108	108	108	108	108	108	108	...	...	...	...	...	...	...	...	...	...	...
										S_y	241	237	227	219	217	214	211	207	...	...	...	...	...	...	...	...	...	...	...
										S_u	379	379	379	379	379	379	379	379	...	...	...	...	...	...	...	...	...	...	...
A513	1025	CW	...	...	...	Tube	(2), (5)	448	517	S_m	172	172	172	172	172	172	172	172	...	...	...	...	...	...	...	...	...	...	...
										S	148	148	148	148	148	148	148	148	...	...	...	...	...	...	...	...	...	...	...
										S_y	448	440	423	408	406	403	394	385	...	...	...	...	...	...	...	...	...	...	...
										S_u	517	517	517	517	517	517	517	517	...	...	...	...	...	...	...	...	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels (Cont'd)																													
A513	1026	CW	...	...	...	Tube	(2), (5)	483	552	S_m	184	184	184	184	184	184	184	184	...	...	...	...	...	...	...	...	...
										S	158	158	158	158	158	158	158	158	...	...	...	...	...	...	...	...	...
										S_y	483	474	455	439	433	427	420	414	...	...	...	...	...	...	...	...	...
										S_u	552	552	552	552	552	552	552	552	...	...	...	...	...	...	...	...	...
A519	1018, 1020, 1022	HR	...	P-No. 1	1	Tube	...	221	345	S_m	115	115	115	115	115	115	115	115	...	...	...	...	...	...	...	...	...
										S	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	...	...	...	...	...	...	...	...	...
										S_y	221	217	208	201	198	195	192	189	...	...	...	...	...	...	...	...	...
										S_u	345	345	345	345	345	345	345	345	...	...	...	...	...	...	...	...	...
A519	1018, 1020, 1022	CW	...	P-No. 1	2	Tube	(4), (29)	414	483	S_m	115	115	115	115	115	115	115	115	...	...	...	...	...	...	...	...	...
										S	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	...	...	...	...	...	...	...	...	...
										S_y	221	217	208	201	198	195	192	189	...	...	...	...	...	...	...	...	...
										S_u	345	345	345	345	345	345	345	345	...	...	...	...	...	...	...	...	...
A519	1018, 1020, 1022	CW	...	...	...	Tube	(2), (4)	414	483	S_m	161	161	161	161	161	161	161	161	...	...	...	...	...	...	...	...	...
										S	138	138	138	138	138	138	138	138	...	...	...	...	...	...	...	...	...
										S_y	414	406	390	376	371	365	360	355	...	...	...	...	...	...	...	...	...
										S_u	483	483	483	483	483	483	483	483	...	...	...	...	...	...	...	...	...
A519	1025, 1026	HR	...	P-No. 1	1	Tube	...	241	379	S_m	126	126	126	126	126	126	126	126	...	...	...	...	...	...	...	...	...
										S	108	108	108	108	108	108	108	108	...	...	...	...	...	...	...	...	...
										S_y	241	237	227	219	217	214	211	207	...	...	...	...	...	...	...	...	...
										S_u	379	379	379	379	379	379	379	379	...	...	...	...	...	...	...	...	...
A519	1025, 1026	CW	...	P-No. 1	2	Tube	(3), (5), (29)	448	517	S_m	126	126	126	126	126	126	126	126	...	...	...	...	...	...	...	...	...
										S	108	108	108	108	108	108	108	108	...	...	...	...	...	...	...	...	...
										S_y	241	237	227	219	217	214	211	207	...	...	...	...	...	...	...	...	...
										S_u	379	379	379	379	379	379	379	379	...	...	...	...	...	...	...	...	...
A519	1025, 1026	CW	...	...	...	Tube	(2), (3), (5)	448	517	S_m	172	172	172	172	172	172	172	172	...	...	...	...	...	...	...	...	...
										S	148	148	148	148	148	148	148	148	...	...	...	...	...	...	...	...	...
										S_y	448	440	423	408	406	403	394	385	...	...	...	...	...	...	...	...	...
										S_u	517	517	517	517	517	517	517	517	...	...	...	...	...	...	...	...	...
A521	1020, 1025, 1030	...	CC	S-No. 1	1	Forging	(31)	205	415	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	205	201	194	188	186	183	181	178	172	170	164	157	152	150	...	...	...
										S_u	415	415	415	415	415	415	415	415	...	...	...	...	...	...	...	...	...
A521	1020, 1025, 1030	...	CE	S-No. 1	2	Forging	(31)	255	520	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels (Cont'd)																													
										S_y	255	250	240	232	229	226	223	219	211	210	201	194	188	185	...	...	...
										S_u	520	520	520	520	520	520	520	520	...	...	...	...	...	...	...	...	...
A521	1035, 1040	...	CG	...	...	Forging 100 mm and under	(1), (31)	380	620	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	380	373	358	345	340	335	330	326	315	312	300	288	279	275	...	...	...
										S_u	620	620	620	620	620	620	620	620	...	...	...	...	...	...	...	...	...
A521	1035, 1040	...	CG	...	...	Forging over 100 mm to 250 mm incl.	(1), (31)	345	585	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	345	338	325	314	310	305	301	297	286	283	272	262	253	250	...	...	...
										S_u	585	585	585	585	585	585	585	585	...	...	...	...	...	...	...	...	...
A653	33	A	...	S-No. 1	1	Sheet	(13)	230	310	S_m	103	103	103	103	103	103	103	103	...	...	...	...	...	...	...	...	...
										S	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9	...	...	...	...	...	...	...	...	...
										S_y	230	225	215	207	204	201	199	196	188	186	...	...	...	...	...	...	...
										S_u	310	310	310	310	310	310	310	310	...	...	...	...	...	...	...	...	...
A668	1020, 1022, 1025, 1026, 1030	...	B	S-No. 1	1	Forging	(8), (31)	205	415	S_m	138	138	138	138	138	138	138	138	138	138	138	138	138	...	...	...	...
										S	119	119	119	119	119	119	119	119	...	...	...	...	...	...	...	...	...
										S_y	205	201	194	188	186	183	181	178	172	170	164	157	152	150	...	...	...
										S_u	415	415	415	415	415	415	415	415	...	...	...	...	...	...	...	...	...
A668	1035	...	B	...	...	Forging	(1), (8), (9), (31)	205	415	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	205	201	194	188	186	183	181	178	172	171	165	157	152	150	...	...	...
										S_u	415	415	415	415	415	415	415	415	...	...	...	...	...	...	...	...	...
A668	1020, 1022, 1025, 1026, 1030	...	C	S-No. 1	1	Forging	(8), (31)	230	455	S_m	152	152	152	152	152	152	152	152	152	152	152	152	152	...	...	...	...
										S	130	130	130	130	130	130	130	130	...	...	...	...	...	...	...	...	...
										S_y	230	225	215	207	204	201	199	196	188	186	179	172	168	166	...	...	...
										S_u	455	455	455	455	455	455	455	455	...	...	...	...	...	...	...	...	...
A668	1035	...	C	...	...	Forging	(1), (8), (9), (31)	230	455	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	230	225	215	210	210	210	210	210	188	186	179	172	168	166	...	...	...
										S_u	455	455	455	455	455	455	455	455	...	...	...	...	...	...	...	...	...
A668	1020, 1022, 1025, 1026, 1030	...	D	S-No. 1	2	Forging	(8), (31)	260	515	S_m	172	172	172	172	172	172	172	172	172	172	172	172	172	...	...	...	...
										S	147	147	147	147	147	147	147	147	...	...	...	...	...	...	...	...	...
										S_y	260	255	244	235	232	229	225	222	214	212	204	196	190	187	...	...	...
										S_u	515	515	515	515	515	515	515	515	...	...	...	...	...	...	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Carbon Steels (Cont'd)																													
A668	1035	...	D	...	...	Forging	(1), (8), (9), (31)	260	515	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	260	255	244	235	232	229	225	222	214	212	204	196	190	187	...	...	...
										S_u	515	515	515	515	515	515	515	515	...	...	...	...	...	...	...	...	...
A668	1030, 1330	...	F	S-No. 1	3	Forging 100 mm and under	(7), (8), (31)	380	620	S_m	207	207	207	207	207	207	207	207	...	...	...	...	...	...	...	...	...
										S	177	177	177	177	177	177	177	177	...	...	...	...	...	...	...	...	...
										S_y	380	373	358	345	340	335	330	326	315	312	300	288	279	275	...	...	...
										S_u	620	620	620	620	620	620	620	620	...	...	...	...	...	...	...	...	...
A668	1030, 1330	...	F	S-No. 1	3	Forging over 100 mm to 250 mm incl.	(8), (31)	345	585	S_m	195	195	195	195	195	195	195	195	...	...	...	...	...	...	...	...	...
										S	167	167	167	167	167	167	167	167	...	...	...	...	...	...	...	...	...
										S_y	345	338	325	314	310	305	301	297	286	283	272	262	253	250	...	...	...
										S_u	585	585	585	585	585	585	585	585	...	...	...	...	...	...	...	...	...
A668	1035, 1040 1045	...	F	...	...	Forging 100 mm and under	(1), (7), (8), (9), (31)	380	620	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	380	373	358	345	340	335	330	326	315	312	300	288	279	275	...	...	...
										S_u	620	620	620	620	620	620	620	620	...	...	...	...	...	...	...	...	...
A668	1035, 1040, 1045	...	F	...	...	Forging over 100 mm to 250 mm incl.	(1), (8), (9), (31)	345	585	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	345	338	325	314	310	305	301	297	286	283	272	262	253	250	...	...	...
										S_u	585	585	585	585	585	585	585	585	...	...	...	...	...	...	...	...	...
A675	75	...	...	S-No. 1	2	Bar	(28)	260	515	S_m	172	172	172	172	172	172	172	172	172	172	172	172	172	...	...	...	...
										S	147	147	147	147	147	147	147	147	...	...	...	...	...	...	...	...	...
										S_y	260	255	244	235	232	229	225	222	214	212	204	196	190	188	...	...	...
										S_u	515	515	515	515	515	515	515	515	...	...	...	...	...	...	...	...	...
Low Alloy Steels																													
A148	Grade 90-60: 4130, 4320, 4330	...	...	S-No. 4	3	Casting	(11), (19), (31)	415	620	S_m	207	207	207	207	207	207	207	207	207	207	207	207	207	207	...	...	...
										S	177	177	177	177	177	177	177	177	177	177	177	177	...	...	...	...	...
										S_y	415	412	406	400	393	385	376	366	353	351	345	344	...	...	...	...	...
										S_u	620	620	620	620	620	620	620	620	620	620	620	620	620	620	...	...	...
A148	Grade 105-85: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (17), (31)	585	725	S_m	241	241	241	241	241	241	241	241	241	241	241	241	241	241	...	...	...
										S	207	207	207	207	207	207	207	207	207	207	207	207	207	207	...	...	...
										S_y	585	582	574	567	556	546	532	518	501	497	489	487	486	486	...	...	...
										S_u	725	725	725	725	725	725	725	725	725	725	725	725	725	725	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																												
A148	Grade 115-95: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (18), (31)	655	795	S_m	265	265	265	265	265	265	265	265	265	265	265	265	265	...	...	...
										S	227	227	227	227	227	227	227	227	227	227	227	227	227	...	...	...
										S_y	655	651	642	633	621	610	595	579	559	555	546	545	544	...	...	...
										S_u	795	795	795	795	795	795	795	795	795	795	795	795	795	...	...	...
A148	Grade 135-125: 4130, 4140, 4320, 4340	...	...	...	...	Casting	(1), (31)	860	930	S_m	310	310	310	310	310	310	310	310	310	310	310	310	310	...	...	...
										S	266	266	266	266	266	266	266	266	266	266	266	266	266	...	...	...
										S_y	860	855	844	832	818	803	783	763	736	730	718	717	716	...	...	...
										S_u	930	930	930	930	930	930	930	930	930	930	930	930	930	...	...	...
A322	4150	...	...	...	...	Bar	(1), (31)	689	793	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	689	680	660	643	632	622	614	607	595	592	580	568	555	540	...	...	...
										S_u	793	793	793	793	793	793	793	793	793	793	793	793	793	793	...	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar 38 mm and under	(1), (31)	620	760	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	620	612	594	578	569	561	553	546	535	533	522	512	500	486	...	...	...
										S_u	760	760	760	760	760	760	760	760	760	760	760	760	760	760	...	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 38 mm to 63 mm incl.	(1), (31)	550	720	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	550	543	528	514	506	498	492	486	476	474	464	454	444	431	...	...	...
										S_u	720	720	720	720	720	720	720	720	720	720	720	720	720	720	...	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 63 mm to 100 mm incl.	(1), (31)	520	690	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	520	512	496	482	474	467	461	455	446	444	435	426	416	405	...	...	...
										S_u	690	690	690	690	690	690	690	690	690	690	690	690	690	690	...	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 100 mm to 175 mm incl.	(1), (31)	520	660	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	520	512	496	482	474	467	461	455	446	444	435	426	416	405	...	...	...
										S_u	660	660	660	660	660	660	660	660	660	660	660	660	660	660	...	...	...
A434	4130, 4140, 4145, 4320, 4340, 8260	...	BB	...	...	Bar over 175 mm to 238 mm incl.	(1), (31)	450	620	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	450	443	430	417	411	404	399	395	387	385	377	369	361	351	...	...	...
										S_u	620	620	620	620	620	620	620	620	620	620	620	620	620	620	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																		
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																													
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar 38 mm and under	(1), (31)	760	900	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	760	749	727	707	696	685	677	668	654	651	638	625	611	594	...	...	...
										S_u	900	900	900	900	900	900	900	900	900	900	900	900	900	900	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 38 mm to 63 mm incl.	(1), (31)	720	860	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	720	711	692	674	664	654	645	637	625	622	609	597	584	567	...	...	...
										S_u	860	860	860	860	860	860	860	860	860	860	860	860	860	860	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 63 mm to 100 mm incl.	(1), (31)	660	790	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	660	650	628	608	599	589	581	574	563	560	549	538	525	511	...	...	...
										S_u	790	790	790	790	790	790	790	790	790	790	790	790	790	790	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 100 mm to 175 mm incl.	(1), (31)	590	760	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	590	581	563	546	538	530	523	516	506	504	493	483	472	459	...	...	...
										S_u	760	760	760	760	760	760	760	760	760	760	760	760	760	760	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BC	...	...	Bar over 175 mm to 238 mm incl.	(1), (31)	550	720	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	550	543	528	514	506	498	492	486	476	474	464	454	444	432	...	...	...
										S_u	720	720	720	720	720	720	720	720	720	720	720	720	720	720	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar 38 mm and under	(1), (31)	900	1 070	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	900	887	860	835	822	808	798	789	773	770	754	738	721	702	...	...	...
										S_u	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	1 070	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 38 mm to 63 mm incl.	(1), (31)	830	1 030	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	830	818	793	771	759	747	737	727	713	710	695	681	666	647	...	...	...
										S_u	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	1 030	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 63 mm to 100 mm incl.	(1), (31)	760	960	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	760	749	727	707	696	685	677	668	654	651	638	625	611	594	...	...	...
										S_u	960	960	960	960	960	960	960	960	960	960	960	960	960	960	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																												
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 100 mm to 175 mm incl.	(1), (31)	720	930	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	720	711	692	674	664	654	645	637	625	622	609	597	584	567	...	...	...
										S_u	930	930	930	930	930	930	930	930	930	930	930	930	930	930	...	...	...
A434	4130, 4140, 4145, 4320, 4340	...	BD	...	...	Bar over 175 mm to 238 mm incl.	(1), (31)	690	900	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	690	680	661	643	632	622	614	607	595	592	580	568	555	540	...	...	...
										S_u	900	900	900	900	900	900	900	900	900	900	900	900	900	900	...	...	...
A471	3Ni–Cr–Mo–V	...	2	...	...	Forging	(1), (10)	620	725	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	620	613	597	583	575	566	560	555	549	547	542	538	532	525	...	...	...
										S_u	725	725	725	725	725	725	721	718	714	714	710	705	699	690	...	...	...
A471	3Ni–Cr–Mo–V	...	3	...	...	Forging	(1), (10)	690	760	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	690	681	664	648	638	629	623	616	610	608	602	597	592	584	...	...	...
										S_u	760	760	760	760	760	760	756	752	748	747	743	738	732	722	...	...	...
A471	3Ni–Cr–Mo–V	...	4	...	...	Forging	(1), (10)	760	830	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	760	751	731	713	703	692	685	678	670	669	662	657	651	643	...	...	...
										S_u	830	830	830	830	830	830	825	820	816	815	811	806	799	788	...	...	...
A471	3Ni–Cr–Mo–V	...	5	...	...	Forging	(1), (10)	825	900	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	825	815	796	778	766	755	747	740	731	730	723	717	710	701	...	...	...
										S_u	900	900	900	900	900	900	894	889	884	883	878	873	865	854	...	...	...
A471	3Ni–Cr–Mo–V	...	6	...	...	Forging	(1), (10)	895	965	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	895	884	862	842	830	818	810	801	792	790	783	777	769	760	...	...	...
										S_u	965	965	965	965	965	965	961	956	952	951	946	940	932	920	...	...	...
A471	3Ni–Cr–Mo–V	...	7	...	...	Forging	(1), (10)	931	1 034	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	931	919	895	874	861	848	840	831	822	820	812	805	798	789	...	...	...
										S_u	1 034	1 034	1 034	1 034	1 034	1 034	1 030	1 025	1 020	1 019	1 013	1 007	998	986	...	...	...
A471	3Ni–Cr–Mo–V	...	8	...	...	Forging	(1), (10)	1 000	1 103	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																												
										S_y	1 000	988	962	939	925	911	902	893	883	881	872	865	857	848	...	...	...
										S_u	1 103	1 103	1 103	1 103	1 103	1 103	1 098	1 093	1 088	1 087	1 081	1 074	1 065	1 051	...	...	...
A471	3Ni–Cr–Mo–V	...	9	...	...	Forging	(1), (10)	1 069	1 172	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	1 069	1 056	1 028	1 004	989	974	964	954	944	942	933	925	917	906	...	...	...
										S_u	1 172	1 172	1 172	1 172	1 172	1 172	1 167	1 161	1 156	1 155	1 148	1 141	1 131	1 117	...	...	...
A490	4137, 4140, 4142, 4145, 4340	1	...	...	...	Bolt	(1)	896	1 034	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	896	884	858	835	822	808	798	789	773	770	754	738	721	702	...	...	...
										S_u	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	1 034	...	...	...
A514	A	...	...	P-No. 11B	1	Plate 32 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...
A514	B	...	...	P-No. 11B	4	Plate 32 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...
A514	E	...	...	P-No. 11B	2	Plate 63 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...
A514	F	...	...	P-No. 11B	3	Plate 63 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...
A514	P	...	...	P-No. 11B	8	Plate 63 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...
A514	Q	...	...	P-No. 11B	9	Plate 63 mm and less	...	689	758	S_m	253	253	253	253	253	253	253	253	253	253	253	253	253	251	...	...	...
										S	216	216	216	216	216	216	216	216	216	216	216	216	216	216	...	...	...
										S_y	689	683	669	657	647	638	629	621	610	608	600	593	587	579	...	...	...
										S_u	758	758	758	758	758	758	758	758	758	758	758	758	758	755	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																												
A514	E	...	...	P-No. 11B	2	Plate over 63 mm to 150 mm incl.	...	621	689	S_m	230	230	230	230	230	230	230	230	230	230	230	230	229	228	...	...	...
										S	197	197	197	197	197	197	197	197	197	197	197	197	197	196	...	...	...
										S_y	621	615	603	591	583	574	567	559	549	547	540	534	528	522	...	...	...
										S_u	689	689	689	689	689	689	689	689	689	689	689	689	689	687	...	...	...
A514	P	...	...	P-No. 11B	8	Plate over 63 mm to 150 mm incl.	...	621	689	S_m	230	230	230	230	230	230	230	230	230	230	230	230	229	228	...	...	...
										S	197	197	197	197	197	197	197	197	197	197	197	197	197	196	...	...	...
										S_y	621	615	603	591	583	574	567	559	549	547	540	534	528	522	...	...	...
										S_u	689	689	689	689	689	689	689	689	689	689	689	689	689	687	...	...	...
A514	Q	...	...	P-No. 11B	9	Plate over 63 mm to 150 mm incl.	...	621	689	S_m	230	230	230	230	230	230	230	230	230	230	230	230	229	228	...	...	...
										S	197	197	197	197	197	197	197	197	197	197	197	197	197	196	...	...	...
										S_y	621	615	603	591	583	574	567	559	549	547	540	534	528	522	...	...	...
										S_u	689	689	689	689	689	689	689	689	689	689	689	689	689	687	...	...	...
A519	4140	4140SR	...	...	...	Tube	(1)	689	827	S_m	276	276	276	276	276	276	276	276	...	...	...	...	...	...	...	...	...
										S	236	236	236	236	236	236	236	236	...	...	...	...	...	...	...	...	...
										S_y	689	680	660	643	632	622	614	607	...	...	...	...	...	...	...	...	...
										S_u	827	827	827	827	827	827	827	827	...	...	...	...	...	...	...	...	...
A519	4142	4142SR	...	...	...	Tube	(1)	689	827	S_m	276	276	276	276	276	276	276	276	...	...	...	...	...	...	...	...	...
										S	236	236	236	236	236	236	236	236	...	...	...	...	...	...	...	...	...
										S_y	689	680	660	643	632	622	614	607	...	...	...	...	...	...	...	...	...
										S_u	827	827	827	827	827	827	827	827	...	...	...	...	...	...	...	...	...
A572	42	...	...	P-No. 1	1	Plate and shapes	(14)	290	414	S_m	138	138	138	138	138	138	138	138	138	138	138	138	138	138	...	...	...
										S	118	118	118	118	118	118	118	118	118	118	118	118	118	118	...	...	...
										S_y	290	287	281	275	269	264	259	255	247	246	240	234	229	224	...	...	...
										S_u	414	414	414	414	414	414	414	414	414	414	414	414	414	414	...	...	...
A572	50	...	...	P-No. 1	1	Plate and Shapes	(14)	345	448	S_m	150	150	150	150	150	150	150	150	150	150	150	150	150	150	...	...	...
										S	128	128	128	128	128	128	128	128	128	128	128	128	128	128	...	...	...
										S_y	345	341	334	326	320	314	309	303	294	292	285	279	273	267	...	...	...
										S_u	448	448	448	448	448	448	448	448	448	448	448	448	448	448	...	...	...
A572	55	...	...	P-No. 1	2	Plate and shapes	...	379	483	S_m	161	161	161	161	161	161	161	161	161	161	161	161	161	161	...	...	...
										S	138	138	138	138	138	138	138	138	...	...	...	...	...	...	...	...	...
										S_y	379	375	367	359	353	346	340	334	324	321	313	307	300	294	...	...	...
										S_u	483	483	483	483	483	483	483	483	483	483	483	483	483	483	...	...	...

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Table NF-I-2100-1M
Design Stress Intensity (S_m), Maximum Allowable Stress (S), Yield Strength (S_y), and Tensile Strength (S_u) Values (Cont'd)

Spec. No.	Material Grade or AISI	Condition Type	Class	P/S No.	Grp. No.	Product Form	Notes	Min. Yield Strength, MPa	Min. Tensile Strength, MPa		Stress and Strength, MPa, for Metal Temperatures, °C, Not to Exceed																	
											38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425
Low Alloy Steels (Cont'd)																												
A579	5Ni–Cr–Mo–V	12a	...	...	...	Forging	(1)	965	1 034	S_m	345	344	343	340	336	331	328	325	324	324	324	324	322	314	...	...	...
										S	296	295	294	292	287	283	281	278	278	278	278	278	276	269	...	...	...
										S_y	965	963	959	953	938	924	910	896	886	884	878	873	864	843	...	...	...
										S_u	1 034	1 032	1 028	1 021	1 007	993	983	974	972	972	972	972	965	943	...	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar 100 mm and less, all shapes	(7), (15)	345	483	S_m	161	161	161	161	161	161	161	161	161	161	161	161	161	161	...	...	...
										S	138	138	138	138	138	138	138	138	138	138	138	138	138	138	...	...	...
										S_y	345	341	334	326	320	314	306	298	292	291	285	279	273	267	...	...	...
										S_u	483	483	483	483	483	483	483	483	483	483	483	483	483	483	...	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar over 100 mm to 125 mm incl.	(7), (14)	317	462	S_m	154	154	154	154	154	154	154	154	154	154	154	154	154	154	...	...	...
										S	132	132	132	132	132	132	132	132	132	132	132	132	132	132	...	...	...
										S_y	317	314	307	301	295	289	284	279	271	269	263	257	251	245	...	...	...
										S_u	462	462	462	462	462	462	462	462	462	462	462	462	462	462	...	...	...
A588	A, B	...	...	P-No. 3	1	Plate and bar over 125 mm to 200 mm incl.	(14)	290	434	S_m	145	145	145	145	145	145	145	145	145	145	145	145	145	145	...	...	...
										S	124	124	124	124	124	124	124	124	124	124	124	124	124	124	...	...	...
										S_y	290	287	281	275	269	264	259	255	247	246	240	234	229	224	...	...	...
										S_u	434	434	434	434	434	434	434	434	434	434	434	434	434	434	...	...	...
A618	Mn–Cu–V	...	II	P-No. 1	2	Tube 18 mm and less	...	345	483	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	345	338	324	311	299	288	276	264	249	245	237	235	233	231	...	...	...
										S_u	483	483	483	483	483	483	483	483	483	483	483	483	483	482	...	...	...
A618	Mn–Cu–V	...	II	P-No. 1	2	Tube over 18 mm to 38 mm incl.	...	317	462	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	317	311	298	285	275	265	254	243	229	226	218	216	214	212	...	...	...
										S_u	462	462	462	462	462	462	462	462	462	462	462	462	462	461	...	...	...
A618	Mn–V	...	III	P-No. 1	1	Tube	...	345	448	S_m	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
										S_y	345	338	324	311	299	288	276	264	249	245	237	235	233	231	...	...	...
										S_u	448	448	448	448	448	448	448	448	448	448	448	448	448	447	...	...	...
A633	A	...	...	P-No. 1	1	Plate and shapes 100 mm and less	...	290	434	S_m	145	145	145	145	145	145	145	145	145	145	145	145	145	145	...	...	...
										S	124	124	124	124	124	124	124	124	124	124	124	124	124	124	...	...	...
										S_y	290	284	273	261	252	242	232	222	209	206	200	198	196	194	...	...	...
										S_u	434	434	434	434	434	434	434	434	434	434	434	434	434	434	...	...	...